AUTOMATION, RATIONALISATION AND CONCENTRATION : A CASE STUDY IN THE BRITISH CHEMICAL INDUSTRY.

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SUMMARY.

This thesis is based upon a case study of the adoption of digital, electronic, microprocessor-based control systems by Albright & Wilson Limited - a UK chemical producer. It offers an explanation of the company's changing technology policy between 1978 and 1981, by examining its past development, internal features and industrial environment.

Part One of the thesis gives an industry-level analysis which relates the development of process control technology to changes in the economic requirements of production. The rapid diffusion of microcomputers and other microelectronic equipment in the chemical industry is found to be a response to general need to raise the efficiency of all processes, imposed by the economic recession following 1973.

Part Two examines the impact of these technical and economic changes upon Albright & Wilson Limited. The company's slowness in adopting new control technology is explained by its long history in which trends are identified which produced the conservatism of the 1970s. By contrast, a study of Tenneco Incorporated, a much more successful adoptor of automating technology, is offered with an analysis of the new technology policy of adoption of such equipment which it imposed upon Albright & Wilson, following the latter's takeover by Tenneco in 1978. Some indications of the consequences by this new policy of widespread adoptions of microprocessor-based control equipment are derived from a study of the first Albright & Wilson plant to use such equipment.

The thesis concludes that companies which fail to adopt rapidly the new control technology may not survive in the recessionary environment, the long-established British companies may lack the flexibility to make such necessary changes and that multi-national companies may have an important role in the planned transfer and adoption of new production technology through their subsidiaries in the UK.

Key words

chemicals, computers, microprocessors, automation, takeover.

LIST OF FIGURES

PREFACE

This thesis had its origins in the "microelectronics debate" of the late 1970s. Some people were arguing that a danger existed from a too rapid diffusion of microelectronics-based automation technology in British industry, which could lead to widespread technological unemployment amongst industrial workers. Others, on the other hand , pointed to the danger of a too slow diffusion of the new technology, relative to overseas competitors, creating even greater damage to output and employment in the UK.

In order to add some empirical basis to such discussions, the Technology Policy Unit of the University of Aston began to conduct surveys of industrial companies who were adopting new production technology.[1] It was discovered, however, that the quality of information derived from the brief visits to firms involved in these surveys was unsatisfactory and so research projects were planned to conduct detailed case studies of single firms and their adoption of new production technology over two years.[2] Credit for organising this particular study must go to Dr. R. Moseley and Professor E. Braun of the Technology Policy Unit and also to the SERC/SSRC joint committee who funded the project for two years. I should particularly like to thank Dr. Moseley for his advice and encouragement in supervising my work, even after he had left the University. Thanks are also due to Albright & Wilson Ltd., for allowing themselves to be the subject of this study by giving me access to their plants and their personnel. I hope that they find my interpretation interesting and take any apparent criticisms in the friendly spirit that I have intended. Mr. Roy Williams, in his role as my industrial supervisor, was essential to the study both by helping me to understand events at Albright & Wilson and by his influence in arranging many of the interviews on which the thesis relies. I would like to thank his secretary Ms. Vicki Parker and all the Albright & Wilson employees who helped me but are too many to name individually.

This thesis did not originate in a theoretical problem and then seek empirical evidence which could test it; rather it grew by following events and seeking to explain and understand them. Therefore, the original conception of the project was altered at several stages in response to developments at Albright & Wilson which raised new questions and suggested new answers.

Originally, in early 1978, it was intended to investigate a programme of adoption of advanced control systems, probably computer control, at various Albright & Wilson plants, to analyse the reasons for adoption and its consequences in terms of output, efficiency and employment. However, it soon became apparent that, despite the enthusiasm of some individuals in the company, Albright & Wilson was not immediately about to embark on such a programme. Only at one plant did it prove possible to study a successful adoption of advanced, electronic control before 1981. I visited this plant, at Rainham, Essex in 1979 and again two years later and had valuable help from staff there, especially Mr. Tony Borrett and Mr. Dave Barratt.

Since my reading in the history of process control technology had madé me aware that Albright & Wilson was already substantially behind much of the chemical industry in that area, the project then turned to an examination of conservative trends at the company and a search for their origins, which appears at Chapter 4. This traditional policy of Albright & Wilson towards control technology was clearly being influenced strongly from 1979 by Tenneco Inc., an American multi-national corporation who had taken over the British firm at the end of 1978. Since it became increasingly clear that decisions were now controlled by Tenneco, I undertook a visit to its corporate headquarters at Houston, Texas in April/May, 1980 and spent two weeks with Tenneco's Operations Technologies Department. The OTD allowed my understanding of Tenneco to develop, as it appears in Chapter 5 and elsewhere in the thesis and I would like to thank all OTD staff, but especially its Director James Lane, who gave me much time and important information. Also the SERC should be thanked for providing financial support for the American visit.

During 1980 and 1981 the impact of Tenneco upon all events at Albright & Wilson became more decisive and the study therefore turned to analysing the manner in which the previously independant company was rationalised, reorganised and re-equipped. This process was still in progress when the research had to be discontinued, but I hope that I have been able correctly to identify the directions in which events at the company were moving and that my characterisation of the 1978-81 period as a 'turning point' or transition in Albright & Wilson, including its use of process control technologies, will remain valid.

Throughout my period at the Technology Policy Unit I received essential stimulation and support from other TPU members, so that this thesis should perhaps be considered as partly a collaborative effort. Finally, I have to thank Professor Braun and Mr. Rothman for providing me with part-time employment after the expiry of the initial project funding and my typist, Mrs. Jill Shilton for her labours on my behalf.

CHAPTER ONE

Introduction.

This thesis is concerned with the application of a new kind of technology to the control of industrial processes. Since the mid-1970s, microelectronic technology has been applied to an increasing number of control tasks in a widening range of industries. One area in which equipment based on microprocessors has been substituting for previous technologies is in the control of the operation of chemical processing plants. Such plants typically consist of one continuous system of pipes, vessels, pumps and valves, through which pass the materials to be transformed by heat, pressure and chemical reactions. Monitoring and controlling the operation of this interconnected system has been accomplished in the past by various combinations of electrical, pneumatic and manual techniques, all of which can potentially be superceded by digital electronic equipment, using microprocessor-based controllers and/or microcomputers.[1]

Most of this thesis consists of a case study of one firm in the British chemical industry, Albright & Wilson Limited, and the study seeks to understand this company's behaviour in adopting microprocessor-based control technology and the consequences for it of this adoption. Such a case study would be of little value if it was merely descriptive. It needs to be situated in the context of our wider understanding of technical change in industry and especially of the current wave of technology associated with microelectronics.

Since it is based in an empirical study of industry, rather than in a problem of theory, the thesis needs to draw upon not one but several areas of literature, from various academic disciplines, for its conceptual framework. The main function of this introduction chapter is to identify these relevant areas in existing literature, which will be referred to in a more detailed way in subsequent chapters, as they relate to the problems of the case study. The contribution which this study has made to the wider problems involved in understanding technical change and the "microelectronics revolution" particularly, will be assessed in the concluding chapter.

This thesis can be seen as part of a general resurgence in interest, over the last five years, in the analysis and prediction of technical change in industry, whose cause and centre of concern has been the application of microelectronics technology to information processing and machine control functions. Many reports have been produced predicting its impact on manufacturing industry generally, on particular industries or types of work,[2] even on particular UK regions.[3] However, the chemical industry and indeed all processing industries have received rather scant treatment compared with the attention given to the engineering industries.[4] This is surprising since the problems of computerising control where production is already a continuous flow of fluid, gas, liquid or powder, in processing industry, are inherently less formidable than in manufacture of discrete components, where new control systems for automation will also require new handling machinery to "fluidise" production. The chemical industry might, therefore, be expected to be treated as a pioneer in the adoption of microcomputer automation and a harbinger of future impacts of the technology in other industries.

The frequently cited reason for this neglect of new control technology in the chemical industry is that this industry was already so highly automated before microprocessors that any further changes to control systems must be only incremental improvements with only marginal impacts.[5] Such views are derived from the "automation debate" of the 1960s, in which chemical plants were used as examples of a form of production which had already completed a transition to "automated" operation that other industries were destined to follow.[6] Both the form of organisation in the chemical industry[7] and the nature of the workforce[8] were seen as having a new, stable and final form, characteristic of automated industry. If these views were correct, then the assumption that further technical change will not have radical effects would be a logical one. However, it will be argued in this thesis (Chapters 2 and 3) that the conclusions of the 1960s were premature and scope for changes of a radical kind did remain in the post-1970 chemical industry and that this potential is in fact being realised by microprocessor-based systems.

The two discontinuities which have affected the chemical industry since 1973 are the onset of economic recession and the radical new technical possibilities presented by microprocessor technology. In combination, they represent sufficiently changed circumstances to warrant new studies of technical change at chemical plants and make the findings of studies in the 1960s and early 1970s no longer applicable, to a large degree, to the present state of the industry. The changes brought by the recession and the technology of process control are the themes of this thesis, which also examines the relationship between economic changes and technical changes in the chemical industry.

Much of the literature which has appeared on the economics of the chemical industry reflected the conditions and preoccupations of the period of economic expansion from 1945 to 1973 and so is unhelpful in analysing current changes. At that time, competitive success relied largely upon exploiting the expanding markets by producing new chemical products. The conditions favouring product innovations were, therefore, a common subject of study, whereas innovation in processes received less attention. In so far as the economics of processes were considered, attention concentrated on economies of scale as a way of reducing costs, since this was a major feature of competition in the chemical industry during its period of rapid growth. However, the recession has tended to reduce the importance of these methods of competition and the new area of technical change lies in raising the efficiency and productivity of chemical plants by improved control systems. The economic consequences of such changes are, as yet, a little explored area of the economics of technical change in the chemical industry but one which needs to receive more attention.

The changes to the economics of production in the chemical industry need to be related to an understanding of the changes which have occured in the technology of process control and for this understanding it is necessary to make use of the technical journals which monitor new developments in such technology.[9] These however, tend only to cover qualitative change and new technical steps, rarely giving an idea of the extent of diffusion of each type of device or the economic costs and benefits of its use. In order to gain an understanding of the actual diffusion of the new control technology it is, therefore, necessary to attempt to inter-relate the separate technical and economic literatures and this is done briefly in Chapter 3 of the thesis.

A useful area of discussion of the relationship between technical change and economic conditions has been provided by the debate on "long-waves" in technology. Attention was first drawn to such waves of innovatory activity by Schumpeter[10] in the 1920s and the idea was revived in the 1970s by Mensch.[11] The notion of long waves in economic activity with 40-50 year cycles of expansion and contraction, was already familiar from Kondratieff.[12] Debate has centred on the co-incidence or rather the counter-cyclical relationship between waves of innovation and waves of economic growth.[13] Much of this debate remains contentious but from it has emerged a commonly-accepted idea that microelectronics, together with bio-technology and some new energy processes, constitute a wave of new process innovations which can form the basis for recovery from the recession and for a renewed period of economic growth.[14] This generalised relationship between microelectronic technology and economic recession forms a background to both the discussion of new technology in the chemical industry which forms Part One of the thesis and also to the case study of technical change in one firm, which forms Part Two.

Since this thesis deals with examples of the diffusion and adoption of new technology, an area of literature relevant to constructing a conceptual framework for the thesis is the branch of industrial economics concerned with the theory of the economics of technical change. Much of it reflected the preoccupations of that period, especially the conditions favouring invention and innovation and the relationship between innovation and growth or competitiveness.[15] Diffusion of innovations and particularly diffusion of process innovations was neglected by comparison. Interest in the diffusion of process technologies only became considerable in the mid-1970s with the articles collected by Nabseth and Ray[16] and the work of Davies.[17] Significantly, the recent contributors have tended to be very critical of the state of studies up to the mid-1970s. Standard diffusion theory is largely derived from Mansfield,[18] whose "epidemic" model tracked the increasing proportion of an array of potential adoptors who use a technology, through time. Since there are few adoptors in the earliest and latest stages of the diffusion process and most adoptions in the middle stage, an S-shaped curve of diffusion is assumed to result. This model has been strongly criticised by Gold[19] for being a static, post-hoc description, which fails to give a dynamic analysis of changes in the technical and economic environment of firms or of the manner in which adoption occurs. Case studies of adoption of new technologies are therefore needed to complement diffusion studies at the level of a whole industry and it is such an adoption study that this thesis aims to provide, in its analysis of Albright & Wilson Ltd.

The same need for adoption studies at the level of individual firms is revealed when examining the literature looking specifically at microelectronics and its diffusion in various industries. A common method has been to estimate the number of potential adoptors of the device, list its advantages over previous technology, mention some possible "barriers" to diffusion and guess at the time scale required for adoption by most firms in the industry.[20] Only empirical studies of the experience of actual adoptors can improve the depth of understanding of diffusion processes and hence the accuracy of such predictions. One approach to adding this empirical basis is to conduct surveys of a number of adopting firms and to seek for correlations between successful adoption and characteristics of firms such as size, profitability or less quantifiable features relating to attitudes or access to information.[21] Examples of such surveys are those by Stoneman[22] for the diffusion of computers in the UK and by Fisher[23] for adoptions of process control computers. The problem is that such surveys can produce lists of relevant factors, but not the detailed processes which have produced the correlations found. As Gold has noted,[24] much more detailed information in the form of analytical case studies of both adopting and non-adopting firms are required to construct an understanding of the nature of the adoption process. Part Two of this thesis aims to provide such an adoption case study for Albright & Wilson Limited.

The intention of this case study is to overcome some of the limitations of the brief studies of adopting firms which are characteristic of surveys. One problem of studying a decision to adopt is that such a decision is not in fact isolated, but part of a continuing process of technology policy-making within a company. Conventionally-used terms to describe inter-firm diffusion, "infection", "imitation" or "band-wagon effect" are too passive in their implication for firms' behaviour. Firms are active, goal-seeking organisations which, as Tivey[25] points out, are essentially purposive. Their technology decisions are only comprehensible within an understanding of the firms' overall objectives and policies. Furthermore, as Gold[26] emphasises, an innovation is not static but appears in a series of progressively modified forms, so that firms have to constantly re-evaluate their policy with regard to any technology in the light of a changing environment and changes in the characteristics of the technology. In this thesis, therefore, the study of Albright & Wilson does not confine itself to a single adoption decision, relating to microprocessor-based control devices, but examines the evolution of company policy and its determinants over many years previously, within the historical development of Albright & Wilson's overall economic and technical position. The company history, by Threlfall,[27] although only descriptive and referring little to events outside the company, has provided important historical material for identifying long-term trends within Albright & Wilson Limited.

A case study which concerned itself entirely with events within firms runs a danger of producing an explanation in terms of the particular competence or dynamism (or conservatism) of managements, which is itself unexplained. The behaviour of any firm is deeply conditioned by changes in its environment and differences in firms' environments may be as significant for propensity to adopt as differences between their internal organisation - a point made by Davies.[28] Therefore, the description of events within Albright & Wilson, which has been obtained from interviews with managers and engineers employed by the company, will be placed as far as possible in the context of the company's position within its industrial environment, both currently and historically. This has involved drawing upon the history of the chemical industry, present economic trends and industrial relations conditions in the industry. When comparing Albright & Wilson with their American parent, Tenneco Inc., it has meant using a context of the comparative British and American industrialisation experiences. The study is, therefore, multi-disciplinary and aims to avoid by that means some of the limitations of abstract, ahistorical studies of the "economics of technical change."

The structure of the thesis reflects the concerns which have been discussed above. It presents both an industry-level study of the diffusion of microprocessor-based control technology in the modern chemical industry and a detailed study of the adoption of such technology by a single British chemical company, linked to the industry-level processes that have been described.

Part One is composed of two chapters. Chapter Two looks at the technology of process control, prior to microprocessors and relates the evolution of process control computers in the 1960s to the economic needs and conditions of the chemical industry at that time. Chapter Three continues this analysis by summarising the changes in the relevant product and factor markets which occured after 1973, outlines the consequences for the economics of production in the chemical industry and presents microprocessor control systems as a technical response to the new demands of the economics of production. Labour, as a special factor of production, is considered separately and the problems associated with operating and maintenance work in the industry are related to the characteristics of the new control technology.

Part Two presents Albright & Wilson as an example of a late adoptor of new control technology and Chapter Four is concerned with seeking the origins of its technological conservatism in the company's past history. Chapter Five gives a constrasting analysis of a more dynamic adoptor of control automation, in a study of Tenneco Inc. Its takeover of Albright & Wilson (A & W) in 1978 forms the starting point for Chapter Six, which examines the changes to control technology policy that Tenneco introduced to A & W. Chapter Seven consists of a plant-level study of the first plant at A & W to be controlled by an electronic digital controller and records the consequences for output and employment at that plant.

The role of Chapter Eight, the Conclusion, is to summarise the findings of the case study and the industry-level study and relate the two. Finally, it discusses the wider academic and policy issues which have arisen and makes suggestions for the directions to be taken by future studies, in the area of the study of technical change and the particular relationships between microprocessor technology and the recession.

P A R T   O N E

CHAPTER TWO

The Development of Process Control Computers during the Period of Economic Expansion (1959-1973).

Introduction.

This chapter will be concerned with computers used for the control of processing operations in industry, especially concentrating on their use in the chemical industry. Industrial application of this technology began in the late 1950s and was, it will be argued here, so radically transformed by the introduction of micro-electronics in the mid-1970s as to have been superceded by what was effectively a new technology. If it is considered, with all its modifications and improvements, as a single phase of process technology, this diffusion of process control computers in the 1960s and early 1970s has to be explained by reference to the requirements of chemicals production in that period. Therefore, it will be necessary to begin by analysing the economic conditions in the industry at that time and identifying the major directions of change in process technology imposed by those conditions.

The main characteristics of process control computer technology, its strengths and limitations, its costs and benefits, can be identified by making use of the technical journals which cover the area.[1] This chapter will then seek to relate these technical characteristics to the particular needs of chemical production created by the period of sustained and rapid growth in the chemical industry during the 1960s and early 1970s.

Economics of the Chemical Industry 1945-73.

According to Mensch[2] it is characteristic of economic recessions that they provoke a wave of innovative activity as firms try to discover new markets by developing new products. As a result, certain 'basic' and 'radical' innovations[3] will be made that are capable of founding or rejuvenating whole industries and it is these new industries which will lead the expansion of the whole world economy into the next general expansionary economic period, lasting several decades. The chemical industry has, since the inter-war period, exemplified rather well this pattern of development. During the 1930s and 1940s, a wave of new products appeared resulting from the "basic innovation" (in Mensch's terminology) of organic polymers. These included synthetic fibres, synthetic rubber and various kinds of plastics. The result was the creation of practically a new industry alongside the staple chemical products of the late 19th/early 20th century industry.[4] A close correspondence exists between the dates of the first appearance of these new polymers, as for example listed by Reuben and Burstall,[5] and the period of generally high innovative activity identified by Mensch in the 1930s and 1940s.[6]

The widespread production of organic polymers was stimulated by the interruption of supplies of natural fibres and rubber to the combatants during the second world war and the post-1945 reunification of world markets led to an enormous expansion in their output. The chemical industry was a leading sector in the post-war economic boom, its growth rate in most countries being twice that of industrial production generally. Within this overall growth, the new products grew much more rapidly than the old-established areas of chemical production, as Figure 1 demonstrates. In particular, polymer production rose dramatically during the post-war period, world output rising from 1 million tons in 1948 to 27 million tons in 1969.

Growth in the chemical industry was, therefore, based on the existence of a high proportion of products in the early phase of their product life cycle, described by Beeching[8] as the

> phase of rapidly expanding demand for the product ... during which demand is likely to outstrip supply, even though output rises quickly and during which profit margins are expected to remain fairly high, even though costs and prices may be expected to fall ... outright competition is not likely to develop because of the patent situation, maintenance of price discipline among a few producers and a state of under-production.

In the 1950s and early 1960s, the chemical industry in general was therefore, dominated by "performance maximising" competition,[9] which favoured technical effort invested in improving and multiplying products, to exploit the expanding markets. Costs were not so crucial to sales and profitability for companies which were reaping the benefits of pioneering new product areas, especially in the developing field of organic polymers.

A key factor which served to contain production costs was the availability of cheap, plentiful oil as a feedstock. Organic (aromatic) chemistry in the early 20th century had been based on the distillation of coal tar but during the 1930s, the US industry had converted to petroleum and European industry did so after 1945. In Britain, the proportion of organic chemicals derived from oil rose from 11% in

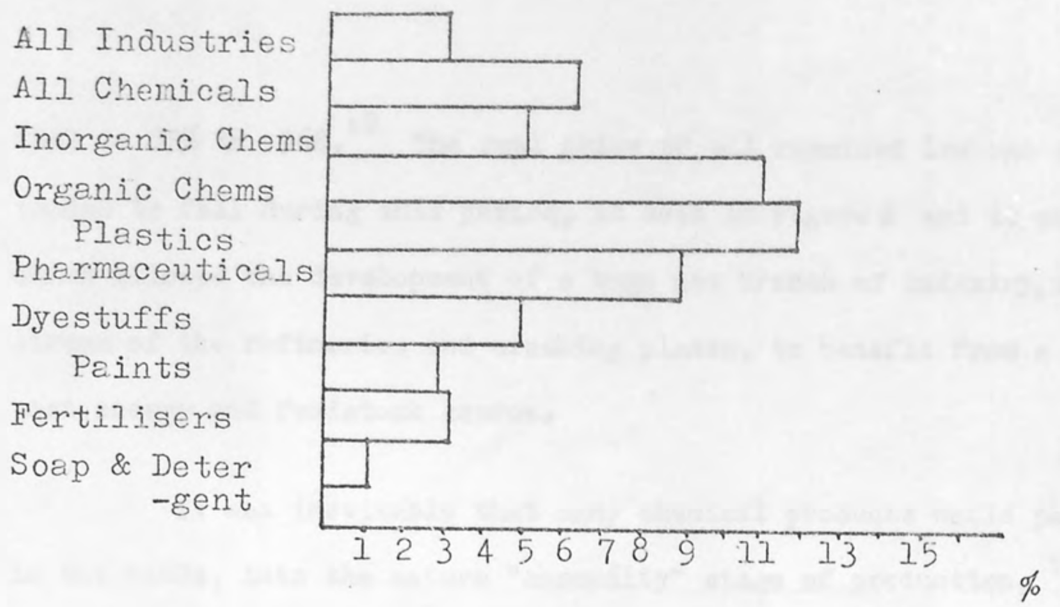


Fig. 1. <u>Comparative growth rates of various areas of UK chemical production</u> (1958-67).
Source: Hunter, L.C., Reid, G.L. and Boddy, D, <u>Labour Problems of Technological Change</u> (London 1970) Table 8.1, p.204.

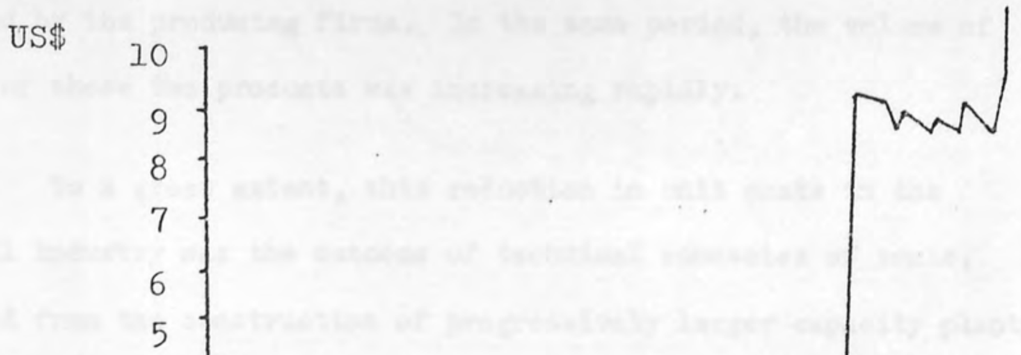


Fig. 2. <u>World oil prices 1950-80</u> (in 1974 prices).
Source: Odell, P.R. and Rosing, K.E., <u>The Future of Oil</u> (London 1980), Figure 1.2, p.27.

1949 to 87% in 1968.[10] The real price of oil remained low and indeed tended to fall during this period, as seen in Figure 2 and it was this which allowed the development of a huge new branch of industry, down-stream of the refineries and cracking plants, to benefit from a low cost energy and feedstock source.

It was inevitable that many chemical products would pass, in the 1960s, into the mature "commodity" stage of production, [11] in which the position of the first producers was eroded by the entry of new competitors, who increased supply to meet potential demand and changed the basis of competition towards being concerned with price reductions. To survive in the price-competitive markets, firms needed to achieve more effective unit cost reductions. Figure 3 shows the success achieved in reducing the prices of two typical organic chemicals, reflecting the successful unit cost reductions achieved by the producing firms. In the same period, the volume of output of these two products was increasing rapidly.

To a great extent, this reduction in unit costs in the chemical industry was the outcome of technical economies of scale, obtained from the construction of progressively larger capacity plants.[12] Unit costs could be reduced because, for a given increase in capacity, a less-than-proportional increase in land, labour and capital costs was needed. The upper limit on such economies of scale must necessarily be set by the size of the market for the product and markets were expanding throughout the 1950s and 1960s, as the result of overall growth in the international economy. In addition, the reduced product prices, achieved by competitive cost reductions,

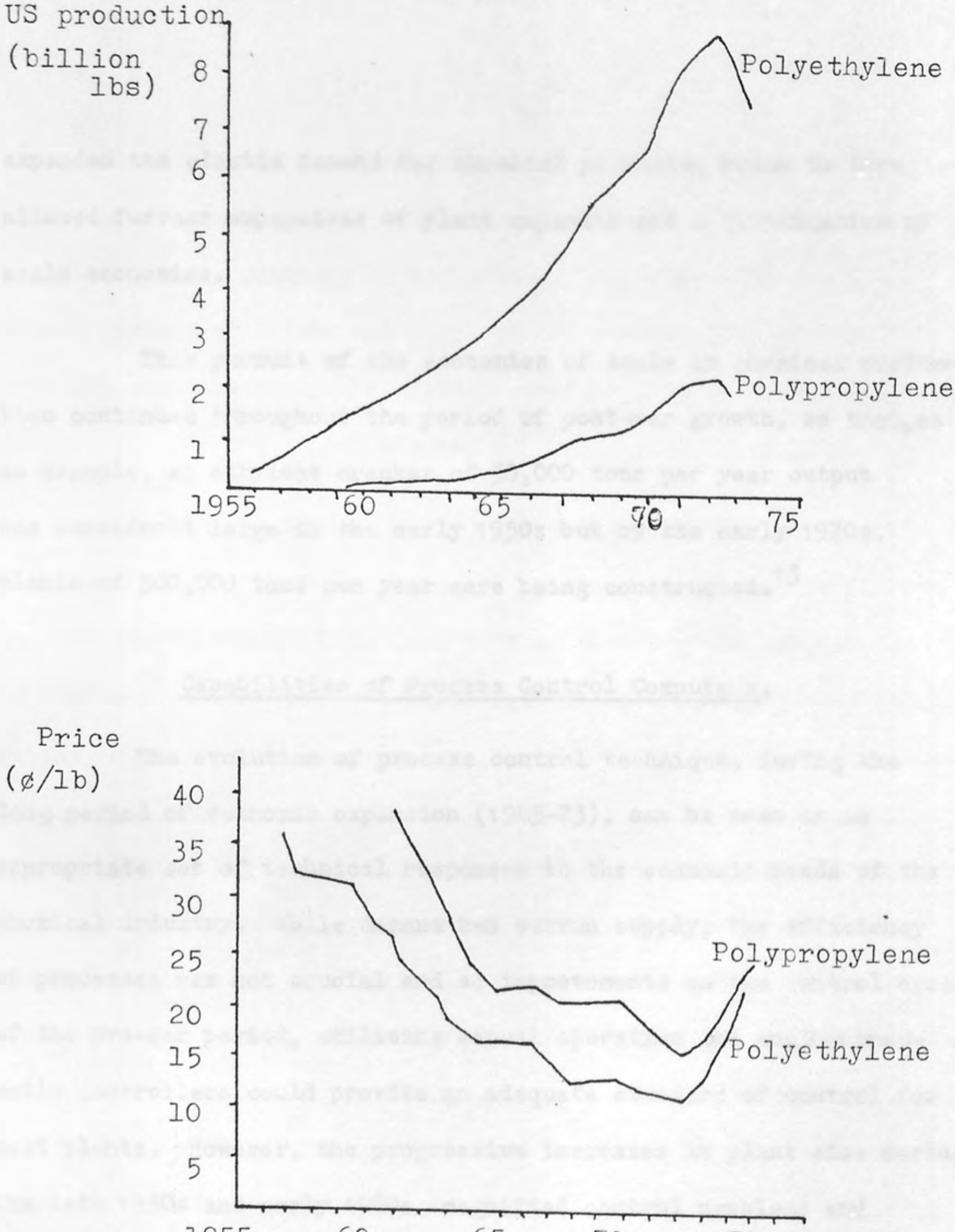


Fig. 3. US output and prices of two organic polymer products (1955-77).
Source: Wei, J., Russell, T.W.F., Swartzlander, M.W., The Structure of the Chemical Processing Industries (New York, 1979), Figures 6.11 and 6.16.

expanded the elastic demand for chemical products, which in turn allowed further expansions of plant capacity and a continuation of scale economies.

This pursuit of the economies of scale in chemical production continued throughout the period of post-war growth, so that, as an example, an ethylene cracker of 50,000 tons per year output was considered large in the early 1950s but by the early 1970s, plants of 500,000 tons per year were being constructed.[13]

Capabilities of Process Control Computers.

The evolution of process control technique, during the long period of economic expansion (1945-73), can be seen as an appropriate set of technical responses to the economic needs of the chemical industry. While demand had outrun supply, the efficiency of processes was not crucial and so improvements on the control systems of the pre-war period, utilising manual operation and analogue pneumatic controllers, could provide an adequate standard of control for most plants. However, the progressive increases in plant size during the late 1950s and early 1960s magnified control problems and provoked experiments in the application of an entirely new kind of technology - the use of process control computers.

On the large plants, pneumatic systems encountered problems from freezing of exposed air pipes and from the lag in signal transmission shown by pneumatic impulses, over distance. For these reasons, electric transmission came to be preferred for large plants and this implied the use of electronically controlled instruments and actuators.[14] Once data was in this form, it was logical to consider using electronic computers, at first as tools for calculating the complex control functions of large plants but then also for the direct control of valves and pumps on the plant. Some of the earliest examples of direct digital control (DDC) were the applications in Britain, in 1962, on ICI plants.[15]

Large plants exaggerated the problem of "process lag", which is the delay between making an upstream change to the process and its downstream consequences, such as changing the composition of the feed of inputs to the plant and seeing a change in the final output composition. Such long lags could lead to a very complex state of disequilibrium, unless the plant could be automatically stabilised by controlling its operation by "feedbacks" of information from instruments monitoring temperatures, flows, pressures and other variables on the plant. The necessary theory of automatic control for achieving such closed control loops had been developed in the 1940s and 1950s but could only be fully utilised when computers capable of satisfying the financial and practical operating requirements of the chemical industry became available.

The crucial innovation for practical process control computers was the transistor, which was developed in the USA during the early 1950s.[16] Transistors increased the reliability and reduced the price of computers to a level which allowed their profitable industrial application on some plants. Although computer prices remained high until the late 1960s, process control computers could be economic because they were a fixed cost, unrelated to output and so on large-capacity plants the benefits from improved control were multiplied by many units of output, allowing an attractive return to be shown on the investment.[17] Consequently, early control computers were suitable for high-volume, continuous processes, typical of the manufacture of basic bulk chemical products. An oil refinery was the first computer controlled process plant in the US (1959)[18] and the first in Britain (1962) was an ammonia/soda plant,[19] both based on high-volume, continuous processes.

Hazard provided a second motive for computerising process control. Many of the new products of the post-war industry involved the use of toxic materials and to remove operators from proximity to the process and to reduce the risks of human error in plant operation, the cost of a computer could be justified. An early example was the computer control of ICI's herbicide plant at Widnes, in 1964.

The mainframe process control computers of the 1960s can, therefore, be regarded as an advance in process control technology which was appropriate to the economic conditions of the period of rapid growth in chemicals output and the competitive pursuit of the economies of scale in giant plants. In this environment, their diffusion was rapid, installations having risen to several thousands by the late 1960s, (see Figure 4). However, the potential number of plants on which the difficulty of control and the volume or hazard of the product made computer control economic as an investment, was not unlimited and the role fulfilled by process control computers for control of chemical processes, during the 1960s, should not be exaggerated. When Stoneman[20] estimated the number of computers in

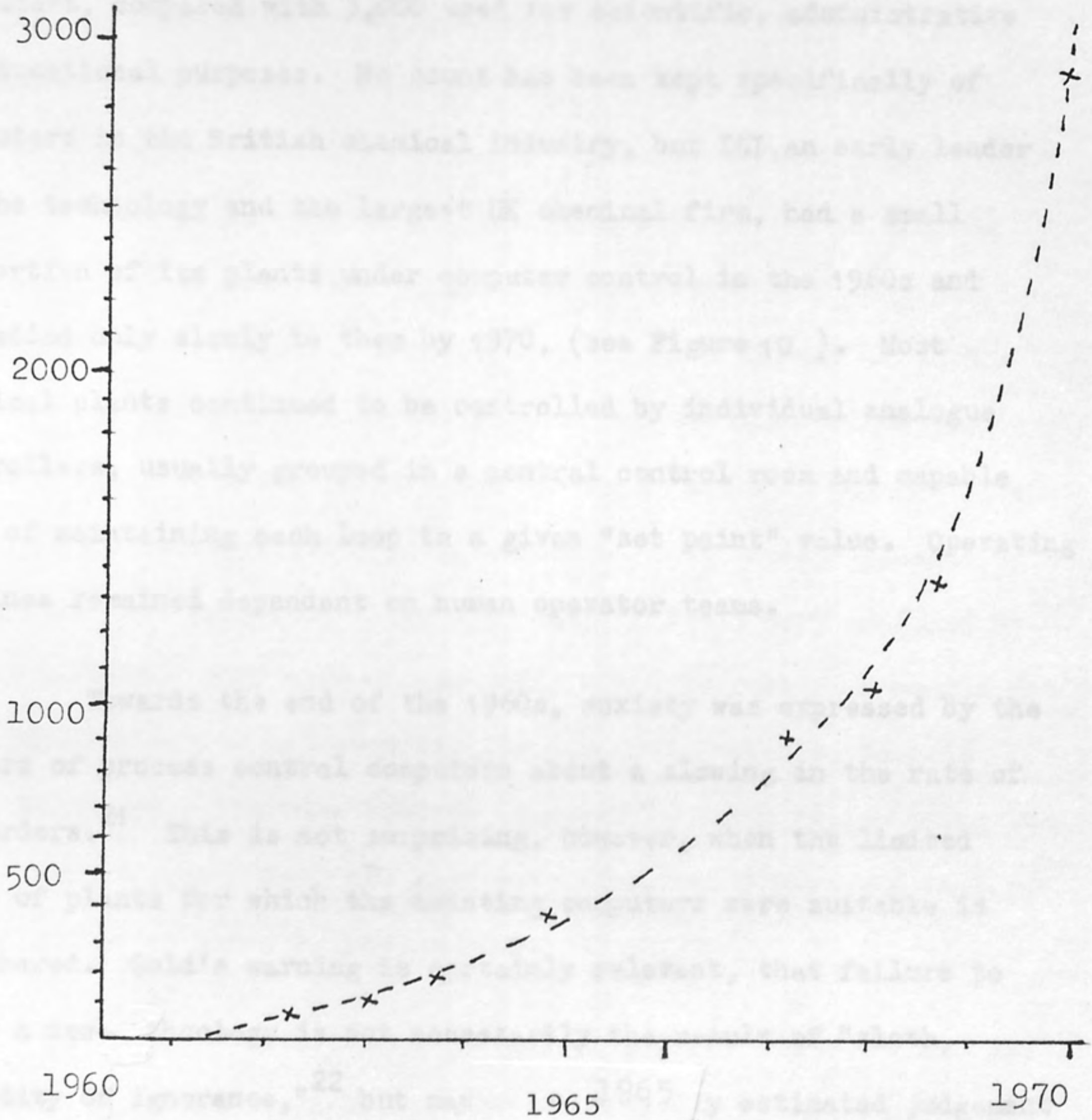


Fig. 4. Total number of process control computers installed in US (1960-1970).
Source: Control Engineering, 23 (September, 1976), p.124.

use in Britain in 1969, he discovered 150 industrial control computers, compared with 3,000 used for scientific, administrative or educational purposes. No count has been kept specifically of computers in the British chemical industry, but ICI, an early leader in the technology and the largest UK chemical firm, had a small proportion of its plants under computer control in the 1960s and had added only slowly to them by 1970, (see Figure 10). Most chemical plants continued to be controlled by individual analogue controllers, usually grouped in a central control room and capable only of maintaining each loop to a given "set point" value. Operating routines remained dependant on human operator teams.

Towards the end of the 1960s, anxiety was expressed by the vendors of process control computers about a slowing in the rate of new orders.[21] This is not surprising, however, when the limited range of plants for which the existing computers were suitable is remembered. Gold's warning is certainly relevant, that failure to adopt a new technology is not necessarily the result of "sloth, stupidity or ignorance,"[22] but may be a correctly estimated judgement of the balance of costs and benefits from adoption of the technology at that stage in its development. According to him, "many innovations never achieve high levels of saturation within the seemingly relevant industrial sector,"[23] because the number of potential economic applications is actually much smaller than may appear. This seems to have been the case with the process control computers existing prior to micro-computers. The limited scope for diffusion was the result of the real limitations of the technology and these limitations will be described in detail in the following section.

The Limitations of Process Control Computers.

The main barrier to more extensive use of process control computers was their high direct and indirect costs. The purchase price of a process control computer in the early 1960s was £20,000-£30,000 but the total cost of computerising a plant had to include extra equipment to interface and monitor the plant, which multiplied this figure several times. A satisfactory rate of return on such a large item of investment was possible only on the high volume plants that made basic bulk chemicals - the upstream "building blocks" of the industry, such as sulphuric acid or ammonia. Most chemical plants made more specialised products, whose economies of scale were confined by smaller markets. They were consequently bound to remain of medium or small capacity and so not economic for computer control. Several plants might share the same central computer as a way of spreading its costs over a larger output but this was clearly only possible on large multi-plant sites owned by one company.

A second limitation on the use of process computers was the unreliability of this technology. In the 1960s they remained, to an extent, an experimental technology and also had, inherently, a construction vulnerable to faults. The central processor unit itself was composed of a huge number of individual electronic components and a correspondingly high number of interconnections. To interface with the plant required a complex system of cables and, if pneumatic controllers were in use on the plant, an array of transducers to convert electronic signals to pneumatic ones. The computer's need for information required many more sensors and a greater concern for instrument maintenance than on plants operating by reliance on human operators. All these features multiplied the possibilities of failure in the system of control and the costs of maintenance, compared with traditional control equipment. Also the vulnerability of concentrating all control functions in one piece of equipment posed the danger of losing all control, something which was never possible with decentralised analog controllers. The danger of total control loss required that computer control had either to be limited to non-hazardous processes[24] or provided with a complete back-up in the form of a second, redundant computer or a complete set of analog controls that could be set manually. The cost of a computer, therefore, was often additional to that of analog controllers, rather than in place of their cost.

A third important source of cost, in addition to the hardware itself, was the special skill and expertise required for designing, installing, operating and maintaining a process computer application.

The design and installation of computer control systems required a rare combination of process engineering, control and computing expertise and its scarcity remained a significant constraint on the diffusion of computers. Similarly scarce was software expertise. Programming remained a laborious and highly skilled task since the software languages developed for scientific and office functions were only gradually replaced by high-level languages, specifically suited to process control. Maintenance of electronic equipment demanded skills outside the scope of traditionally trained instrument mechanics and technicians. Training programmes were expensive and wages remained high for capable electronic instrument artificers.[26]

Whatever the theoretical advantages of computer control for a process, more traditional methods always had the advantage of being compatible with the existing skills in the work force and established working practices. Maintenance of specialised teams of engineers, programmers and maintenance staff for computer controlled plants was only practicable for the largest companies, with a substantial number of plants suitable for such controls, so that a continuing programme of computerisation could be planned. These factors tended to reinforce the identification of computer control with the larger companies and in the context of the British chemical industry this meant that ICI tended to retain its leading position in the use of control computers.

Within the large companies which possessed the necessary financial and personnel resources to make a committment to a programme of computer use, only the large plants were likely to show an attractive rate of return through large-scale cost reduction in their operation. These were generally producing basic chemicals in continuous productions. Continuous plants usually had fewer variables, fewer changes and altogether simpler operation than batch plants and so suited better the limited capabilities of computers. Sequencing of batches is a more difficult operation, in theory, than continuous production. On the other hand, batch plants were probably producing for more specialised, less competitive markets, so traditional control techniques could give an adequate performance.

Conclusion.

The diffusion of process computers, before the introduction of microelectronics, was a diffusion among a strictly limited range of potential adoptors. The technology was prevented by its own technical characteristics from offering a general answer to the problem of automating control on chemical plants because process computers were essentially a technical response to a particular kind of control problem, derived from hazardous processes or from plants of a new scale. In these limited roles, they were a quite successful technology.

Process control computers can be regarded as a process innovation characteristic of the period of economic growth, in the 1960s and early 1970s, during which the chemical industry was engaged in a competitive pursuit of the economies of scale in production. The transition from growth in markets for chemical products to stagnation and recession has created new economic needs in the industry and the technology of process control has changed dramatically in order to satisfy these new needs. The relationship between the economics of recession and the new microprocessor-based control equipment is the subject of the next chapter.

CHAPTER THREE

Economic Recession and the Diffusion of Micro-processor-based Control Systems in the Chemical Industry.

Introduction.

In the previous chapter it has been suggested that while the large expensive process control computers of the 1960s formed an appropriate technology for the evolution of chemical production in the period of economic expansion, micro-processor-based equipment is a response to the new problems of production in the current economic recession. This chapter will examine this latter connection more thoroughly, to support the argument that the simultaneous occurrence of the onset of recession in the mid-1970s and the diffusion of micro-computers for process control from the same period, was actually the result of a causal relationship between them. After examining the changed requirements of production that have been created by the recession, the characteristics of micro-processor-based systems will be examined to determine whether they, in fact, offer benefits that have made them particularly attractive to potential adoptors in the chemical industry.

Economics of Recession in the Chemical Industry.

In 1976 it was suggested, by Mensch[1], that the growth in industrial output characteristic of the 1960s was slowing down and would be replaced by stagnation or contraction, with the result that the output of particular industries and whole national economies since 1945 would describe an S-shaped curve.[2] The onset of severe recession in 1980 has tended to confirm his prediction. The chemical industry has reflected this movement from growth to recession by exhibiting an S-shaped curve in its output as shown in Figure 5 , with the high growth rates of the 1960s slowing and even reversing, during the late 1970s.

Mensch [3] argued that the end of economic growth in the 1970s was explicable in terms of the simultaneous saturation of markets for those products which had formed the leading industries of post-war growth, such as cars, plastics and electrical goods. Those products had originated in a burst of innovative activity during the 1930s and 1940s, since when few radically new product areas had been developed, so that the saturation of markets for the leading products caused an overall slowing down in economic activity. In the chemical industry, as the previous chapter has pointed out[4], the products which led the dramatic growth of the industry in the 1950s and 1960s were those which first appeared twenty years earlier, especially the organic polymers, so that the industry has been characterised by the kind of simultaneous life cycles in its leading products described by Mensch. Synthetic fibres, rubber and plastic materials have largely completed their

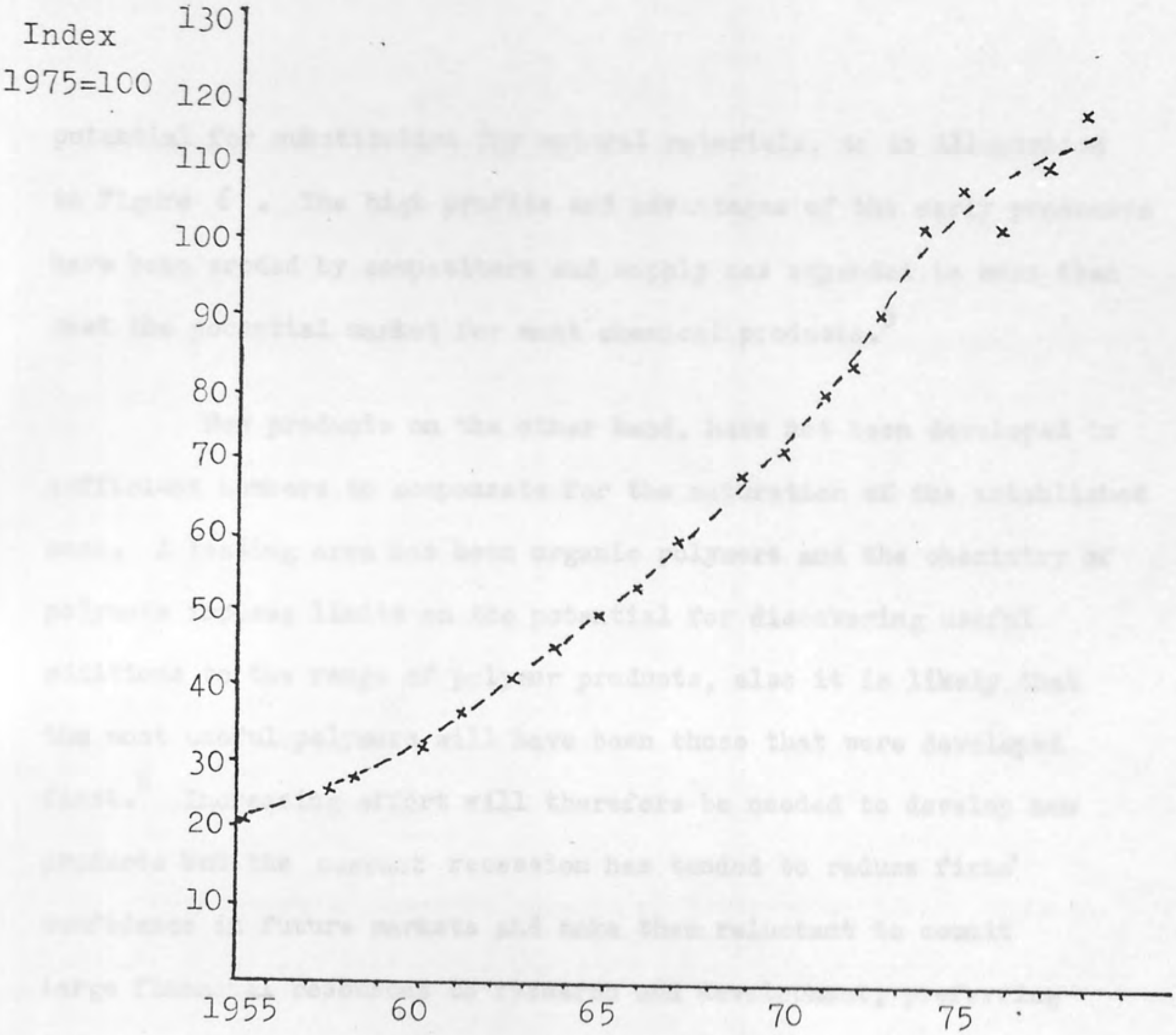


Fig. 5. Output of world chemical industry (1955-78).
Source: UN Statistical Yearbooks (New York, various years.)

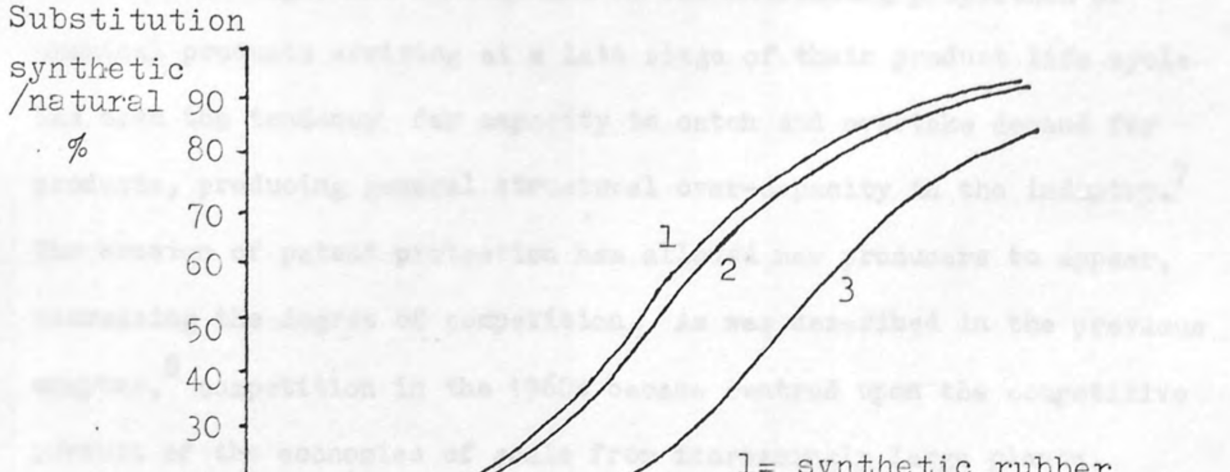


Fig. 6. Substitution curves for synthetics against natural products (1920-90).
Source: Mensch, G., The Stalemate in Technology, (Cambridge, Mass. 1979), Figure 2.5

potential for substitution for natural materials, as is illustrated in Figure 6 . The high profits and advantages of the early producers have been eroded by competitors and supply has expanded to more than meet the potential market for most chemical products.[5]

New products on the other hand, have not been developed in sufficient numbers to compensate for the maturation of the established ones. A leading area has been organic polymers and the chemistry of polymers imposes limits on the potential for discovering useful additions to the range of polymer products, also it is likely that the most useful polymers will have been those that were developed first.[6] Increasing effort will therefore be needed to develop new products but the current recession has tended to reduce firms' confidence in future markets and make them reluctant to commit large financial resources to research and development, preferring investments that can yield more rapid and more certain returns.

An important consequence of the increasing proportion of chemical products arriving at a late stage of their product life cycle has been the tendency for capacity to catch and overtake demand for products, producing general structural over-capacity in the industry.[7] The erosion of patent protection has allowed new producers to appear, increasing the degree of competition. As was described in the previous chapter,[8] competition in the 1960s became centred upon the competitive pursuit of the economies of scale from increasingly large plants. Planning such high capacity plants often meant planning for speculative demand which did not materialise. Newly-industrialising countries added to world capacity, especially oil-producing countries eager to add value to their oil by building a downstream chemical industry. These factors led to a world structural over-capacity in the chemical industry that tended to support Mandel's depiction of the recession of the late 1970s as essentially an over-production crisis.[9]

The results of this over-capacity, together with static or falling demand for chemical products have been a new intensity of price competition and downward pressure on product prices. To individual firms this appeared as a crisis of profitability and an intensified need to reduce production costs in order to survive in the price-competitive markets.

The favoured method of unit cost reduction in the 1960s had been to reduce unit fixed costs by increasing the size and output of chemical plants, as described in chapter 2, but conditions in the industry since 1973 have tended to close off that path.[10] In 1973 the world price of oil started a series of sudden upward movements, as shown in Figure 2, and similar rapid cost inflations occurred in other raw materials and energy sources. Since these are variable costs,the price rises immediately affected production costs. Furthermore energy and materials costs increase linearly with output so the rises were impervious to economies of scale which only affect fixed costs.[11]

At the same time that variable cost inflation was damaging the chemical industry, it also suffered from inflation in fixed costs. Figure 7 shows the increases in the cost of constructing new plants. Escalation of plant costs during construction frequently resulted in

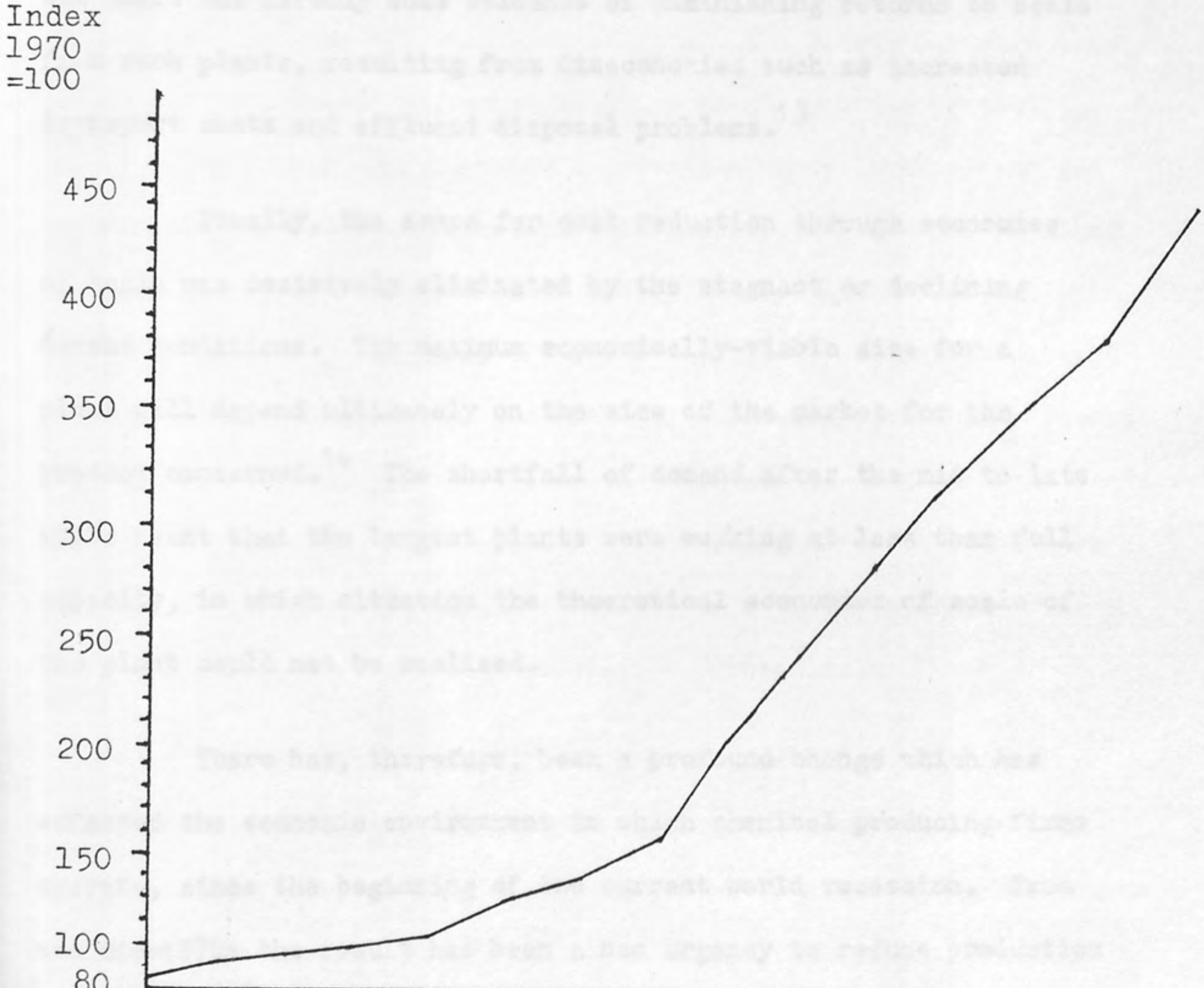


Fig. 7. "Process Engineering" plant construction cost index (1966-80).
Sources: Process Engineering (October, 1975), p.79 and
Process Economics International, 2, (3), (Spring, 1981),
p. 2-3.

the expected return on new plants being completely eroded before they could begin production.[12] Such escalation of fixed costs tended to reduce the economic incentive to build giant new plants but there was already some evidence of diminishing returns to scale from such plants, resulting from diseconomies such as increased transport costs and effluent disposal problems.[13]

Finally, the scope for cost reduction through economies of scale was decisively eliminated by the stagnant or declining demand conditions. The maximum economically-viable size for a plant will depend ultimately on the size of the market for the product concerned.[14] The shortfall of demand after the mid to late 1970s meant that the largest plants were working at less than full capacity, in which situation the theoretical economies of scale of the plant could not be realised.

There has, therefore, been a profound change which has effected the economic environment in which chemical producing firms operate, since the beginning of the current world recession. From the mid-1970s the result has been a new urgency to reduce production costs.[15] Since this has not been possible via increased economies of scale, the need has been to reduce unit costs by more efficient operation of plants of the existing sizes and designs. Improved process control of all kinds of processes has therefore been a vital technical requirement for regaining profitability in the chemical industry,[16] and it is against this background that the radical changes in control technology during the late 1970s, that have been associated with micro-electronics, have to be seen.

Microprocessor Technology for Chemical Process Control.

In chapter 2, the mainframe process control computers were described as a solution to the problem of controlling large continuous or hazardous plants and the limitations of this technology were seen to prevent its use as a general solution to all process control tasks. The urgent need for such a general advance in the technique of process control to improve product quality, utilisation of plant and efficiency in factors such as energy, materials and labour, which has been imposed on the industry since the mid-1970s, has encouraged the rapid development of a radically new technology for control, based on microprocessors. This overcame the limitations of previous control computers by a combination of new characteristics that have enabled it to become the means of achieving a rapid, general advance in the efficiency of chemical production processes.

During the late 1960s, computers were affected by the appearance of integrated electronic circuits. These provided increased computing power for reduced cost.[18] "Minicomputers" were sufficiently inexpensive to find applications on many plants for which control by mainframe computer would have been uneconomic, but they formed in fact, only a brief transition to "microcomputers" which achieved a much more dramatic advance in miniaturisation. From the first commercially available microprocessor in 1974, microcomputers were developed rapidly and applied to process control during the late 1970s.

Microcomputers can be used in quite different ways from previous control computers. The mainframe computer was a large, expensive item that demanded a highly centralised control configuration, with all the information on a large plant being centralised to a single computer. Sometimes one computer would be shared by several plants on the same site. The microcomputer, however, is sufficiently small and cheap to be available for a single part of the plant, a number of them then being linked into a decentralised "distributed control" system, such as the Honeywell TDC 2000 system, first offered in 1975. The next logical step was to use a microprocessor to control a single actuator on the plant. In 1978, Xomox produced a valve with a dedicated microprocessor built into it.[18] A whole system, in which each control loop had its own microprocessor was "Provox" in 1980.[19] These developments have moved the technology of process computing from the necessity to link all parts of the plant to a single expensive programmable logic device, to plants in which programmable logic can be actually built into every point of the plant at which control occurs.[20] The development of control technology has been so fast in the late 1970s and early 1980s that it is true to say that a radically new, radically more effective type of technology has become available which is applicable potentially to all process control functions on all kinds of process.[21]

The crucial element in the diffusion of microprocessor-based control technology has been its low cost compared with previous devices. Medium scale integration devices fell in price from $50 in 1962 to $1 in 1972. Large-scale integration has brought the cost of complex electronics down to a level which is negligible compared with other plant equipment costs. Even when equipment to interface the microcomputers to the plant and to the operators is included, these systems are generally substantially cheaper than analog controllers. As electronic hardware has standardised and entered mass production its price has tended to fall over time. Standardisation is possible because varied software enables the same device to be used flexibly in a wide variety of situations. Software has also been cheapened by standardisation in modular packages dedicated to the standard control functions. By this means, programming skills have been made unnecessary for using computer control on the plant, since devices are preprogrammed by the manufacturers. In fact, software can even interact with the operator and provide guidance through operating routines.. The savings in labour costs associated with microprocessor-based systems will be further discussed in the following section.

A second major limitation on the use of early process control computers was posed by problems of unreliability but these have been almost eliminated by microprocessor-based systems. Micro-electronics is inherently resistant to damage and failure, since all connections are embedded in silicon chips and the techniques of quality control developed for aerospace applications have resulted in very low failure rates. Circuits can be programmed to self-test and diagnose faults, while the modular construction and cheapness of the devices allow faulty sections to be easily replaced. For the first time in process control technology, more complex and sophisticated equipment has not required an increase in maintenance requirements.

Reliability has been further enhanced by the move from centralised to decentralised control. In "distributed" systems, a failure of particular control devices does not affect the other controllers which have considerable autonomy in their ability to control the routine operations of their part of the plant. Total system failure has therefore, become almost impossible, so that expensive back-up controls are no longer necessary.

Clearly, the advantages of the new micro-processor-based control systems greatly extend the potential scope for applying programmable, automated control of processes in the chemical industry. Microprocessor systems are able to satisfy the need for a radical improvement in the efficiency of all kinds of chemical processing plants and this qualitative leap in the capabilities of control technology has resulted in a quantitative explosion in the use of computers for process control. The actual pattern of diffusion of the new technology will be discussed later in this chapter.

One other important aspect of the qualitative change in control technology remains however, to be analysed. This far, the evolution of control computers has been explained in terms of a need for technical efficiency in plant operation, but this approach cannot satisfactorily include the changes which are involved in the introduction of microprocessor technology to the role of labour in the chemical industry. Labour has a special character which separates it from other inputs to production. In Friedman's phrase, it is "a commodity ultimately controlled by an independant and often hostile will."[22] Advances in the automation of plant processes have therefore, a 'political' dimension, in that they affect the relationship between management and labour on chemical plants. Therefore, the role of labour and its relationship to changing control technology will be considered separately, in the following section.

Computer Control and Labour in the Chemical Industry.

During the 1960s, considerable attention was paid by management theorists and industrial sociologists to the relationship between the technology of process production, especially in the chemical industry, and the nature and organisation of work which accompanied it.[23] The most influential study was that of Blauner.[24] His central theme was that the technology of process plants represented the final 'automated' stage of production and that chemical workers showed the characteristics of the future industrial workforce in all industries.[25] In fact, chemical process technology in the 1960s has proved to be very much transitional and the change to micro-processor control systems has revealed much more scope for further automating chemical plants. Blauner's idea that radical changes in the role of labour in the chemical industry were completed by the mid-1960s has, therefore, been completely undermined by the advent of micro-processor control systems.

The idea that manual labour in the chemical industry had been eliminated, leaving an irreducible core of workers to operate and maintain the plants, led to the conclusion that further reductions in the number of workers would not be possible.[26] Further technical change was not expected to have the intention or result of creating technological unemployment. However, the tasks remaining to human operators on plants controlled by analog control devices or early computers, were essentially those relating to monitoring, recording and adjusting plant behaviour[27] and these have been precisely the functions capable of automation by cheap, compact micro-processor-based control systems. They offer artificial logic functions, combined with programmability and memory capacity, allowing automatic supervision of any level of plant control.

Blauner, saw the characteristic of work in the chemical industry as being a change from manual skill to "responsibility."[28] This has to be regarded however, as a short-lived phase, during which the unreliability of instrumentation and control equipment and the lack of cheap, powerful computer capability, required a considerable input of operator supervision and monitoring.[29] Microelectronic devices, on the other hand are likely to be considerably more reliable than human operators, both in the sense of being less likely to fail and in being programmable by management. Under these conditions it has become feasible and desirable to consider plants that can be run by a single operator or are completely automated.

Before the introduction of microelectronics, increased automation of control always meant increased complexity of equipment and increased maintenance problems. Further automation was expected not to reduce the total number of workers but to change the ratio of skilled maintenance workers to semiskilled operators, thus 'upgrading' the average level of skill in the industry.[30] As indicated in the previous section however, microelectronic devices have inherently low maintenance requirements, so that they have broken and reversed this relationship between sophistication of control and the demands upon maintenance staff. Since microelectronic devices are usually replaced rather than repaired, the numbers and skill requirements of maintenance workers will tend to be reduced as the new technology is introduced.[31]

It is clear that those who thought that further reductions in the numbers of workers on chemical plants would not be feasible have been proved wrong. A further argument, however, was that there could be no significant incentive to attempt to displace labour since in a capital-intensive form of production wages form only a small part of total costs.[32] This argument also relied on the special conditions of expanding markets and the concentration on realising economies of scale. In the recession, pressure on profitability has made all costs significant and any means to reduce labour costs is likely to be exploited.[33] When plants are operating at less than full capacity it becomes important to reduce fixed costs and labour may be seen as an area where this is possible. As computer control spreads onto smaller plants and batch rather than continuous plants, where labour productivity is less than on very large continuous plants, the attractions of reducing the workforce are likely to be higher. Finally, the recession means that technological unemployment is unlikely to be masked, as it often was in the 1960s, by redeployment onto expanded or new plants[34] and will appear more frequently as redundancies.

It is important to understand, however, that wage costs are not the only, or even the most important cost of labour. A plant which relies on human operators' skill and attention, to a large extent, will require that management must make efforts to supervise and control the workforce. In the 1960s, chemical workers were portrayed as significantly less strictly controlled and supervised than those in other industries and as having higher pay and better conditions.[35] This was seen as either the direct outcome of the nature of process technology itself,[36] or of the strong bargaining power given to the workforce by the technology[37] but in either case as being characteristic of all capital-intensive, highly mechanised kinds of production.

A very different analysis of this kind of privileged position of "responsible autonomy" has been given by Friedman.[38] Rather than being an inevitable feature of capital-intensive industry, he suggests that it should be seen as one possible strategy for management control of the workforce where more direct methods are not possible. Such a policy of control by concessions and allowing some autonomy will have costs, however - notably less than maximum intensity of work and scope for the substitution of workers' objectives for those of management. Friedman has seen the need to make these concessions as being a result of the strong position of labour during "full employment" conditions in the economy, when high profitability made the costs tolerable. As growth ended in the industry, the level of conflict in the industry has increased sharply, as the different interests of workers and management have been emphasised and the strategy of "responsible autonomy" put under increasing strain.[39]

Microelectronic control systems offer to management a way out of these problems by gaining a direct control over the operation of the plant, that relies much less on the co-operation of human operators. Strategies for plant operation can become totally programmed to optimise plant performance according to objectives laid down by management and the ability of operators to change or disrupt production routines can consequently be reduced. Supervision of the workforce may also be automated, to a degree, since computer systems can automatically monitor and record changes on the plant for management. In general, microprocessor-based controls allow a much more direct control over plants and less reliance on the attentiveness and co-operativeness of operators and for this reason the diminution in the role of chemical workers which has become possible constitutes a powerful attraction towards introducing such systems, whether or not actual reductions in staff numbers also result.

A disincentive to exploiting the labour-saving potential of new control technology has been the possibility of resistance by a workforce which feels threatened by the changes implied. Again, the recession has changed the climate by making fear of plant closures from lack of competitiveness more serious than fears of technological unemployment. Indeed any investment is likely to be welcomed as safeguarding at least some jobs. Also the nature of microelectronic technology tends to avoid resistance. Being essentially modular, it can be introduced piecemeal, so that its labour-displacing effects are spread over a period of time. Technological unemployment tends to be hard to identify because it is confused with the effects of recession and rationalisation of production. For these reasons, resistance to automating technology must be expected to be lessened during the recession.

The same change from economic expansion to recession in the chemical industry which has made changes in the technology of process control necessary, has also forced the technology into forms which transform the role of labour on chemical plants in the direction of deskilling and displacement of operators and maintenance workers. Also, microprocessor-based systems are a means towards increasingly direct control over the plant and its operators by management. In the environment of recession these characteristics of the technology provide significant reasons for its adoption by chemical companies onto their plants.

The Diffusion of Microprocessor-based Process Controls in the Chemical Industry.

Earlier sections of this chapter have discussed the nature of the potential advantages for the chemical industry obtainable from adopting microprocessor controls. This section will continue the analysis by looking at the way in which these potential advantages have been realised in the actual pattern of diffusion that has resulted.

In discussing the determinants of technical change in industry, Mensch has asserted that :

> The actual implementation of new technologies - that is the timing and direction of innovation - depends upon the degree of stagnation in the old technologies and the attractiveness of the new alternatives.[40]

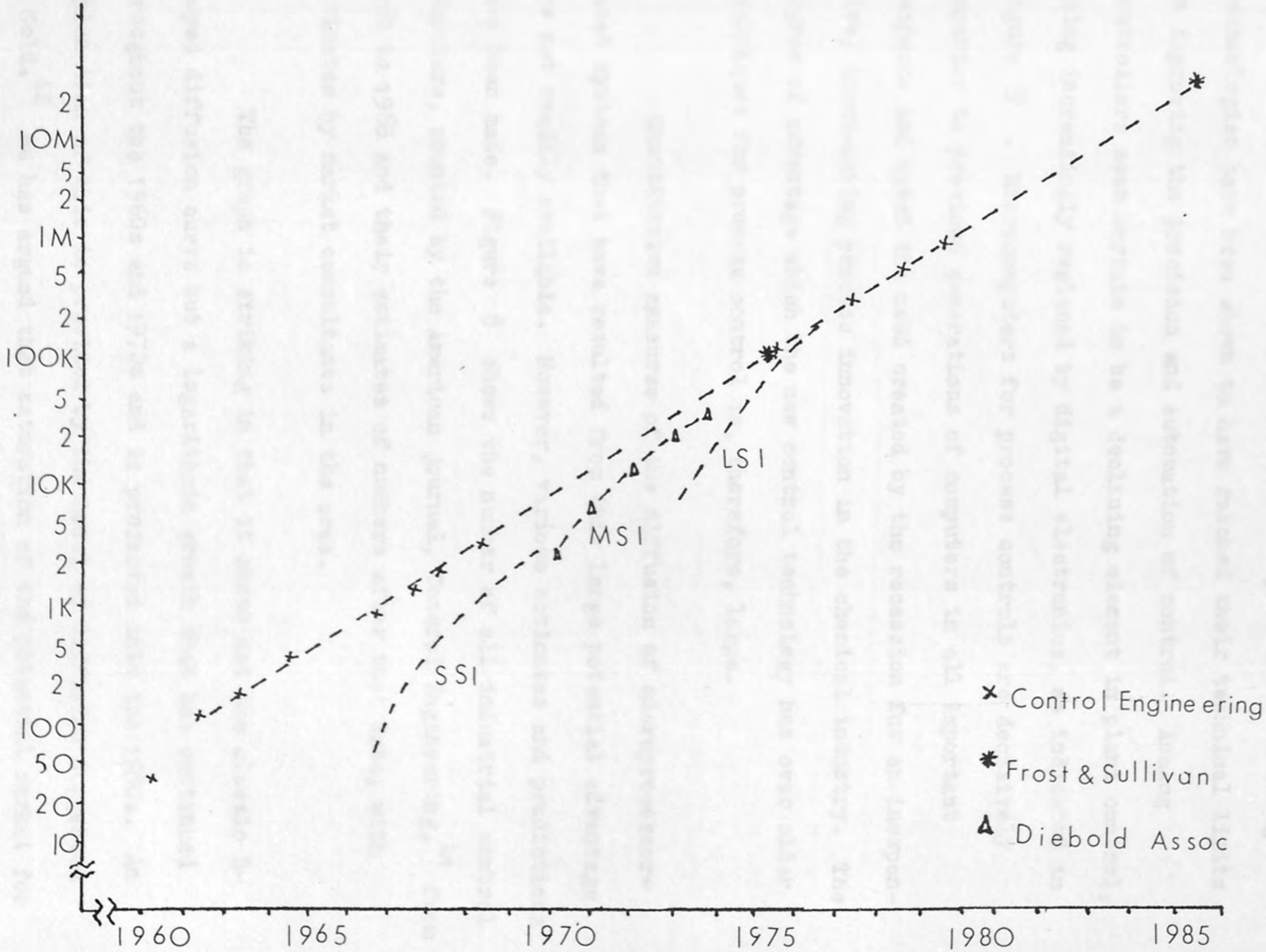


Fig. 8. Total numbers of industrial control computers installed in US (1960-1970 and estimated 1970-85.)
Source: Control Engineering (September, 1976, p.124 and June, 1978, p.49).

This is certainly applicable to the recent revolution in process control technology. In this chapter and chapter 2 the existing technologies have been shown to have reached their technical limits in improving the precision and automation of control. Analog controllers seem certain to be a declining element in plant control, being increasingly replaced by digital electronics, as indicated in Figure 9 . Microcomputers for process controls are decisively superior to previous generations of computers in all important respects and match the need created by the recession for an inexpensive, input-saving process innovation in the chemical industry. The degree of advantage which the new control technology has over older techniques for process control is, therefore, large.

Quantitative measures of the diffusion of microprocessor-based systems that have resulted from this large potential advantage are not readily available. However, various estimates and predictions have been made. Figure 8 shows the number of all industrial control computers, counted by the American journal, Control Engineering,[41] from 1960 to 1968 and their estimates of numbers after that date, with estimates by market consultants in the area.

The graph is striking in that it shows not the classic S-shaped diffusion curve but a logarithmic growth that has continued throughout the 1960s and 1970s and is projected into the 1980s. An explanation of this is provided by the model of diffusion suggested by Gold.[42] He has argued that saturation of the potential market for an innovation need not be observable if the innovation appears in a series of forms with improved characteristics,so that the number of

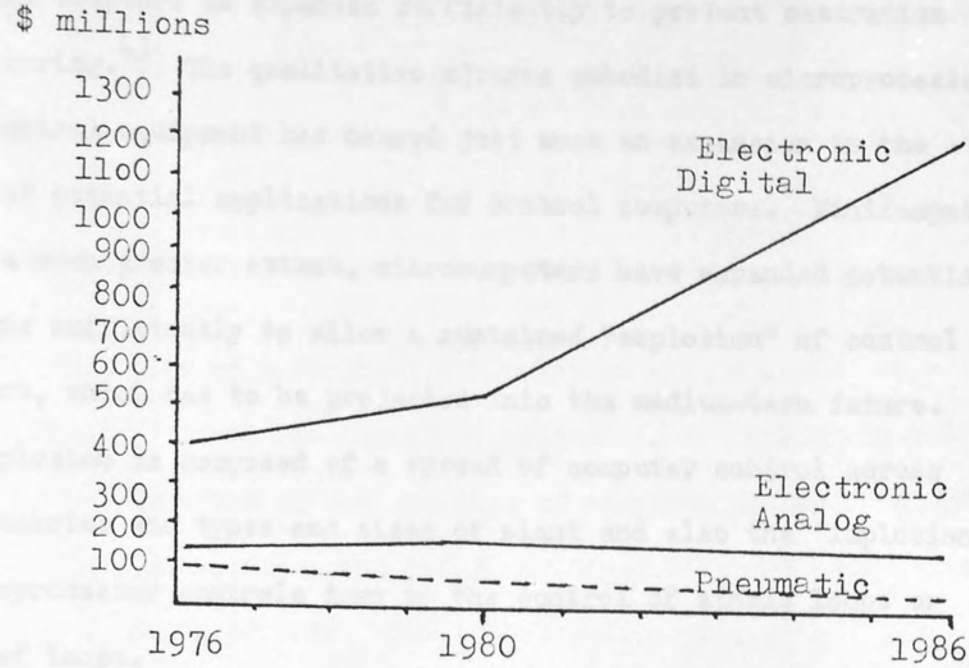


Fig. 9. Projected market for process control equipment (1976-86).
Source: Frost & Sullivan consultants report "Process Control Equipment Market" quoted in Control Engineering (October, 1979, p.57.)

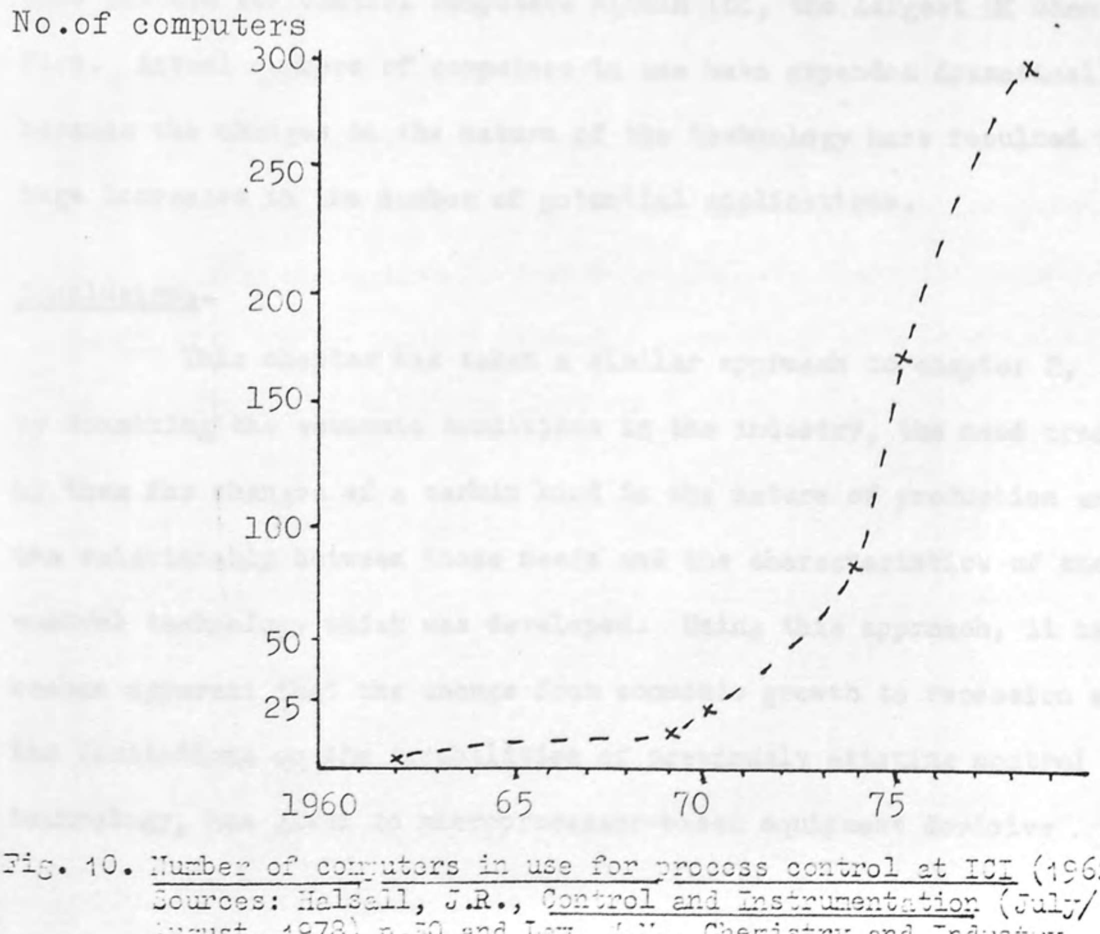


Fig. 10. Number of computers in use for process control at ICI (1962-78).
Sources: Halsall, J.R., Control and Instrumentation (July/August, 1978) p.50 and Law, W.M., Chemistry and Industry, (16th April, 1977), p.298.

potential adoptors is expanded sufficiently to prevent saturation from occuring.[43] The qualitative advance embodied in microprocessor-based control equipment has caused just such an expansion in the number of potential applications for control computers. Minicomputers and, to a much greater extent, microcomputers have expanded potential adoptions sufficiently to allow a sustained "explosion" of control computers, which has to be projected into the medium-term future. This explosion is composed of a spread of computer control across new industries and types and sizes of plant and also the "implosion" of microprocessor controls down to the control of single loops or groups of loops.

Figures for the number of computers used specifically in the chemical industry are not available, but Figure 10 shows the same pattern for control computers within ICI, the largest UK chemical firm. Actual numbers of computers in use have expanded dramatically because the changes in the nature of the technology have resulted in huge increases in the number of potential applications.

Conclusions.

This chapter has taken a similar approach to chapter 2, by examining the economic conditions in the industry, the need created by them for changes of a certain kind in the nature of production and the relationship between those needs and the characteristics of the control technology which was developed. Using this approach, it has become apparent that the change from economic growth to recession and the limitations on the capabilities of previously existing control technology, has given to microprocessor-based equipment decisive advantages and benefits which outweigh their costs. These considerations go some way towards explaining the rapid diffusion of the technology which has taken place since the mid-1970s and the expectations of continued, explosive growth in numbers through the 1980s, despite the world recession in the chemical industry.

This kind of industry-level analysis has, however, very definite limits. As it was argued in Chapter 1, diffusion studies need to be complemented by case studies of adoption at the level of individual companies, where the decisions concerning new production equipment are, in fact, made. The industry-level study that has comprised Part One of this thesis serves to illuminate the context in which adoption decisions are taken and in general they seem to be explicable in terms of rational responses to the situation of the industry but in order to understand how diffusion will manifest itself in a population of very different firms, it will be necessary to examine in depth the process of adoption in individual firms. Therefore, the same problems relating to the adoption of microprocessor-based control systems which have been investigated for the whole chemical industry will now be pursued through a case study of a UK chemical producer, Albright and Wilson Limited.

P A R T   T W O

CHAPTER FOUR

Albright and Wilson Ltd. - The History of Technical Change in a British Chemical Company.

Introduction.

Chapter 3 has argued that the chemical industry, as a whole, needs to adopt microprocessor-based control equipment in order to achieve increased efficiency in the operation of its plants to restore profitability in the industry. From the point of view of individual firms in a competitive environment, this means that proficiency in the technology of automated process control will be crucial to survival during the recession. This chapter examines the history of a UK chemical company and shows how failure to rapidly respond to the new emphasis on process control formed an important component in the company's commercial failure. In order to understand this sluggishness in taking advantage of new process control technique, however, it is necessary first to look at the trends and traditions inherited from the company's long past, which it will be argued provide a powerful explanation of its inability to compete successfully in the changing economic and technical environment of the 1970s. This chapter will, therefore, provide an outline of the evolution of the company, especially its changing ability to respond to technical change in its industry since the mid-19th century.

The main source for the history of Albright and Wilson Ltd. must be Threlfall's centennial history,[1] published in 1951. It is full of valuable descriptive detail but does not situate the evolution of the firm in the context of the general history of the chemical industry, or of British industrialisation, so this chapter must represent a first attempt to provide this context. It will concentrate on the role of technical change in the company's history and, unlike Threlfall's book, which finishes in 1951, will bring the analysis forward to consider the behaviour of Albright and Wilson (A & W) in the contemporary period, characterised by an economic recession and a revolution in process control technology.

Successful Pioneers.

When Arthur Albright began commercial manufacture of phosphorus in 1844, he was in the position of both providing a new product and founding a new industry. Although elemental phosphorus had been prepared from bone ash in 1777 by Scheele, commercial production was only slowly established[2] and the early 19th century British match industry relied on imported phosphorus from France and Germany. By beginning production in Britain and selling more cheaply than the foreign producers, Albright was able to capture the British market within a few years and establish himself as the only UK supplier - a classic example of a monopoly established by the pioneer producer.

The monopoly position was reinforced by Albright's purchase of Schrotter's patent on the preparation of the 'red' allotrope of phosphorus.[3] This avoided the problems of the 'white' form of phosphorus, which, being poisonous and spontaneously liable to explode, created serious hazards in its production and in its use in the match industry. A huge market for red phosphorus was created by the invention of 'safety' matches by the Lundstrom brothers in Sweden in 1855. The following year Albright formed a partnership with John Wilson and together they built up a position as monopoly suppliers of red phosphorus to match companies, who were themselves monopolists in their own countries. In Britain, the sole producer was Bryant and May Ltd., who obtained the patent on safety matches in 1857. The whole European market for phosphorus was more or less divided between Albright & Wilson (A & W) and a French company.[4] Arthur Albright devoted himself to building up a world-wide market for match phosphorus, which A & W was to dominate for the remainder of the 19th century.

Albright's conception of making "common phosphorus matches for the million"[5] was typical of the new opportunities for mass production of household products being seized by British entrepreneurs, in the early 19th century. Imperialism and steam transportation were opening a world market for manufactured goods. For a brief period between the 1820s and 1870s, British industrialists "held a virtual monopoly of the supply of manufactured goods"[6] and A & W must be seen as part of this temporary monopoly by the pioneers of industrialisation.

The huge and expanding world market for phosphorus and A & W's position as a monopolistic supplier meant that the price and quality of the product were not crucial. Thus the technology of production could be crude and inefficient and, in fact, altered little from 1850 to 1890.

The coal-fired retort process consisted of "a series of highly elaborate stages."[7] First, bone ash or phosphate rock was treated with sulphuric acid, to yield phosphoric acid, which was concentrated and mixed with charcoal and coke. The mixture was then dried, ground and charged into fireclay retorts.[8] These had to be charged and emptied individually every few days, in a very labour intensive operation, which was for the workers at A & W, "a hot, messy and dangerous job."[9] The retorts were only about four feet in length and increased output was obtained by multiplying their number, so that by 1877 the works at Oldbury, Staffordshire, had 83 furnaces, holding 1,992 retorts.[10]

In energy terms also, the directly-fired furnaces were inefficient, described by Threlfall as "gluttonous coal eaters,"[11] but Staffordshire coal was cheap and this was decisive in an energy-intensive process. A & W paid 1/10 of the price for coal than that paid by their French competitors,[12] and this cost advantage was decisive as long as coal remained the energy source for phosphorus reduction.

The raw material was phosphate rock, which soon replaced bone ash, and it remained cheap throughout the 19th century, its price falling steadily as new deposits were exploited (Figure 11). Sulphuric acid was available from the neighbouring alkali works and the Midlands canal system provided cheap transport for both materials and products.

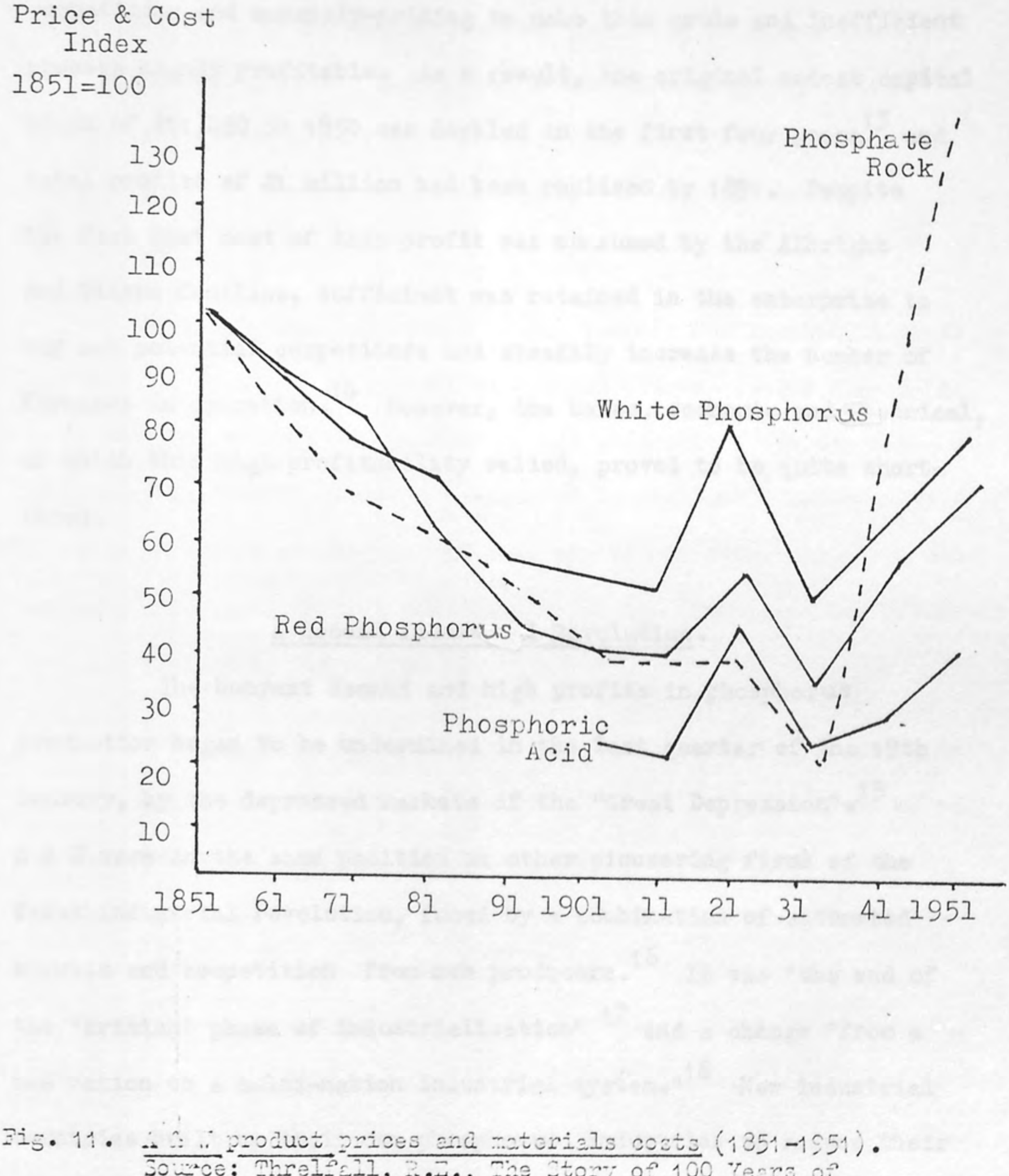


Fig. 11. A & W product prices and materials costs (1851-1951).
Source: Threlfall, R.E., *The Story of 100 Years of Phosphorus-making*, 1851-1951, (Oldbury, Staffs. 1951), p.219.

Cheap energy and materials combined with lack of competition and monopoly-pricing to make this crude and inefficient process highly profitable. As a result, the original modest capital stock of £11,450 in 1850 was doubled in the first four years,[13] and total profits of £1 million had been realised by 1891. Despite the fact that most of this profit was consumed by the Albright and Wilson families, sufficient was retained in the enterprise to buy out potential competitors and steadily increase the number of furnaces in operation.[14] However, the bases, economic and technical, on which this high profitability relied, proved to be quite short-lived.

<u>A Second Industrial Revolution.</u>

The buoyant demand and high profits in phosphorus production began to be undermined in the last quarter of the 19th century, by the depressed markets of the "Great Depression".[15] A & W were in the same position as other pioneering firms of the first industrial revolution, faced by a combination of saturated markets and competition from new producers.[16] It was "the end of the 'British' phase of industrialisation" [17] and a change "from a one nation to a multi-nation industrial system."[18] New industrial countries built up their own phosphorus industries to reduce their dependence on British imports and tariffs were erected to hinder importers to Germany and the USA.

Albright and Wilson responded in two ways. One was to start production in North America to avoid the tariffs.[19] The second was to concentrate on its monopoly position within the British Empire, while having to accept the increased competition in Europe and the US. Inevitably however, the period of undisturbed high profits was at an end and company profits fell from £56,000 in 1874 to £17,000 in 1879, recovered in the 1880s, but suffered renewed falls in 1890 and 1891.[20]

The general saturation of the markets for industrial goods and the new pressure to compete on product prices created a need for cost-reducing process innovations in all industries. In the chemical industry, the 1870's formed a "decade of innovation"[21] which created a range of new processes that allowed continuous flow production and reduced unit costs through economies of scale. The major new processes are represented in Figure 12.

The application of electricity to industrial processing in metallurgical and chemical industries formed an important part of this "second industrial revolution" at the end of the 19th century. It was applied to the reduction of phosphorus by Readman, who patented an "electrothermal" process in 1888.[22] The "brutal simplicity"[23] of the new process allowed substantial savings in labour and energy, while greatly increasing the optimum size of plants. Electric furnaces could operate continuously, unlike the individually-charged retorts. It was no longer necessary to treat the phosphorus rock with acid and the new furnaces produced molten phosphorus directly, eliminating the lengthy distillation stage.[24] Instead of multiplying the number of retorts, increased capacity could be obtained by scaling-up the first electric furnaces, giving a potential for economies of scale that was pursued over the next century.

It was significant that this important process innovation was not invented by A & W but also significant that they were in a position to exploit it by buying up the Phosphorus Reduction Company, formed to make use of Readman's patent, closing their works and building successful electric furnaces at Oldbury.[25] From being successful innovators, A & W had moved to the position of monopolists, able to control new technology to reinforce their established monopoly position. In the USA, they similarly bought competitors at the Niagara Falls hydro-electric site and established their own electric furnaces there.[26] In Canada, they achieved a similar monopoly position by the purchase of the Electric Reduction Company (ERCO) of Buckingham, Quebec, in 1902.[27]

Albright and Wilson Ltd. had successfully responded to the challenge of the new phosphorus-reduction process but a long-term mismatch was created between the demands of electric reduction and the characteristics of the enterprise that had been inherited from its origins in the first industrial revolution. Consequently, the company achieved only a partial adoption to the changes required by the new process.

Most importantly, the phosphorus industry changed to the use of a new energy source and this had consequences for the location of production. Access to the cheap coal of the English Midlands had been A & W's principal cost advantage in its early days and when the advantage moved to sites of cheap electricity, usually hydro-electric power, the whole basis for A & W's UK operations was undermined. As a result, the company's North American subsidiaries increased in importance, until, in 1919, the UK phosphorus-making operation was totally closed and the ERCO plant in Quebec took over the supply of all British and Canadian markets.[28] The trend towards a migration of phosphorus production by A & W across the Atlantic is illustrated diagrammatically in Figure 14.

The new technology of electrothermal reduction also had implications for the scale and organisation of the businesses needed to operate it. The furnaces represented a very expensive piece of investment and it became apparent that the accumulated profits of the A & W partnership were an inadequate capital resource and, in 1892, capital was doubled to £¼ million by the issue of shares to fifty private shareholders, including a large holding by members of both families.[29] Three sons of Arthur Albright and three sons of John Wilson entered the company to provide additional managerial expertise and the increased importance of specialised scientific knowledge was recognised by the creation of a post of Research Director for Sir Richard Threlfall, a university-trained chemist and chemical engineer.[30] However, Albright and Wilson Ltd. remained essentially a family firm of a kind typical of early and mid-19th century industry, but increasingly anachronistic in an area of industry that was becoming capital-intensive, science-intensive and organised to take advantage of the economies of scale in production.

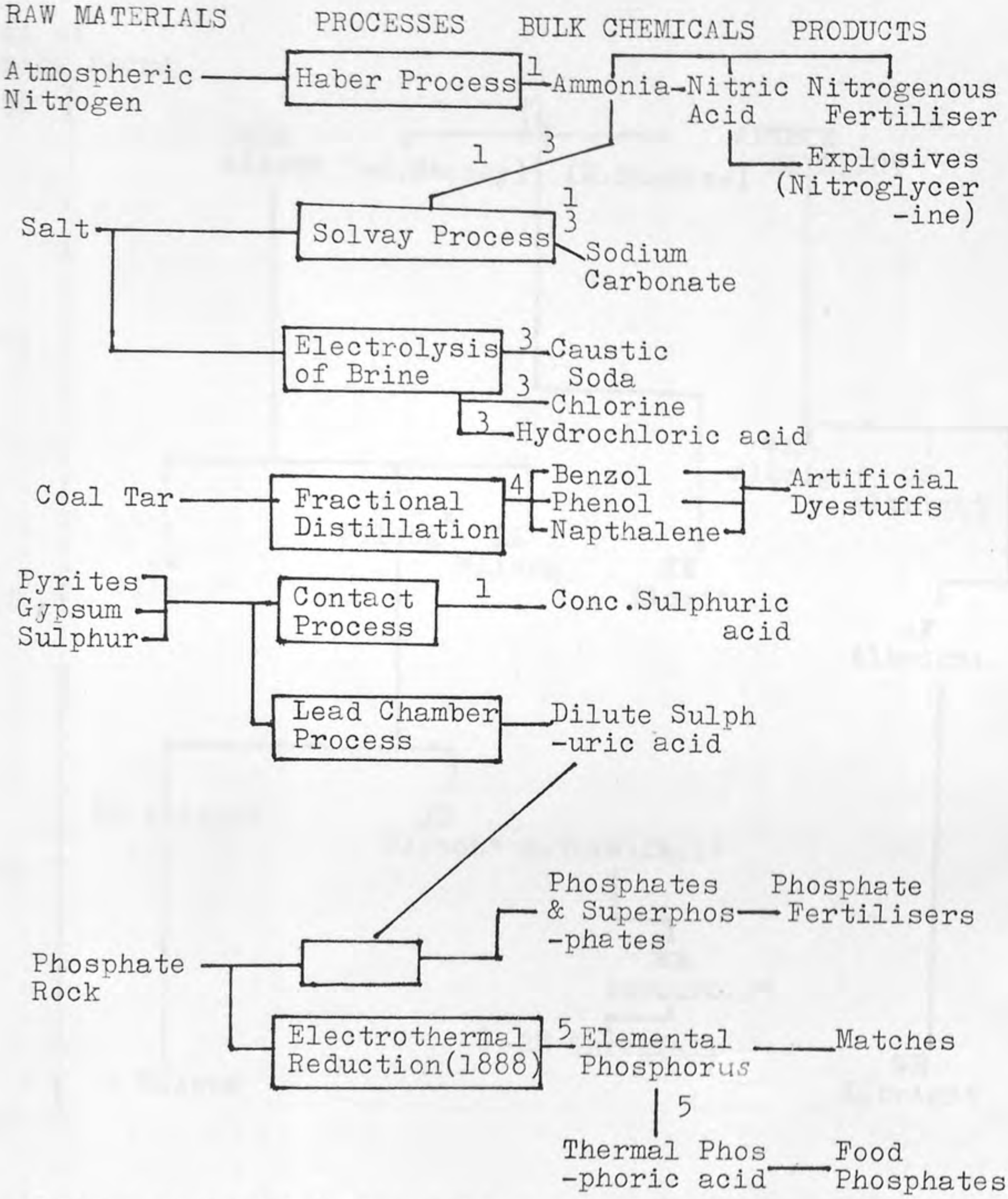
Accumulating Problems in the Inter-war Period.

The unfavourable economic conditions of the inter-war period served to highlight the structural problems that had accumulated in

A & W. World War I created a short-lived expansion in the production of phosphorus for shells, flares and smoke bombs[31] but, in 1919, the company was suddenly exposed again to international competition in its traditional products. Foreign governments had built up phosphorus industries for munitions purposes and the loss of A & W's export markets contributed to the closure of the Oldbury furnaces, from 1919 to 1940. The company's first financial loss[32] was recorded in 1921 and marked the end of the period in which its pioneering origins had ensured monopoly profits.

The inter-war period was characterised by increasing restrictions on trade, imposed both by tariff barriers and the construction of cartel agreements in many industries. A & W's reaction was typical of much of traditional British industry in adopting defensive policies of reliance on its monopoly in the British Empire, "an unofficial system of protection"[33], and on import tariffs around the UK market.[34]

The chemical industry experienced an acceleration of the trend towards mergers and the construction of giant firms during the inter-war years. This was, in part, a response to depressed markets and low profits[35] but also had a technical basis in the huge amounts of capital required to bear the costs and risks of the large-scale, continuous-process plants, resulting from the process innovations of the late 19th century. Typically, each process came to be dominated by a single company, creating a monopoly in each industrial country. Figure 12 shows this process and its results in Britain. Albright & Wilson had reached this monopoly position in



Companies dominating processes.

1 = Brunner Mond Co.	)	
2 = Nobel Co.	)	I.C.I
3 = United Alkali	)	1926
4 = British Dyestuffs Corps.	)	
5 = Albright & Wilson		

Fig. 12. Major chemical processes and companies in the early 20th century British Chemical industry.
Source: Hardie, D.W.F., and Pratt, J.D., A History of the Modern British Chemical Industry (Oxford, 1966), Chap. 2 & 3 and chart facing page 380.

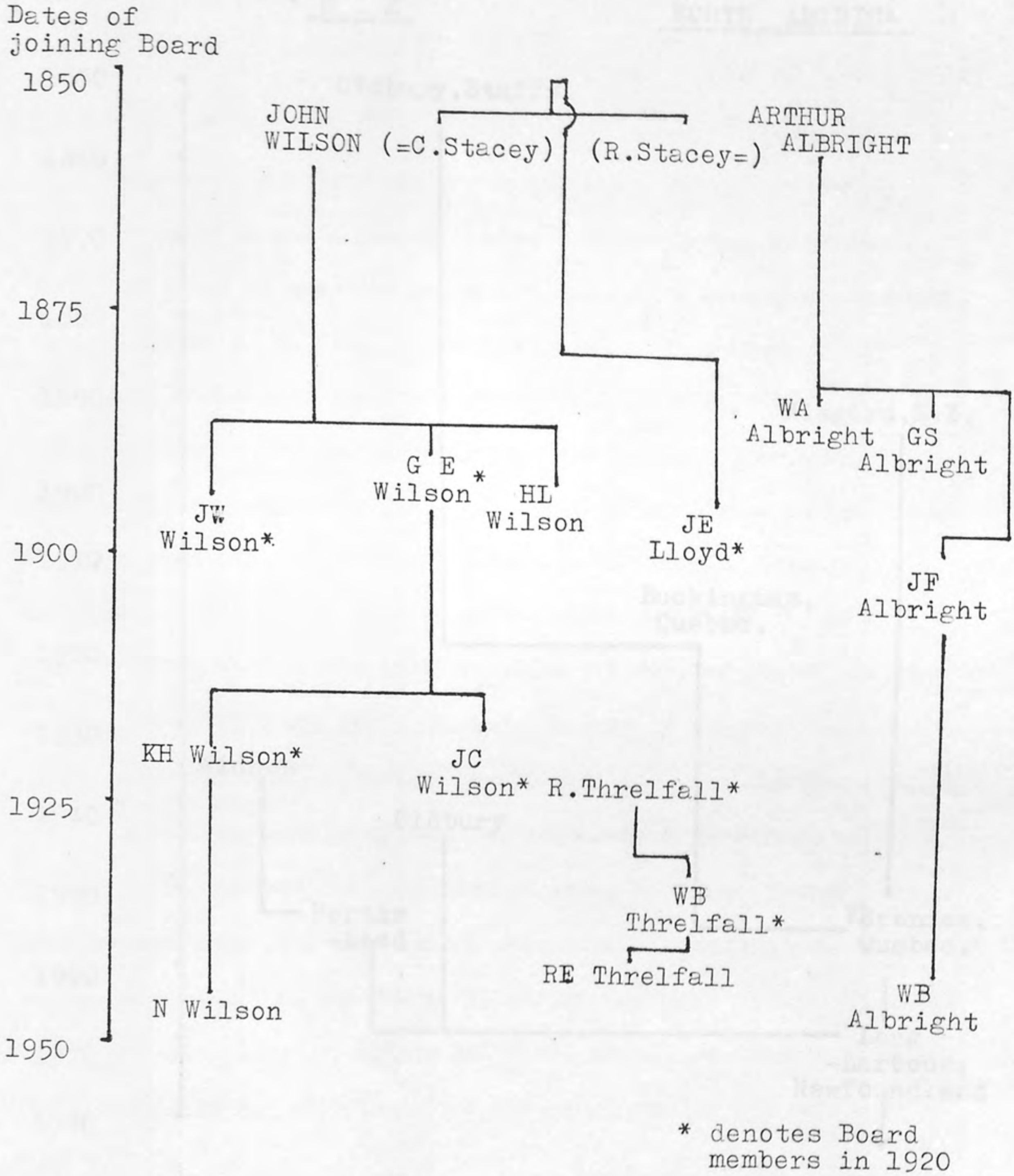


Fig. 13. Family relationships among directors of Albright & Wilson Ltd. (1851-1951).
Source: Threlfall, R.E., The Story of 100 Years of Phosphorous-making, 1851-1951, (Oldbury, Staffs. 1951), p. 246 and 165.

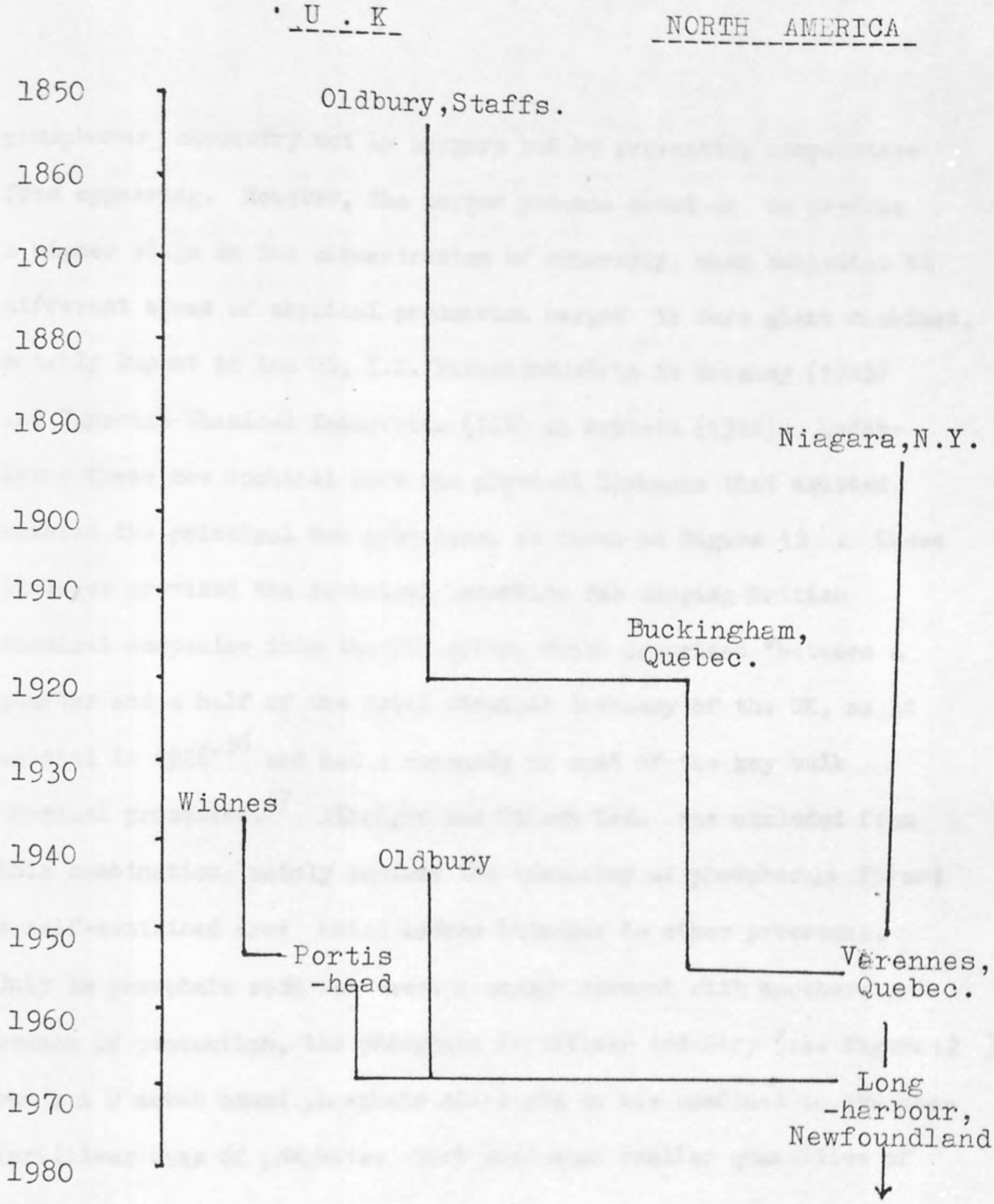


Fig.14. Concentration and re-location of A & W's phosphorous reduction facilities (1851-1981).
Source: Threlfall, R.E., *The Story of 100 Years of Phosphorous-making, 1851-1951* (Oldbury, Staffs. 1951).

phosphorus chemistry not by mergers but by preventing competitors from appearing. However, the merger process moved on to produce a higher stage in the concentration of ownership, when companies in different areas of chemical production merged to form giant combines, notably Dupont in the US, I.G. Farbenindustrie in Germany (1925) and Imperial Chemical Industries (ICI) in Britain (1926). Underlying these new combines were the physical linkages that existed between the principal new processes, as shown in Figure 12 . These linkages provided the technical incentive for merging British chemical companies into the ICI group, which comprised "between a quarter and a half of the total chemical industry of the UK, as it existed in 1926"[36] and had a monopoly on most of the key bulk chemical processes.[37] Albright and Wilson Ltd. was excluded from this combination, mainly because the chemistry of phosphorus formed a self-contained area which lacked linkages to other processes. Only in phosphate rock was there a common element with another branch of production, thé phosphate fertiliser industry (see Figure 12) but A & W never owned phosphate mines and so was confined to the non-fertiliser uses of phosphates that used much smaller quantities of rock.

A & W remained as an independant producer, confined to one area of chemistry and, from this period, was a relatively small concern within the chemical industry. ICI at this time employed 40,000[38], while A & W had a work-force of 550.[39] This small size was to have several disadvantages. Big combines possessed huge resources for planning and constructing large new plants, for research and development of new products, for covering losses and for buying competitors and suppliers. In all these areas, A & W came to be in danger of under-capitalisation - a problem rather belatedly recognised by the decision to become a Public Company, in 1948.[40] Significantly, only half the assets at this date were in the UK operations and half were overseas, mainly in North America.

Another advantage of large corporations arose from the use of specialised teams of managers and engineers to replace the individual talents of inventors and entrepreneurs. This "managerial revolution"[41] was well advanced in America by 1939 and to a lesser extent in the leading industries of other countries and can be seen as a necessary accompaniment to large-scale, capital-intensive, science-based technologies.[42] The continued reliance of A & W on the sons and grandsons of Arthur Albright and John Wilson, apparent from the composition of the board of directors (Figure 13) - began to be increasingly anachronistic. In the 1950s, the company still had a managing director who was a grandson of Arthur Albright.[43] Inevitably, the continued role of the families and the slow recruitment of new talent reinforced tradition and caution in the company, at the expense of diversification and expansion.

Commitment to a narrow range of products formed another area of structural weakness in A & W. Electrothermal reduction had cheapened and expanded phosphorus production, without an immediate extension of the range of products derived from phosphorus .[44] The market for match phosphorus remained sluggish and increasingly competitive. A demand for phosphorus for munitions provided only temporary relief in the two World Wars and major new product areas needed to be developed. Some new phosphorus salts, such as phosphorus halides were sold but the only other existing markets were in phosphate fertilizers, for which A & W lacked both access to rock deposits or to large agricultural consuming regions, or alternatively phosphate chemicals for new consumer products. This latter area was chosen by A & W for expansion and during the 1930s they developed their output of chemical ingredients for toothpaste, baking powder, pharmaceuticals and water softeners.[45] A new phosphoric acid plant on Merseyside provided the basis for these products, which rapidly became more important than the 19th century staples such as match phosphorus. This new business rejuvenated A & W's UK operations, while the phosphorus reduction process was moved to North America (Figure 14) but the limited market for these quality phosphates prevented A & W from growing very rapidly or securing its long-term profitability through a broad range of products.

The inter-war period laid the foundations for a renewed growth of A & W in the post-war period, based on the new phosphate products and its Canadian phosphorus plants. The favourable markets of the post-war period, however, tended to obscure the company's underlying structural problems. In both process technology and products, the company's performance had enabled it to survive but not to join the leading areas of post-war chemical production. The company's original monopoly and subsequent established position had enabled it to survive changing technical and economic conditions but at the cost of accumulated structural weaknesses, inherited from the past. When economic conditions again began to become less favourable, in the 1970s, these inherited weaknesses produced an inadequate response to new technical challenges and the final failure of the company as an independant concern. A & W's performance in the conditions of the 1970s will be evaluated in the following section.

Pressure to Reduce Production Costs in a Competitive Market.

During the 1960s and 1970s, A & W was competing in an increasingly unfavourable market environment. The demand for phosphorus chemicals could not sustain its immediate post-war growth rate and the market began to stagnate along with the general slow-down of economic growth in the late 1960s and early 1970s. Environmental limits to phosphate production became apparent and the industry was affected by government regulation to limit the phosphate component in detergents and the quantities of "phossy" water effluent from phosphorus plants.[46] As demand reached its limits an expansion in the number and size of plants resulted in a strong tendency to overcapacity [47] which led, in the US, to a 50% reduction in output of phosphorus between 1969 and 1975.[48] Even in A & W's traditional Commonwealth markets, local producers began to offer strong competition in phosphorus -derived chemicals.

In this highly competitive market situation, it became apparent that A & W's long history of monopoly in certain markets had been disguising a basic lack of competitiveness. From the early 1960s, A & W showed steadily declining profitability, as seen in Figure 15 . Geographical factors continued to be important in

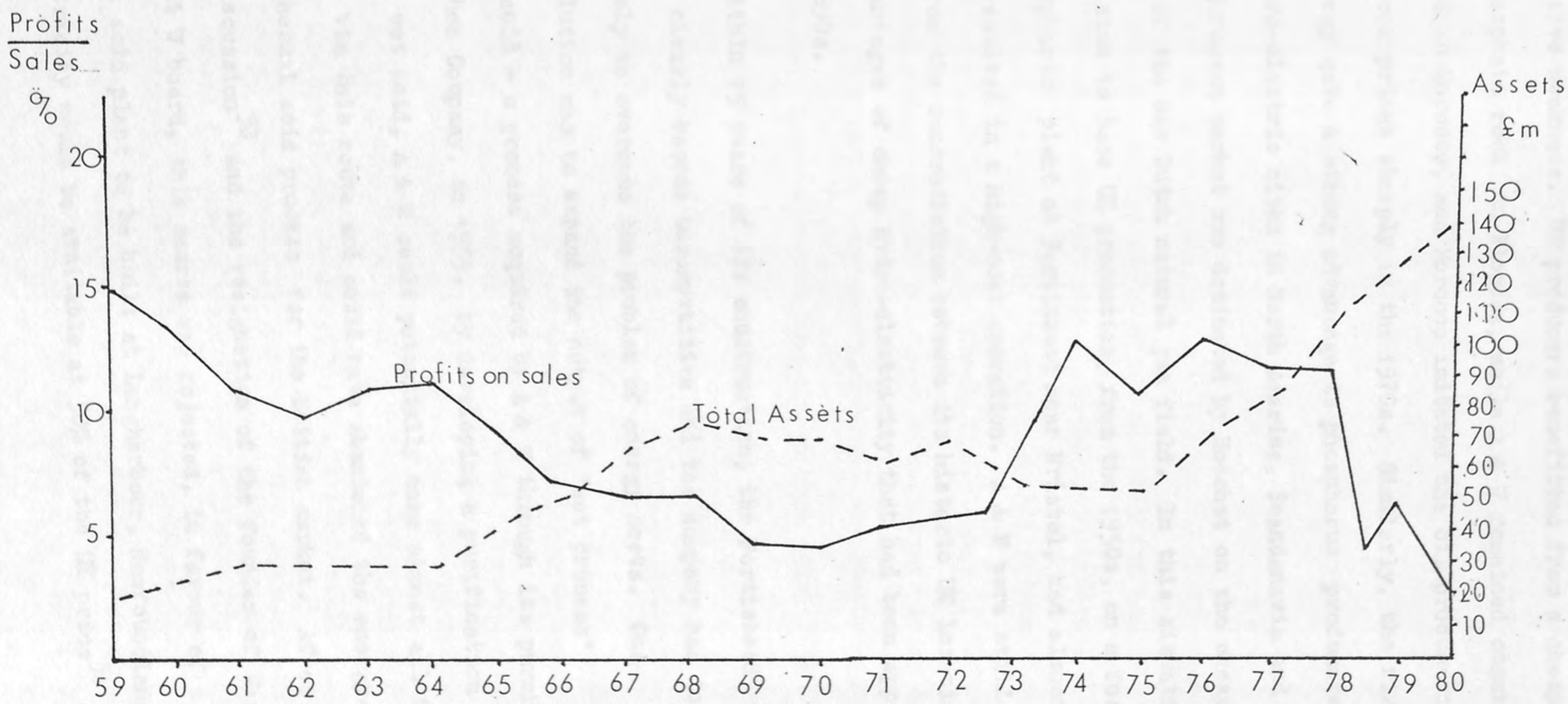


Fig. 15. A & W profits on sales and total assets (1959-80).
Source: A & W Annual Reports, various years.

this competitive weakness. US producers benefitted from a cheaper source of phosphate rock in Florida, while A & W remained committed to the source in Morocco, and Morocco imitated the oil producers by forcing up rock prices sharply in the 1970s. Similarly, the rising costs of energy gave a strong advantage to phosphorus producers close to hydro-electric sites in North America, Scandanavia and the Alps. The European market was dominated by Hoechst on the cheap energy base of the new Dutch natural gas field. In this situation, A & W's decision to base UK production, from the 1950s, on a fossil-fuelled phosphorus plant at Portishead near Bristol, had almost inevitably resulted in a high-cost operation. A & W were still suffering from the contradiction between its historic UK location and the advantages of cheap hydro-electricity that had been apparent since the 1890s.

Within 15 years of its construction, the Portishead plant[49] had clearly become uncompetitive and the company had to act decisively to overcome the problem of energy costs. One possible solution was to expand the output of "wet process" phosphoric acid - a process acquired by A & W through its purchase of the Marchon Company, in 1955. By developing a purification process for wet acid, A & W could potentially make almost all its UK products via this route and could have abandoned the energy-intensive thermal acid process for the British market. After vigorous discussion[50] and the resignation of the founder of Marchon from the A & W board, this course was rejected, in favour of a huge new thermal acid plant to be built at Longharbour, Newfoundland. Hydro-electricity would be available at 50% of the UK price[51] and cheap Florida rock could be brought by sea to the deep-water harbour, there. Special ships were designed to bring elemental phosphorus across the Atlantic, to make thermal acid and phosphates at the UK sites. With this huge new investment in the late 1960s, A & W planned to finally solve the locational dilemma that they had inherited.

As the earlier history of A & W had shown, electrothermal reduction of phosphorus had implications not only for the location but also for the scale of production. By the late 1960s, A & W was a relatively small producer in an industry that had become highly concentrated in a handful of giant firms, as indicated by Figure 16. These were mainly combines with interests in many other areas of chemical production and in some cases owned oil and natural gas operations, also. Inevitably, they possessed much greater capital resources for investment and could stand risks and losses more easily than A & W, which remained completely dependent on phosphorus-derived products.

The concentration of ownership in the industry was matched by a concentration of production in the pursuit of economies of scale in giant plants. In 1902, the A & W electric furnace at Oldbury had consumed 250 KW of power.[52] Furnaces of several megawatts were built in the inter-war period and in the 1950s A & W's Portishead and Varrennes (Quebec) plants were using about 15 MW. Economies of scale in the 1960s raised the size of plants built or planned by European and American producers to 65 MW.[53] Similarly, the output of these furnaces dwarfed earlier plants, so that A & W found themselves competing with Hoechst's concentration of three plants in Holland that

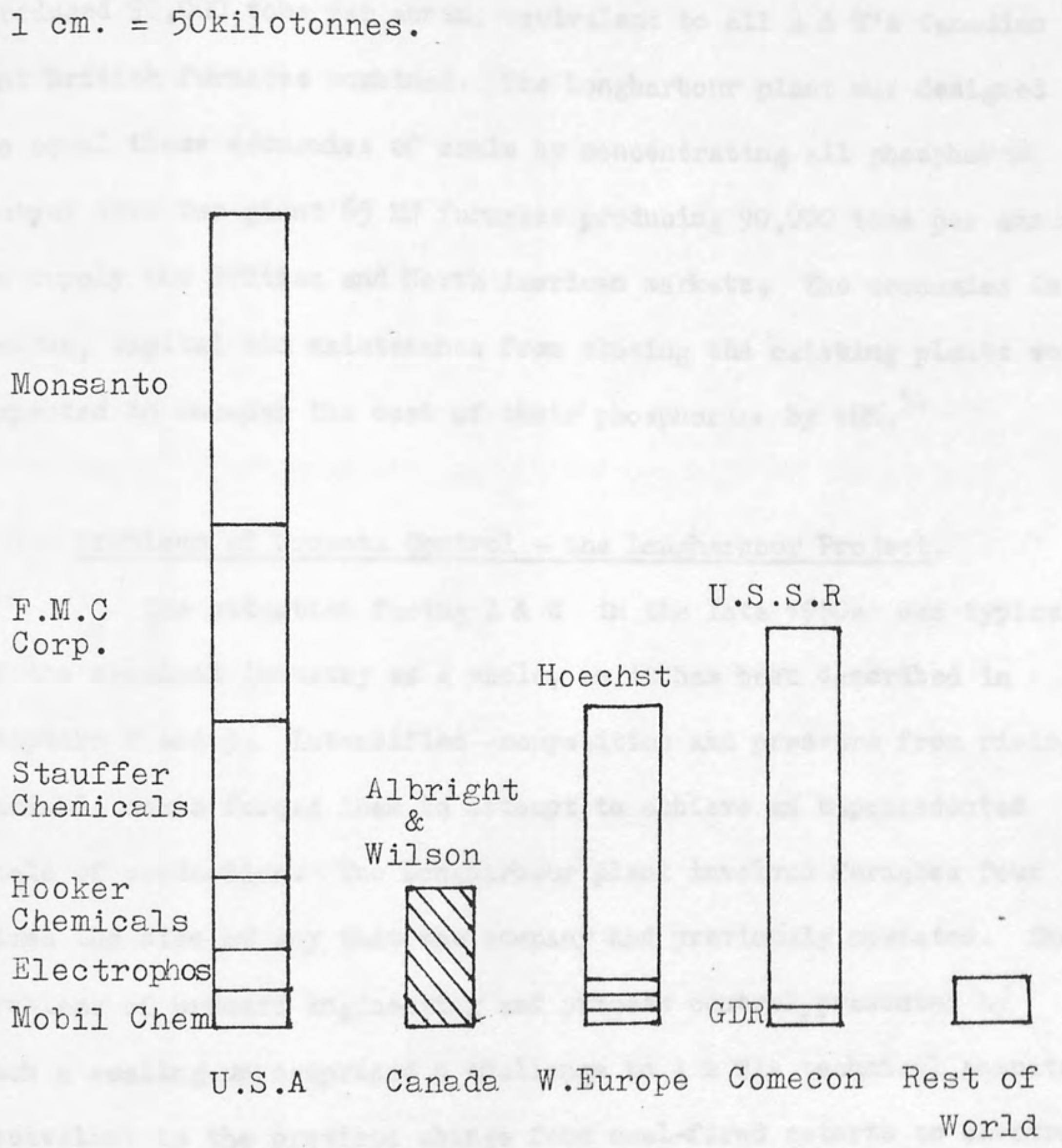


Fig. 16. Major world elemental phosphorus producers (1976). Source: Childs, A.G., "Phosphorus, Phosphoric Acid and Inorganic Phosphates" in Thompson, R., The Modern Inorganic Chemicals Industry, (London, 1977).

produced 90,000 tons per annum, equivalent to all A & W's Canadian and British furnaces combined. The Longharbour plant was designed to equal these economies of scale by concentrating all phosphorus output into two giant 65 MW furnaces producing 90,000 tons per annum, to supply the British and North American markets. The economies in labour, capital and maintenance from closing the existing plants were expected to cheapen the cost of their phosphorus by 18%.[54]

Problems of Process Control - the Longharbour Project.

The situation facing A & W in the late 1960s was typical of the chemical industry as a whole, as it has been described in chapters 2 and 3. Intensified competition and pressure from rising variable costs forced them to attempt to achieve an unprecedented scale of production. The Longharbour plant involved furnaces four times the size of any that the company had previously operated. The problems of process engineering and process control, presented by such a scaling-up, comprised a challenge to A & W's technical competence equivalent to the previous change from coal-fired retorts to electro-thermal furnaces in the 1890s but in the 1970s the company's technical performance proved inadequate and this was crucial to A & W's final commercial failure.

The Longharbour project was thought necessary because of the uncompetitive nature of the Portishead operation but this in turn resulted partly from A & W's inability to make the Portishead plant operate correctly.[55] Using powdered rock it suffered from blockages and an uneven composition of constituents in the furnace, resulting in disturbances and discontinuous operation. This problem really arose from the increased size of the furnace and required for its solution an additional technique which was to pelletise the rock before it was introduced into the furnace. This was demonstrated when the plant was briefly restarted in the 1970s, using pelletised rock from Longharbour. The decision not to invest in a pelletising plant at Portishead indicated a tendency to under-estimate the problems of engineering and control on large plants and to make false economies - something that continued through the Longharbour project. "The whole Longharbour project, so splendid in conception, for years proved near-disastrous in execution," admitted A & W's company journal,[56] after the technical failures of the plant had finally caused losses great enough to end the firm's independent existence. The increased scale and the innovative design of the plant created control problems that were beyond the company's competence to resolve. Built in 1968-9, the plant was still not operating in a completely satisfactory manner ten years later.

Control of the furnace electrodes proved a persistent problem.[57] Fifty-five inches in diameter, they were near the limits of mechnical strength for jointed graphite and tended to crack under stress. To prevent this, they needed to be raised and lowered in accordance with changing electrical conditions in the furnaces, which required the operators to know the precise position of the electrode tips. However, no direct measurement of the tip position was available. Operators, therefore, had to infer its position from temperature changes, which were influenced by other factors, with the result that frequent electrode breakages occurred and a specially-trained team of operators was needed to replace damaged electrodes as quickly as possible.

Another problem,[58] derived from the large size of the furnace, was that of maintaining an optimum ratio of carbon to calcium phosphate. This was controlled by varying the composition of the feed to the furnace and these variations eventually changed the composition of the slag, which was regularly tapped from the bottom of the furnace. The problem was one of process lag, typical of large process plants, with a lag of 6-12 hours between a change in feed and a stable new value for the slag composition, so that optimum feed was difficult to maintain. The answer lay in combining "feedback" control from the slag with "feedforward" control from the feed constituents - a complex problem, which as has been indicated in chapter 2, is of the kind that would be expected to require a computer model of how changes occur through the furnace.

A & W's methods of dealing with these problems relied on traditional approaches but these never succeeded in operating the plant to full efficiency. The tradition of relying heavily on the skills of operators, which was effective on smaller plants in areas where the workforce was highly experienced, was inadequate in Newfoundland where the industry was quite new and the plant of a new scale and design. The instrumentation[59] was inadequate for monitoring and centralising all the information on plant performance that was needed for advanced control strategies and the complexity of the control task on such a large plant was eventually recognised to require a degree of computer automation. Eventually, after 10 years of problems and after A & W had been taken over by the US company Tenneco Inc., microprocessors were applied to monitor furnace temperatures and electrode positions and to monitor and centralise information on the plant's overall performance, to operator displays.

The tendency to underestimate the problems caused by such an increase in the scale of the plant led to a number of other "misplaced economies in construction".[60] A small cost saving was hoped for from allowing ERCO engineers to design the plant,[61] rather than buying a proven design, and by allowing them to continue trying to obtain a satisfactory performance from it for years before the task was given to A & W's Central Engineering Department. An important misplaced economy in design was the lack of an effluent plant,[62] again a problem that has been magnified on large plants. The poisoning of local fisheries by "phossy" water resulted in a 6 month closure of the plant in 1969, while the old Portishead and Oldbury works were restarted, phosphorus was bought for £1½ million and £50,000 a day spent on keeping Longharbour idle.[63] Belatedly, an effluent plant and pelletising plant were constructed.

Meanwhile, the erratic performance of the plant during 1968-71, damaged the precipitators which removed particles from the hot furnace gas, and they had to be replaced with ones of a more rugged design. The precipitator and electrode problems led to a number of major shutdowns during 1971-1974, which resulted in much reduced output. For example, the output in 1973 was 40,000 tons, compared with the design output of 72,000 tons.[64] Both furnaces were again closed for restructuring in 1975 and one did not reopen until two years later. Altogether, by 1979, 32 major modifications to the plant could be listed[65] and even after this, furnace control still stood in need of improvement.

The inability of A & W to engineer and control this vital plant had disastrous results for the company. Ten years of expenditure on Longharbour starved A & W's other operations of vital investment funds, so that the modernisation of other plants was delayed and the investment programme of the 1960s slowed (see Figure 15). The effects on overall profitability were also disastrous, resulting firstly in the sale of various recently acquired businesses and then in an increasing dependence on Tenneco Incorporated, a US based multi-national conglomerate. In 1969, Tenneco took a 10% share in A & W, then in 1971 it gave them a $42 million loan, followed in 1974 by taking a further 49.8% shareholding, which it finally converted into outright ownership of the whole company in 1978, converting it into a subsidiary and ending its 133 year existence as an independent British concern.

Conclusions.

A & W's failure as an independent company was in large part due to its inability to meet successfully the challenge presented by the new process engineering and control problems of the 1960s and 1970s. The Longharbour project exhibited, in a crucial instance, this technical inadequacy. By surveying the history of the company, it is possible to see this failure,not as the result of isolated bad decisions, but as the culmination of a long-established trend in A & W's relationship to changing technology in its industry.

In the first wave of technology that established the phosphorous industry in the 1850s, A & W played a leading role. The second major period of innovation was associated with the change to electro-thermal reduction of phosphorous and they adapted successfully to it, in the technical sense, but retained what were to become increasingly anachronistic geographical and organisational characteristics. As a result, by the 1960s the company was lacking the financial and technical possibilities which relied on improved process control techniques. As a consequence, it failed to maintain its commercial viability as an independent company.

Chapter 6, which examines the changes to A & W that followed its takeover by Tenneco, will look in more detail at A & W's use of process control technology and its relative conservatism in this crucial area. The analysis of the company's long-term problems, which has been developed in this chapter, can then be used to provide an explanation for this conservatism. The company's lack of capital resources, tendency to make false economies in investment and caution in making use of digital electronic control systems, will be seen to have had important consequences for its UK operations and the performance of its plants.

This chapter has shown A & W's poor responsiveness to the potential of the advances made in control technology during the late 1970s and sought an explanation in the nature and past development of the company. In the next chapter, a similar approach will be applied to A & W's new parent company, Tenneco, whose very different character will be seen to have produced very different policies and performance in the area of new control technology.

CHAPTER FIVE

Tenneco Incorporated - an Example of the Successful Adoption of Automated Control Technology.

Introduction.

Chapter 4 has examined the experience of one company, Albright and Wilson Ltd., which failed to make the necessary progress in exploiting the new technology of process control that became available during the 1970s. This failure was identified as a major contributor to the commercial failure of the company. In this chapter, the very different experience of Tenneco Inc. will be analysed to give a contrasting example of technological and commercial success by an industrial enterprise.

In the same fashion that technological inadequancy and commercial failure were inter-related in the case of A & W, this chapter will explore the relationship between competence in new technology and commercial strength and success in Tenneco. Just as an explanation for A & W's inability to exploit new control technology successfully was revealed by analysing the nature and history of the company, so Tenneco's more active and effective policies towards computer control technology will be situated in the context of its different evolution and characteristics.

No company history has yet been written for Tenneco, for various reasons. It is a relatively young company, whose growth was is very rapid and which is not particularly associated with any single product area, being a conglomerate with interests in various industries. The information in this chapter relating to Tenneco's past is therefore derived mostly from Tenneco's own minor publications[1] and from interviews with employees, whose memories of the company may span a considerable part of its history.

Tenneco's Energy Base.

When considering Albright and Wilson, the availability of cheap, abundant British coal was seen to have been a vital factor in promoting the early success of the company but when phosphorous reduction changed to the electro-thermal process, long-term problems were created for the company's UK operations. This decline in the relative importance of coal and the substitution of other energy sources has been characteristic of the 20th century and the same long term change that caused problems for A & W has been the source of Tenneco's rapid growth, since Tenneco originated in the production and distribution of oil and natural gas - the main energy sources for mid-20th century industrial growth.

The change from coal to oil and gas has important geographical consequences, with the reduced importance of coal being related to the relative decline of the 19th century industrial areas such as Britain and the expansion of the liquid fossil fuels being related to the enormous expansion of the United States' economy. As a US fuel producer, Tenneco has been selling to a rapidly growing market, both as the result of the substitution of liquid fossil fuels and the overall growth of the American economy (see Figure 17). Furthermore, not only was oil and gas cheap and indeed falling in price until 1973,[2] but America's abundant resources of these fuels has kept energy prices there consistently and substantially lower than in the UK (Figure 18). Cheap energy has powered America's post-1945 growth in output and created steadily expanding sales for Tenneco.

Tenneco originated in 1943, as the Tennesse Gas Transmission Company.[3] Its first operation was the construction of a pipeline to carry natural gas from South Texas to the strategic war industries of Tennessee and Virginia, including the Manhattan Atomic Bomb project. This initial limited purpose was, however, greatly expanded after 1945, through the ambition of the company's founder, Gardiner Symonds. The pipeline was extended to reach the great industrial cities of the Mid-West and North-East, new branches being added almost annually to create the network of gas pipelines mapped in Figure 19 .

Comparison of the map of Tenneco's pipelines (Figures 19 & 20) with that of America's fossil fuel resources, shows that the company was exploiting the geographical dimension of the change from a coal-powered to an oil and gas-fired economy. It linked the gas fields of the Gulf States, Texas and Louisiana to the old industrial centres of the North, which had been built up on the coalfields.

In particular, the growth of Tenneco has been closely related to the fossil fuel resources of Texas, which contains 40% of US oil and natural gas production.[4] Tenneco's headquarters in the centre of

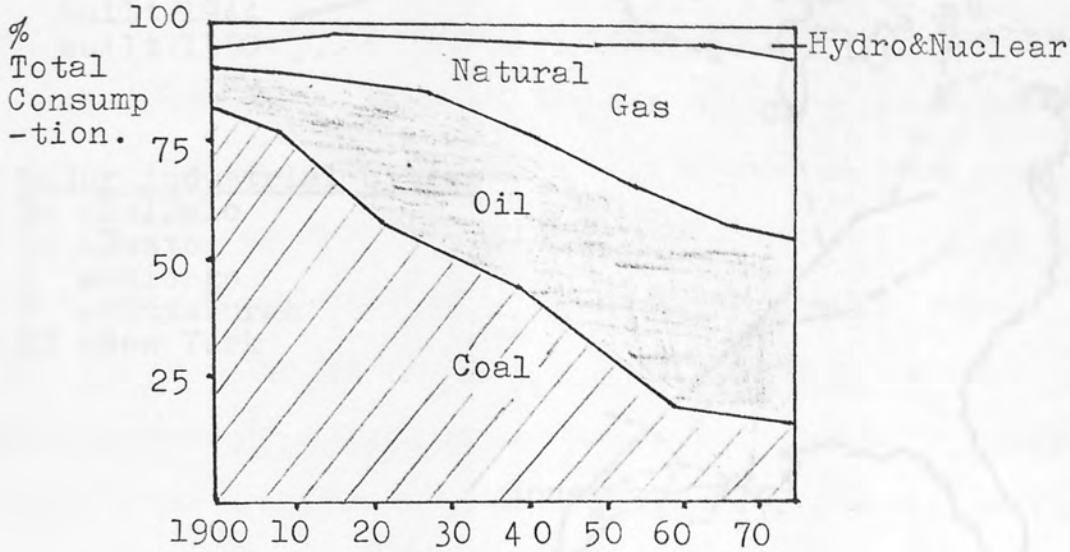


Fig. 17. US Energy consumption by fuel sources (1900-75)
Source: Estall, R., A Modern Geography of the United States (Harmondsworth, 1976), p.254.

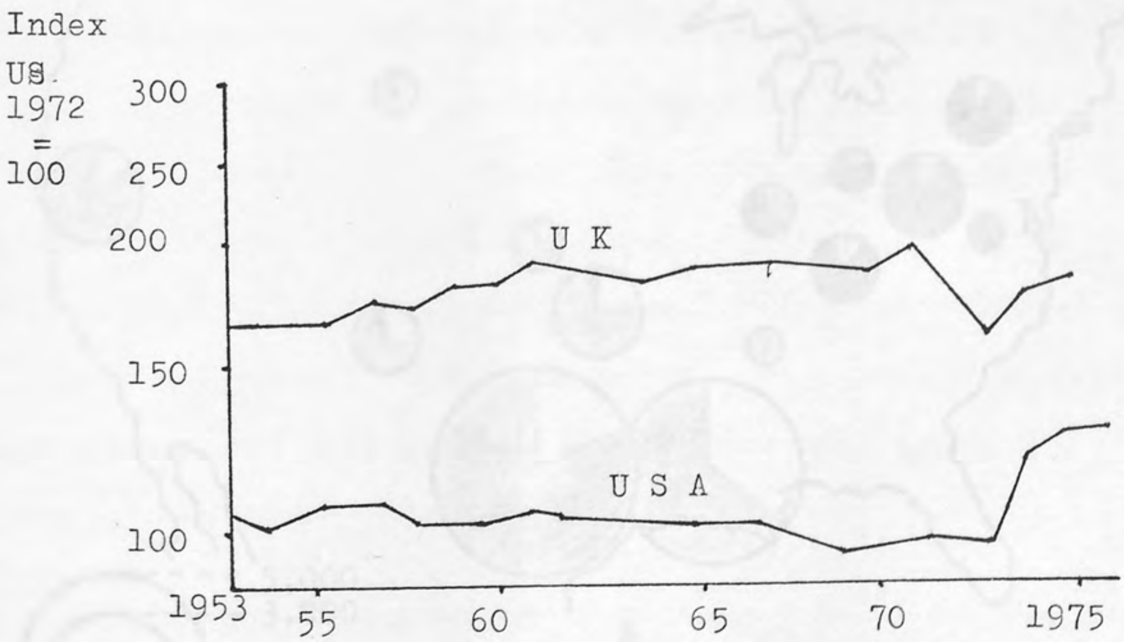


Fig. 18. Comparative energy prices to US and UK consumers (1953-76).
Source: Robson, M., "World Energy Prices," Futures, 13, (5), (October, 1981), p.417.

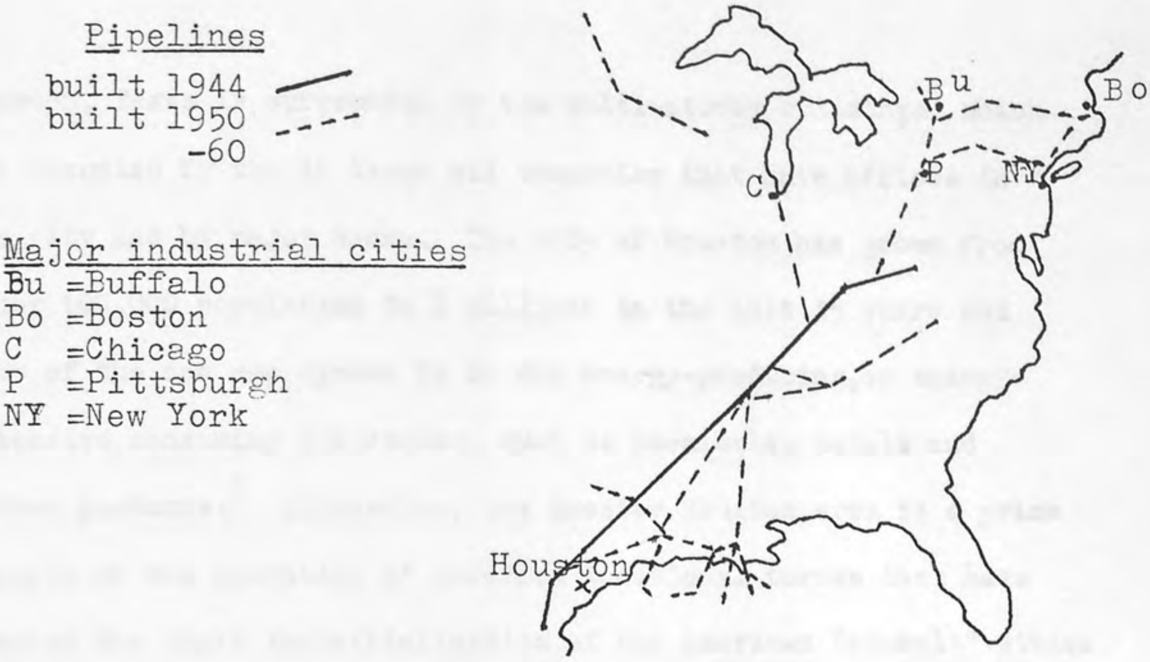


Fig. 19. The Tenneco natural gas transmission pipeline network.
Source: Anon, "25 Remarkable Years of Tenneco,"
Tenneco, II, (Autumn, 1968).

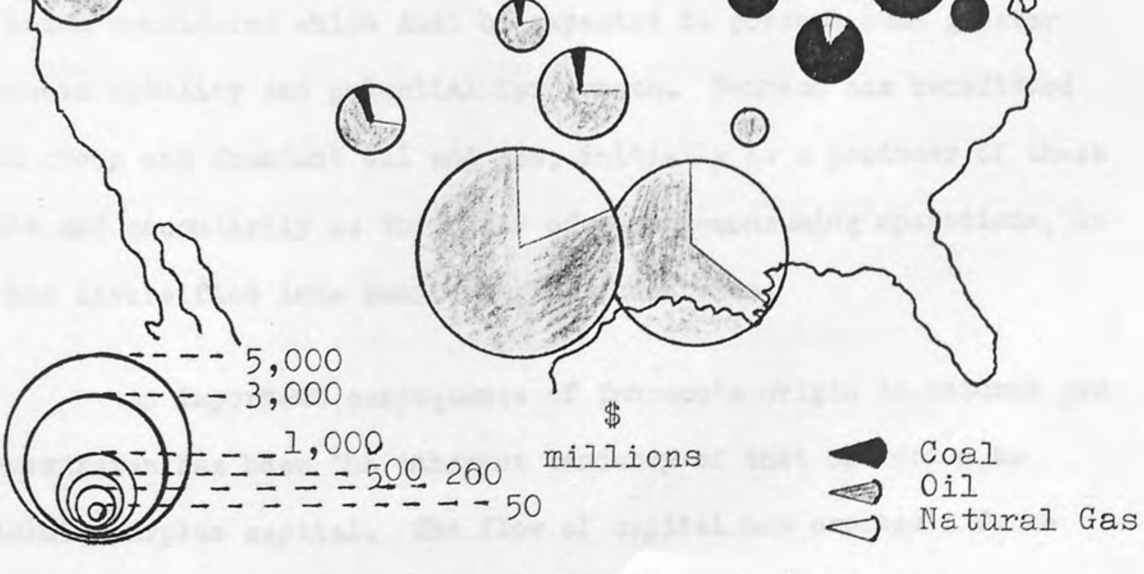


Fig. 20. The location of fossil fuels production in the US.
(1971-by value).
Source: Estall, R., A Modern Geography of the United
States (Harmondsworth, 1976), p.254.

Houston, Texas is surrounded by the multi-storey buildings which are occupied by the 24 large oil companiex that have offices in the city and by major banks. The city of Houston has grown from under 100,000 population to 2 millions in the last 35 years and most of the new employment is in the energy-producing,or energy-intensive consuming industries such as chemicals, metals and rubber products.[5] Altogether, the Greater Houston area is a prime example of the operation of powerful locational forces that have created the rapid industrialisation of the American "sunbelt" cities of the West and South and the growth of Tenneco has been closely associated with the same forces.

Whereas the conditions which created A & W at its site at Oldbury, in the English Midlands, were those which existed in the mid-19th century, the conditions which have created Tenneco are essentially the location of abundant liquid fossil fuel resources during the mid-20th century. Therefore, with Tenneco, an enterprise is being considered which must be expected to possess much greater economic vitality and potential for growth. Tenneco has benefitted from cheap and abundant oil and gas, initially as a producer of these fuels and secondarily as the owner of energy-consuming operations, as it has diversified into manufacturing industries.

An important consequence of Tenneco's origin in natural gas transmission has been the inherent tendency of that operation to generate surplus capital. The flow of capital has created a force of expansion in the company, which has led it to acquire new businesses and diversify into new industries, finally creating a multi-industrial, multi-national conglomerate group of companies. Initially, the expenditure on constructing the network of pipelines was considerable and this enabled it to expand rapidly, laying down parallel pipes to achieve a total 16,000 miles in length and capacity of 5,000 cubic feet per day by 1979.[6] However, new expenditure was low after the first rapid construction phase, being 7.2% of assets, lower than for other Tenneco businesses.[7] Labour costs are similarly small, with 3,000 employees, using $½ million worth of assets per employee.[8] Costs, therefore, are low, while the flow of gas and income is continuous and so during the 1960s and 1970s it was steadily expanding the stock of capital available for acquisitions. The contrast with Albright and Wilson and their long history of low profitability and undercapitalisation is extremely marked.

Growth from Diversification.

Powered by the surplus capital generated by its energy businesses, gas and oil production and transmission, Tenneco has exhibited a very dramatic growth rate, becoming by 1980 approximately 12 times the size attained by A & W after its 130 years of existence. The relative sizes and growth rates are illustrated in Figure 21. In the first 35 years since its foundation as the Tennessee Gas Transmission Company, Tenneco had grown to be the 19th largest industrial corporation in the US, 45th largest in the world, with sales of greater value than any British company, except British Petroleum. Tenneco can be considered typical of the rise to dominance

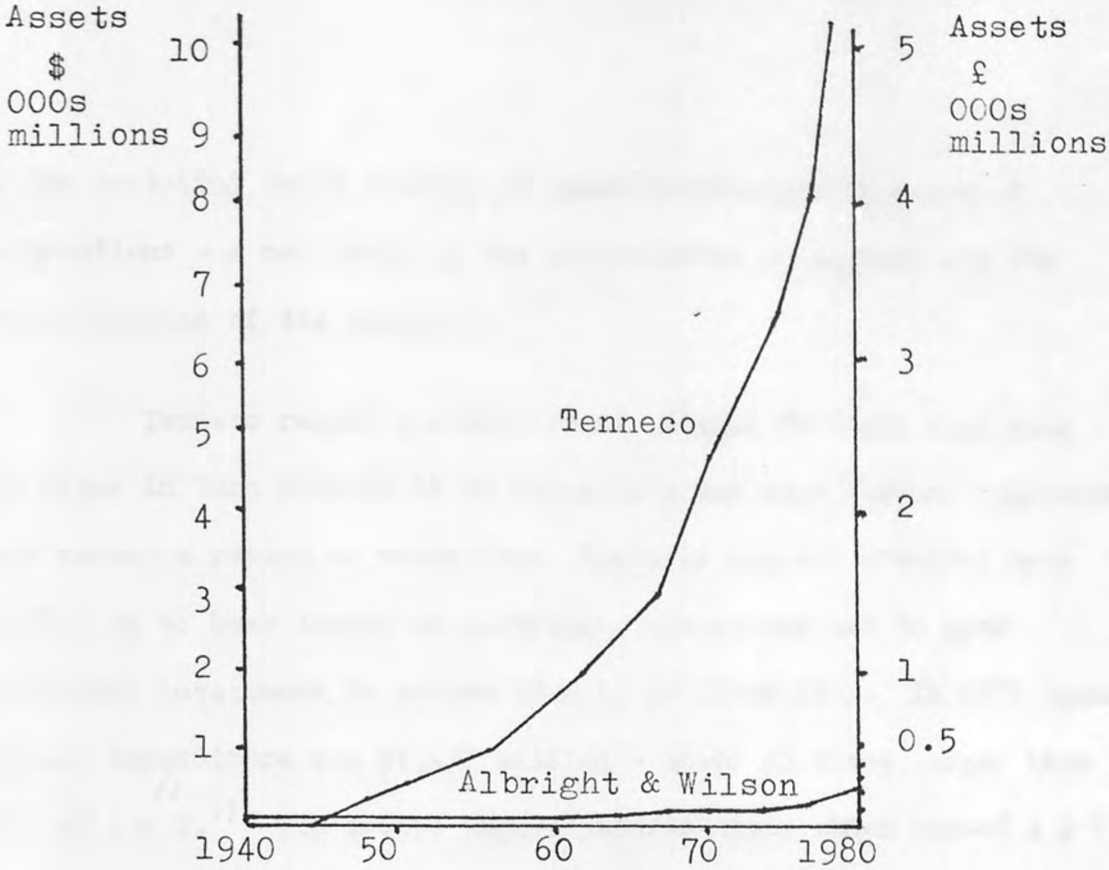


Fig. 21. Comparative sizes and growth rates of Tenneco and A & W (1940-80, value of assets.)
Sources: A & W Annual Reports (1968 and 1979) and Tenneco Annual Report 1979 and Tenneco, II, (Autumn, 1968), p.15-27.

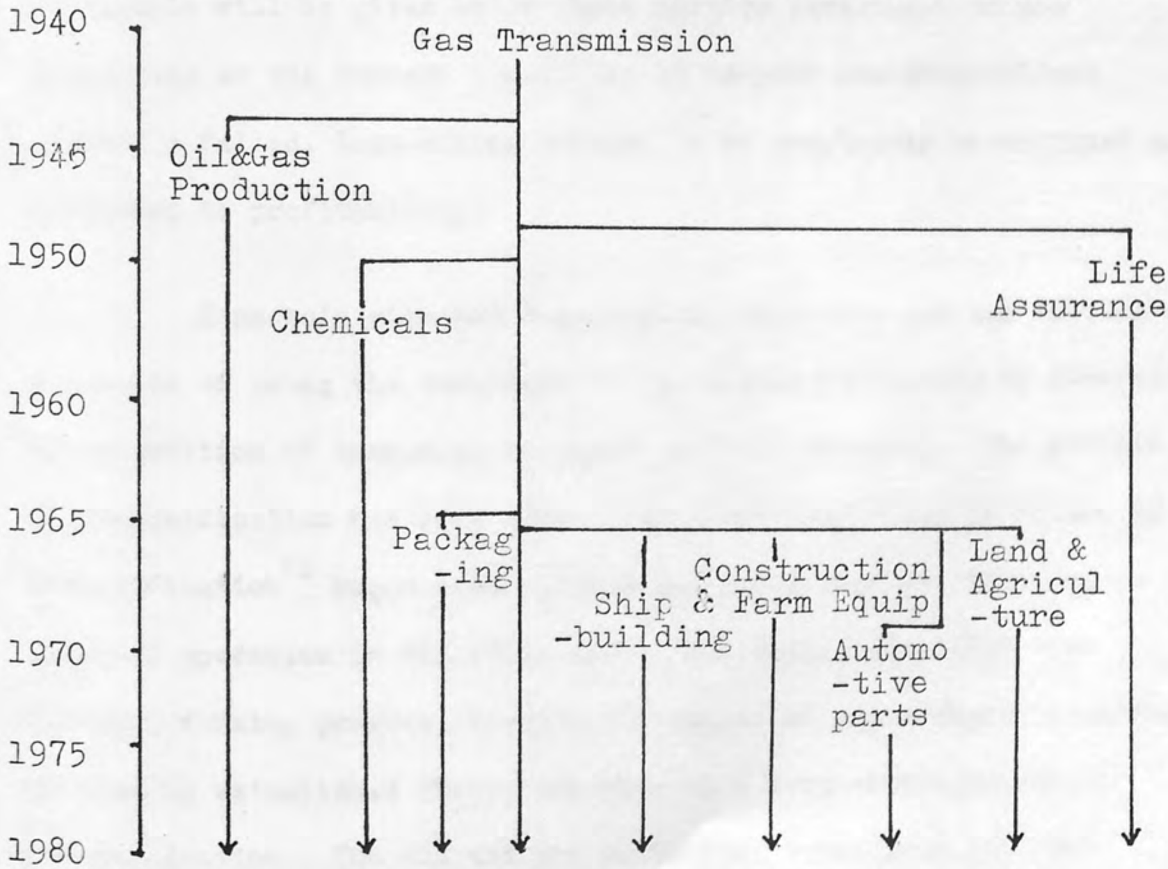


Fig. 22. Diversification of the Tenneco conglomerate (1943-80).
Source: Anon, "25 Remarkable Years of Tenneco," Tenneco II, (Autumn, 1968).

in the post-1945 world economy of giant US-based, multi-national corporations - a new stage in the accumulation of capital and the centralisation of its ownership.[10]

Tenneco reaped a number of advantages from its huge size and these in turn allowed it to accumulate and make further acquisitions, even during a period of recession. Enormous capital reserves have enabled it to bear losses on particular operations and to make sufficient investment to return them to profitability. In 1979 their capital expenditure was $1,477 million - about 23 times larger than that of A & W.[11] The severe undercapitalisation, which caused A & W to make false economies on its plants and prevented the modernisation of equipment, has not been a problem in the same way for Tenneco and an example will be given below where massive investment in new technology at the Tenneco subsidiary of Newport News Shipbuilders enabled a failed, loss-making concern to be completely re-equipped and converted to profitability.

Tenneco's size and huge capital resources are the outcome of a process of using the surpluses in the energy businesses to diversify by acquisition of companies in other areas of industry. The process of diversification has been summarised diagrammatically in Figure 22. Diversification[12] began with oil and gas production and some petro-chemical operation in the 1950s but it was during the 1960s that Tenneco, finding progress towards the status of major energy producer blocked by established firms, embarked on a large-scale policy of diversification. The oil and gas production operations led them increasingly into downstream chemicals production, organics, poly-vinylchloride, plastics and polyurethane foam. In a different direction, Tenneco bought land for its mineral potential and became involved in agriculture and land management. Through the acquisition of Kern County Land Company in 1967, further agricultural interests were added and also J. I. Case, the tractor manufacturer and Walker Manufacturing, a maker of car exhausts, both Kern subsidiaries.

The acquisition policy provided Tenneco with considerable control over its markets, partly by the relationships between product areas, for example chemical fertilisers, tractors and agricultural land and also by vertical integration to gain control over sources of raw materials. Tenneco's acquisition of the Packaging Corporation of America has been followed by the purchase of huge forest areas in Georgia and Florida. Again, the contrast with A & W which owned neither its raw materials, nor its energy source, nor direct outlets to consumers, is most marked.

Other acquisitions seem to have been made purely for the purpose of diversification across various kinds of businesses, for example, Tenneco's purchase of life assurance[13] and ship-building concerns. Such diversification has had the advantages of spreading risks and limiting the consequences of unfavourable conditions in particular markets. Figure 23 shows the rates of return on capital for the major business sectors since 1975. Some businesses have shown large fluctuations in profitability during this period, yet the average for the conglomerate's rate of return has been remarkably stable. Generally, the onset of recession harmed the manufacturing interests but this was balanced by an improved return on oil and gas. By contrast, energy profits were so low at one point in the 1960s that

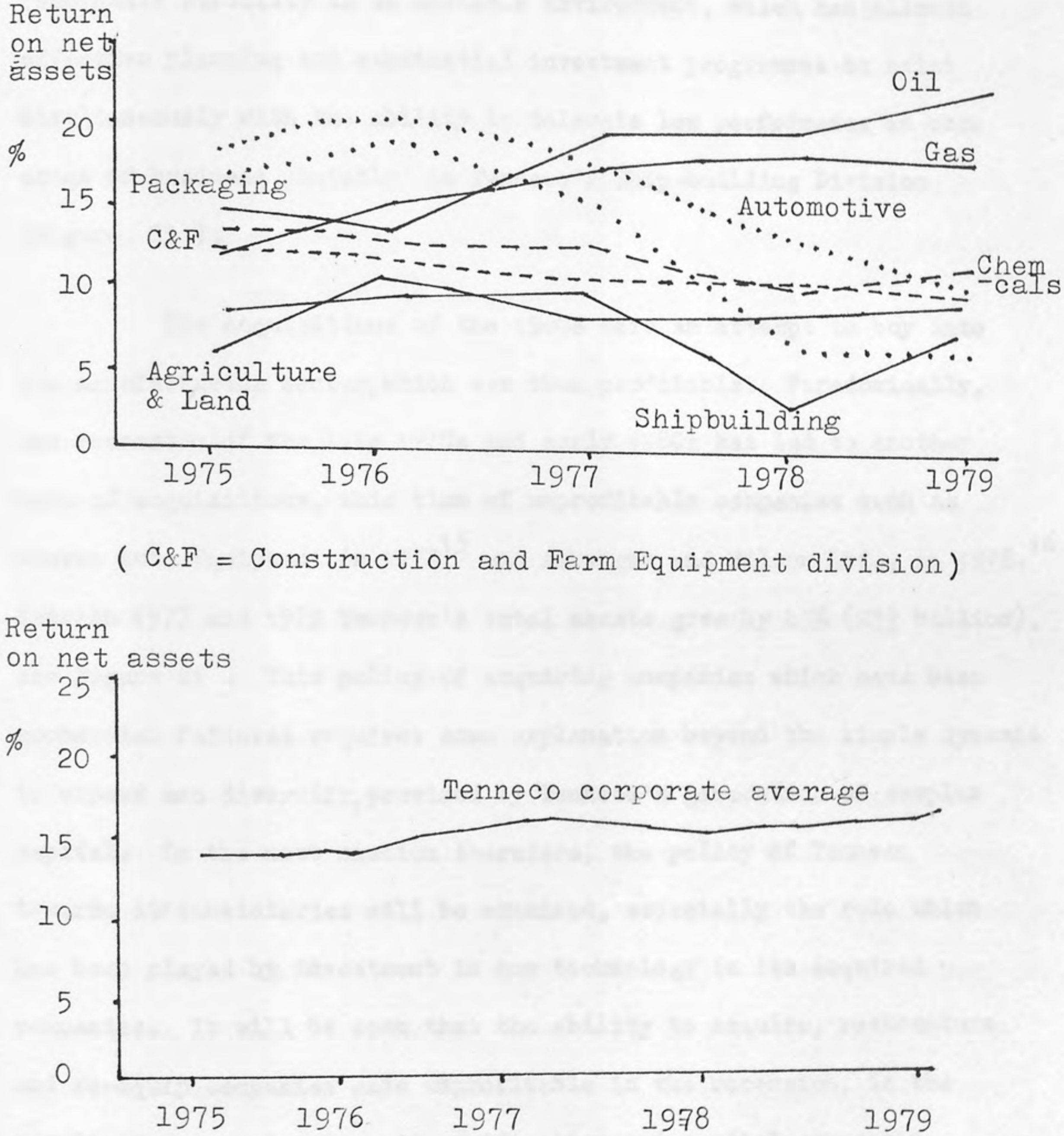


Fig. 23. Rates of return of major Tenneco business division (1975-79).
Source: Tenneco Annual Report (1979), p.6-7.

Tenneco considered becoming mainly a manufacturing company.[14] The consequences of a conglomerate structure, therefore, have been a remarkable stability in an unstable environment, which has allowed effective planning and substantial investment programmes to exist simultaneously with the ability to tolerate low performance in some areas of business, notably in Tenneco's Ship-building Division (Figure 23).

The acquisitions of the 1960s were an attempt to buy into the manufacturing sector, which was then profitable. Paradoxically, the recession of the late 1970s and early 1980s has led to another wave of acquisitions, this time of unprofitable companies such as Monroe Auto Equipment in 1977[15] and Albright and Wilson Ltd., in 1978.[16] Between 1977 and 1979 Tenneco's total assets grew by 43% (£3½ billion), see Figure 21 . This policy of acquiring companies which have been commercial failures requires some explanation beyond the simple dynamic to expand and diversify, provided by Tenneco's generation of surplus capital. In the next section therefore, the policy of Tenneco towards its subsidiaries will be examined, especially the role which has been played by investment in new technology in its acquired companies. It will be seen that the ability to acquire, restructure and re-equip companies made unprofitable in the recession, is the result of Tenneco's size, diversification and capital-generating energy operations, features that have been described in this section.

Policies for Raising Productivity.

Tenneco is an example of a new kind of organisation of the ownership and control of industry. As a conglomerate, it includes companies engaged in primary production, manufacturing, retailing and finance which often have no relationship to each other, apart from their common ownership by Tenneco. It is an example of industrial ownership having out-grown any single branch of production to become a type of pure investment and management organisation.

Tenneco's Board of Directors and small corporate management staff cannot be concerned with the details of the businesses, in such widely dissimilar kinds of production. The actual administration of the companies is in the hands of the Presidents of the Divisions, who are also Chief Executives of the companies, so that, as one of them has expressed it, "Tenneco really serves as a Board of Directors for the individual companies."[17] Tenneco is therefore, not an organisation for the management of production, but for the control of capital, considered in purely financial terms. The rate of return on investment has become the common yardstick for varied kinds of business and the role of the Tenneco Board is mainly to allocate financial resources between the companies and to fix the profit targets that they will be expected to reach. To people in the Tenneco-owned companies it may well seem that "Tenneco only cares about the bottom line."[18] This yardstick of profitability is used with some precision. In 1979 a Tenneco Executive Vice-President, visiting London, explained that the overall corporate objective was an 18% return on assets, for non-energy companies the target was 15%, and that companies unable to reach this return over time would be sold.[19] Since almost all Tenneco companies had a rate of return below this target in 1979, as shown in Figure 23 , this policy puts pressure on all companies to raise the rate of return, while the ruthless closing of unprofitable operations by Tenneco in the past, for example portions of its chemical operations in the 1960s,[20] makes the threat a credible one.

The general policy of setting profit targets and giving company Chief Executives autonomy in managing their companies to attain the target, must be departed from where companies are persistently unprofitable and need large-scale restructuring and re-equipping to achieve long-term profitability. Tenneco's apparent policy of deliberately acquiring companies which can be bought cheaply because the recession has revealed them to be not commercially viable, in their existing form, obviously requires an active involvement in the organisation and re-organisation of such companies. In chapter 6, the effects of this active restructuring policy by Tenneco towards A & W during the period 1978-1981 will be examined, but here another example will be given of its application, to raising the rate of return for Newport News Shipbuilding Company. Purchased in 1968, it demonstrates Tenneco's policy of active restructuring of an unprofitable enterprise a decade before the purchase of A & W and within, rather than outside, the USA. The whole process of the transformation of Newport News has been described and justified by the company Chief Executive at the time, who not only played a leading role, but was to become influential in developing similar strategies elsewhere, since he later became President of Tenneco itself.[21]

Newport News was founded in 1886 and continued as a private family firm until 1940. A monopolistic position as the largest private ship-yard for the US navy probably protected the firm from the consequences of poor management and failure to modernise its equipment and led to an uncompetitive cost structure. After its purchase of Newport News, Tenneco made the re-organisation of management and the replacement of production facilities the basis of its efforts to regain profitability at the ship-yard.

Management was subjected to new, highly demanding standards. According to the Chief Executive, "there's been a higher standard of performance required of people. They either met that standard - or they went their separate ways."[22] Tenneco made it clear that they supported "hard profit criteria and any means to achieve them".[23] The Chief Executive told the firm that "Tenneco has put together a strong management team, and said, 'It's your responsibility to get the job done'."[24]

Having re-organised management at the firm and made it clear what was required of them, Tenneco embarked on a huge programme of investment to re-equip the production facilities. In 1978 capital spending in the ship-yard was $2 million - 20 times what it had been in 1968, the year before Tenneco's takeover.[25] According to the Chief Executive, Tenneco

A major thrust of the investment programme during the 1970s, was the reduction of costs in every part of the operations by the introduction of automated equipment. Metal parts used at the yard were standardised, allowing computerised stock control to be introduced and an automated plate handling facility to be built, in which automatic cranes and computer-controlled conveyors almost completely replaced previous manual tasks. Labour reductions were also achieved in the machine shops by the introduction of numerically controlled flame-cutters. Between 1973 and 1978 one million man-hours of labour were claimed as having been saved and further reductions followed from the application of direct digital control by computer of the flame-cutters, in 1979. Cut plates were then welded by skilled welders and automated welding equipment "has more than doubled welders' productivity."[27] Even the productivity of designers was dramatically increased by computer-aided design equipment, using a special programme that allowed the time taken for designing a ship to be reduced from 18-24 months to 3-4 months.

All this investment in labour-saving technology had profound implications for the security of employment at the yard and therefore, a willingness to defeat worker resistance to the programme formed another essential element in the restructuring strategy. Tenneco fought a long struggle to prevent unionisation of the Newport News ship-yard. In the early 1970s, the Machinist's Union tried but failed to organise the workforce[28] and in the mid-1970s the Steel-workers Union led a long strike for recognition, which the company delayed giving until 1978.[29] Design staff resisted reductions in their numbers by legal action, union organisation and a 10 month strike.[30] In general, however, Tenneco was successful at introducing its automating equipment and permanently reducing the labour requirements of the yard and showed itself willing to accept short-term losses from industrial action. This history of labour relations at Newport News helps to explain the opposition of British trade unions to Tenneco's purchase of Albright and Wilson in 1978.

The example of Newport News makes clear the nature of Tenneco's policy towards raising the rate of return in its subsidiary companies, a policy which has become more active and interventionist in the period of economic recession. It consists of firstly, the reorganisation of management to bring it into conformity with Tenneco's methods and goals and secondly, the introduction of automating production equipment, on a massive scale, with the aim of achieving substantial reductions in labour requirements, wherever possible. The deployment of large capital resources for investment and the successful exploitation of the most modern production technology, especially computer-controlled automation, are key elements in the strategy. In the following section this role of computerised control of production for raising costs will be considered in more detail by examining how Tenneco has developed and made use of its expertise in this area of technology.

The Management of Process Control Automation.

Tenneco was not among the pioneers such as Texaco[31], and Monsanto[32] in the use of computer control for process plant, despite being engaged in similar large-scale continuous processes and in the same geographical area of the USA. In fact, Tenneco delayed its entry into this technology for a further 10 years, until the end of the 1960s, probably both because the high profitability of the oil and gas industries made the productivity of factors such as labour less than crucial and because of a tradition stemming from the founder Gardiner Symonds,[33] that Tenneco would utilise proven technologies rather than experiment with new ones.

The falling profitability suffered by Tenneco's oil and gas interests in the late 1960s, coupled with a realisation that computer control was becoming an established technology for improving the efficiency of continuous process plants, led to the first application of computer control in Tenneco, to its sprawling gas pipeline network.[34] Gas transmission is a relatively uncomplicated process, using a single, continuously-flowing material with no reactions. Computer control at a gas compressor station was the pilot project, which was soon followed by a scheme involving 60 compressor stations and 200 remote flow sensors on the pipeline. The ability of electronic instrumentation to monitor remote locations and transmit data over long distances was combined with the suitability of existing computers to provide centralised data processing, economically, for large-scale process plants.

During the 1970s, increases in the power of computers and decreases in their cost made a wider range of applications economically feasible. The experience gained by Tenneco was transferred from the Gas Pipeline operation to install computer control at an acetylene plant and its associated oxygen plant at Pasadena, Texas and a paper-making plant in Tennessee.[35] Both were large, continuous processes and computer control yielded encouraging financial returns.

An important milestone in the progress of Tenneco's use of process computers was its first application to a batch process, which was made in 1974 on the new polyvinylchloride plant at Pasadena.[36] Computers were by that time cheap enough to form a very small part of the total cost of the new plant and economics of scale were very favounable since the plant replaced two existing plants in New Jersey. The computer controlled, at first, five reactors, extended to eight and then to ten, allowing a doubling of the original capacity during the life of the computer. The improvements in the effectiveness of control provided by the computer allowed an estimated 50% increase in output over manual operation, for a 7% increase in capital cost.[37] The ratio of direct labour to output was reduced to one tenth of that at the old New Jersey plants and automation reduced the risks from carcenogenic substances involved in production of PVC.[38]

The experience of computer control at the Pasadena PVC plant convinced Tenneco that computer-based automation should become part of its strategy for cost reduction and profitability, wherever it was feasible. The development of micro-processors has allowed a further transference of computer control to take place, from the process industries to be applied in Tenneco's manufacturing companies, with the results which have already been described, for example, at Newport News' ship-yards. Increased power to control, from devices of diminishing size and cost, made micro-processor automation into an integral part of cost reduction efforts in a variety of Tenneco companies, during the late 1970s.

The organisation of Tenneco's expertise in the field of computer control has followed the same pattern, dramatically expanding from its early beginnings. The original group of enthusiastic engineers in the Gas Pipeline Technical Services Division was consolidated, in 1970, into the Industrial Automation Department (IAD). Their successes in organising computer applications to plants led in 1975 to their detachment from the Gas Transmission Company to become a department of corporate management, available for consultancy to any Tenneco company.[39] Since automation had come to be seen as a generally applicable technique for cost reduction, the function of the IAD was, significantly, defined in financial rather than technical terms, as "assisting divisions to improve productivity and return on net assets employed."[40] The Director of the IAD has also defined his mission in financial terms;

The Industrial Automation Department provided Tenneco with a pool of scarce talent, by recruiting people with relevant experience from other companies.[42] Tenneco offered them high salaries and a career in spreading computer automation through the Tenneco companies, while they offered Tenneco companies a free consultancy service in selecting suitable projects and appropriate equipment and in instructing and guiding company staff during its installation. A valuable economy of scale in expertise has resulted, giving companies access to advice beyond their own resources. The IAD has been one of the few corporate services created additional to companies' own management resources.

The improvements to the technology of computer automation represented by micro-processors and the impact of severe recession are now, at the beginning of the 1980s, pushing Tenneco's IAD into a further phase.[43] The need to reduce costs in all the companies and the huge number of opportunities to use micro-processor-based control devices to achieve savings, means that the task of managing automation projects has much outgrown IAD's staff of 9 engineers and a systems expert. Consequently, it s role has moved from consultancy to an emphasis on teaching and training, to develop pools of expertise within each Tenneco company, so that there can be local "self-sufficiency and expertise in the identification of automation opportunities and implementation of projects"[44] because "within the Tenneco companies there are now literally hundreds of these opportunities,"[45] according to IAD. To continue this diffusion of expertise, automation task forces have been set up in three companies, as a first step towards ending the status of computer automation as a very specialised new technology and making it into a routine part of the management of production, throughout the Tenneco group. The emphasis of these groups is upon searching out possibilities for automation to combat the impact of the recession, by reducing costs and improving competitiveness, wherever possible. In this, Tenneco is conforming to the pattern of other large American companies, who have set up similar automation task forces.[46]

Conclusions.

An examination of the nature and history of Tenneco has revealed the causes of its strength and dynamism as an enterprise. Tenneco's basis in the production, transmission and use of the abundant oil and gas resources of the US Gulf States has provided it with a source of rapidly accumulating surplus capital. This capital has been used to acquire business operations in a range of other industries, so that Tenneco has grown into a giant conglomerate corporation. Its size and diversified character have ensured very large and reliable flows of capital for further acquisitions and investment in its companies. By comparison with A & W, which has lacked a cheap energy source, remained confined to a single area of production and has been consistently under-capitalised, Tenneco represents a dynamic and expansionary agent for accumulating and modernising industrial production.

Tenneco has come to use automating technologies as a central element in its strategies to raise the profitability of its companies. In particular, it is now using micro-processor-based control technologies as a means to achieve substantial cost reductions in companies whose profitability, in the recession, is unacceptably low.

The first condition, which has made this widespread adoption of new control technology possible in the Tenneco corporation, has been the availability of massive funds for investment and the consequent ability to buy companies with out-dated production facilities and undertake large-scale investment programmes to re-equip them with highly productive new technology.

The second necessary condition has been the experience acquired, during the 1970s, in the area of computer control of processes. It has been essential for Tenneco's success in exploiting the advance in technology made possible by micro-processors. This experience and the size of the conglomerate have allowed a pool of scarce expertise to be created for implementing automation projects and from this pool, knowledge and experience are being diffused through the companies. The result is a planned application of new control technology to a very wide range of production operations.

This chapter has provided the background to the evolution of a policy and a practice with regard to process control automation, making use of micro-computers, which contrasts strongly with the conservative tradition of A & W. With the Tenneco takeover of A & W in 1978, these two differing policies came into contact with each other. Tenneco's efforts to alter A & W's established behaviour in this area will be described in the next chapter.

CHAPTER SIX

A & W's Policy for Process Control Technology (1978-81).

Introduction.

Chapters Four and Five have examined the different experiences of Tenneco and Albright and Wilson and seen how those experiences led to very different states of preparedness in the two companies for the successful adoption of the new technology of microcomputers for process control. The understanding of Tenneco and A & W, which has been derived from these studies, can now provide the background to analyse the impact of Tenneco's control over A & W, especially with regard to process control automation, after its purchase of the British company in 1978.

Chapter Four ended with a description of the inadequate performance of A & W in process control and this was seen to have had disastrous consequences, especially in the vital Longharbour project. In fact no process control computers of any kind had been adopted by A & W at the time of the Tenneco purchase. This Chapter will analyse in more depth the reasons for this conservatism, using the understanding of A & W's long-term weaknesses which was developed in Chapter Four.

The past behaviour of Tenneco as a technologically dynamic enterprise gave strong indications of the attitude that it would take to the backwardness of its new British subsidiary, in control automation. It was experienced, over more than ten years, in exploiting the potential for computer control of processes wherever possible. The example of Newport News exemplified the central role of production automation in Tenneco's approach to raising the profitability of its unsuccessful companies. Drawing upon this understanding of the immediate past history of both Tenneco and A & W, this Chapter examines the interaction of the two companies and their two different traditions in the period between 1978 and 1981 which included Tenneco's takeover and restructuring of A & W to conform to its own objectives and methods.

Tenneco Objectives and the Purchase of A & W.

In order to understand Tenneco's policies towards A & W it is necessary to consider how the purchase related to Tenneco's overall corporate strategies and its objectives in making this purchase in 1978. From the point of view of Tenneco, A & W formed part of a long-term pattern of expansion outside the original US base of the corporation. The fact that Western Europe contained $\frac{3}{4}$ of Tenneco's foreign assets[1] is not surprising, since Europe is the largest single market for both energy and manufactured goods outside the USA. In this respect, Tenneco has followed the same direction as other large US companies, which have established a strong presence in the West European economies since 1945. Tenneco has also not been unusual in making Britain its first base for expansion into Europe. Its acquisition of Globe Petroleum in 1966 gave Tenneco a first operation in Britain, to which were added chemicals, tractor assembly and car exhaust production, to make the UK its most important area of overseas production, containing $\frac{1}{2}$ of Tenneco's foreign assets.[2] From this base in Britain,[3] Tenneco was able to extend its marketing and production facilities into other European countries. For example, its purchase of Harmo Industries, a car accessory company, formed a first step to further acquisitions for its Automotive Division in France and Sweden. The acquisition of A & W conformed to this pattern since, in addition to its UK operations, the company possessed chemical plants in France, Italy and Spain, with marketing organisations in other European countries. These foreign subsidiaries of A & W consistently showed much higher profitability than the UK operations, as indicated in Figure 24, so that by its purchase of the whole group Tenneco obtained these profitable foreign operations at a low price, owing to the unprofitable character of the UK businesses.

A second attraction for Tenneco in the purchase of A & W lay in the former's role in the British sector of the North Sea oil fields, established by its purchase of a 31.5% share in the Heather field in 1973. In 1978, following its acquisition of A & W, Tenneco was able to bid successfully for a further licence area, using its new "British" aspect with a joint Tenneco GB/A & W application. The revenue generated from Tenneco's share in the North Sea production was in sterling, which exchanged for dollars at an unfavourable rate, so the acquisition of A & W provided a means for Tenneco to retain its surplus sterling revenue by acquiring assets in the UK. Tenneco's aims were summarised by A & W's new Texan chairman: "we wanted more involvement in the UK and because of our North Sea oil, we had the money to do it."[4]

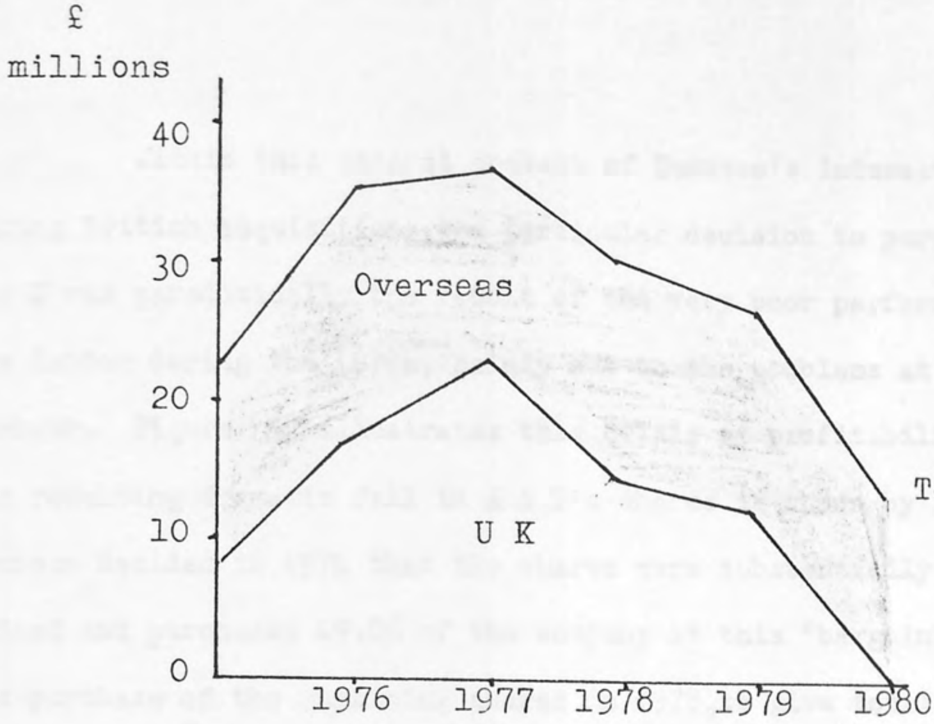


Fig. 24. Operating profits of A & W's UK and overseas businesses (1976-80).
Source: Albright World, 1980 Annual Report for Employees, p.6.

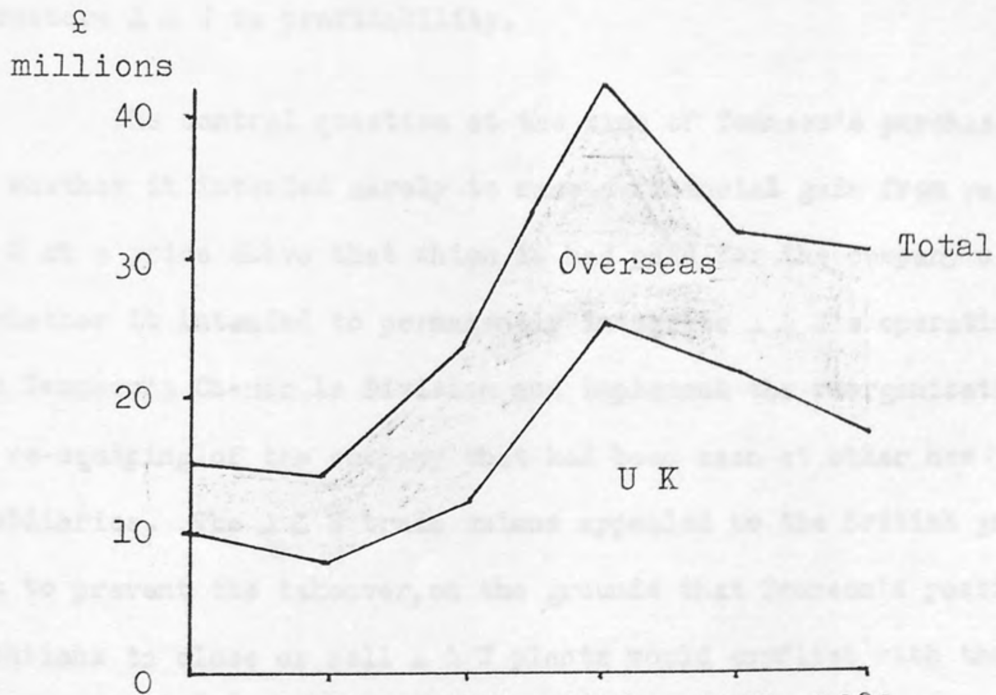


Fig. 25. Capital expenditure on A & W's UK and overseas businesses (1976-80).
Source: Albright World, 1980 Annual Report for Employees, p.6.

Within this general context of Tenneco's interest in making British acquisitions, the particular decision to purchase A & W was paradoxically the result of the very poor performance of the latter during the 1970s, mainly due to the problems at Longharbour. Figure 15 illustrates this crisis of profitability and the resulting dramatic fall in A & W's shares is shown by Figure 26. Tenneco decided in 1974 that the shares were substantially underpriced and purchased 49.8% of the company at this "bargain" price. The purchase of the remaining shares in 1978, to give total ownership of A & W, may be explained by reference to Figure 24 which shows the disastrous fall in profitability that year, especially in A & W's UK operations. Tenneco decided that it needed to take full control of A & W, in order to safeguard its existing investment by directing the rationalisation and new capital expenditure programmes needed to restore A & W to profitability.

The central question at the time of Tenneco's purchase was whether it intended merely to make a financial gain from reselling A & W at a price above that which it had paid for the company's shares, or whether it intended to permanently integrate A & W's operations into Tenneco's Chemicals Division and implement the reorganisation and re-equiping of the company that had been seen at other new subsidiaries. The A & W trade unions appealed to the British government to prevent the takeover, on the grounds that Tenneco's possible intentions to close or sell A & W plants would conflict with the Labour government's policies for industrial democracy and the regeneration of British industry.[5] Tenneco gained government approval for its

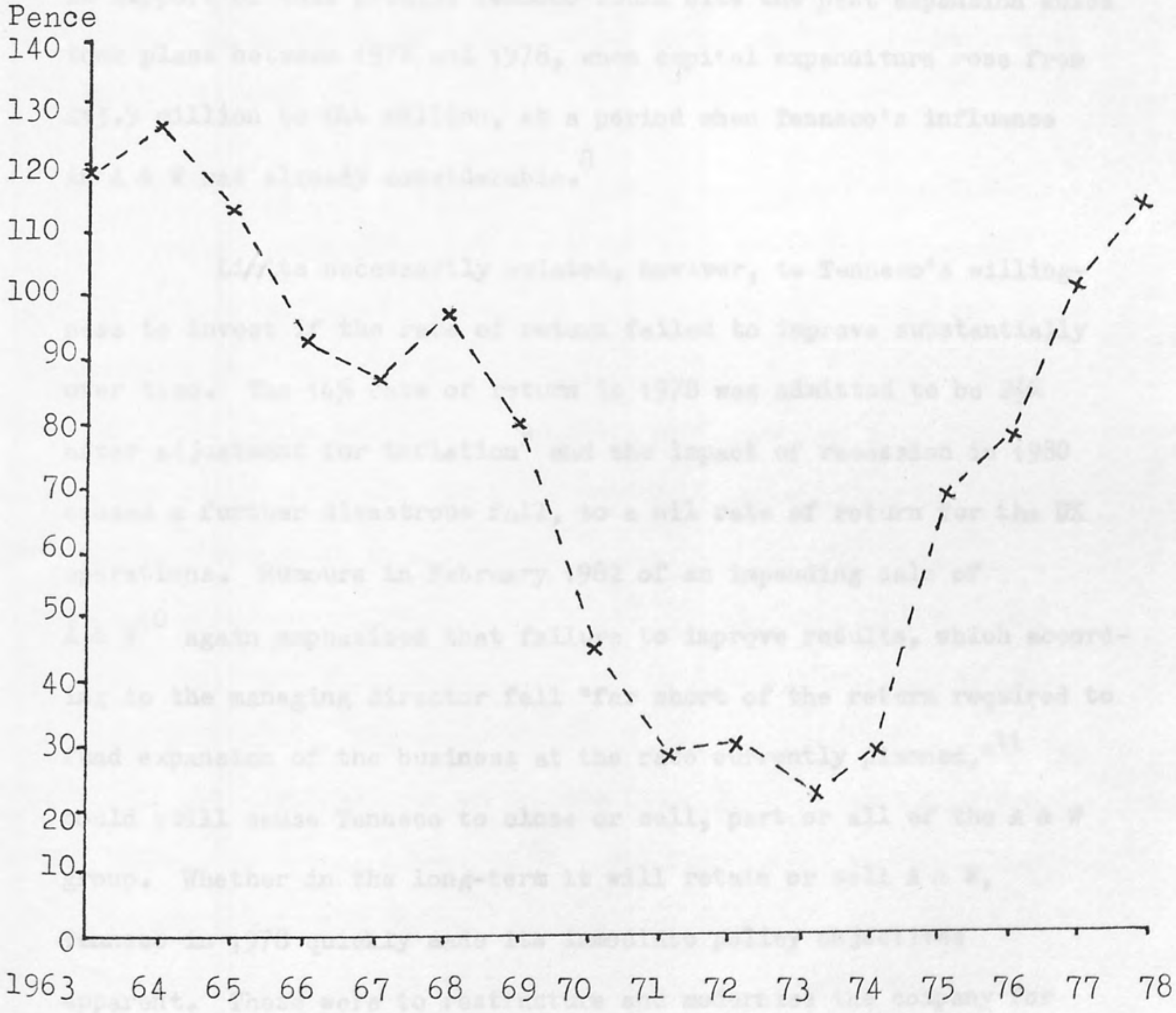


Fig. 26. A & W Share prices (1963-79).
Source: Financial Times, 1st April, each year.

takeover of A & W, only after clearly stating their "intentions in regard to internal growth."[6] The new A & W chairman, in an interview in March 1979, promised that Tenneco's intention was to expand A & W and to continue to fund investments designed to increase productivity.[7] In support of this promise Tenneco could cite the past expansion which took place between 1976 and 1978, when capital expenditure rose from £13.9 million to £44 million, at a period when Tenneco's influence in A & W was already considerable.[8]

Limits necessarily existed, however, to Tenneco's willingness to invest if the rate of return failed to improve substantially over time. The 14% rate of return in 1978 was admitted to be 2½% after adjustment for inflation[9] and the impact of recession in 1980 caused a further disastrous fall, to a nil rate of return for the UK operations. Rumours in February 1982 of an impending sale of A & W[10] again emphasised that failure to improve results, which according to the managing director fell "far short of the return required to fund expansion of the business at the rate currently planned,"[11] could still cause Tenneco to close or sell, part or all of the A & W group. Whether in the long-term it will retain or sell A & W, Tenneco in 1978 quickly made its immediate policy objectives apparent. These were to restructure and modernise the company for increased efficiency and profitability. The implementation of these policies and their impact upon A & W, between 1978 and 1981, will be discussed in the following section.

Policies for the Restructuring of A & W.

Tenneco's policies for restructuring A & W can be briefly described as centralising control, reducing costs and raising efficiency in the company, in order to increase profitability. This approach characterised the changes made at the level of company policy-making, in the organisation of management and at the individual production sites.

Control over A & W company policy-making was established by some rapid changes, that had the effects of centralising control over decisions and subordinating it to Tenneco's corporate headquarters in Houston. Between 1977 and 1979, the number of A & W directors was reduced from eleven to seven, through the retirement of five non-executive directors - all men whose position derived from individual or family involvement in A & W over a long period, including a remaining grandson of Arthur Albright.[12] On the new, smaller Board of Directors, men whose background was in Tenneco took most of the dominant positions. The new chairman of A & W was a Tenneco vice-president and also chairman of Tenneco Gas. Despite his assurance that "it was never our intention to Americanise A & W and that remains,"[13] by 1980 Americans held the most powerful positions in the company. Two new deputy managing directors were appointed, both also holding directorships in other Tenneco companies.

This relationship between A & W and Tenneco did not conform to the model of autonomy for subsidiary companies in the Tenneco group, which was described as usual, in Chapter 5. The new chairman of the Board formed a direct link to Tenneco's corporate headquarters, where he held the position of executive vice-president and acted as a "transatlantic commuter"[14] between Britain and Houston. Tenneco showed its determination to control tightly the capital investments it was making in A & W, by requiring all investments over £100,000 proposed in Britain to be approved by the Tenneco board in Houston.

A key role in centralising decision-making and ensuring the implementation of Tenneco's policies for A & W was played by a Texan who occupied the new Board posts of Deputy Managing Director and Director of Operations. All divisional management was made responsible to him and that gave him control over all production operations, since a reorganisation of management was undertaken[15] to reduce the six former business sectors to four divisions which also incorporated previous parts of corporate management departments (Administration and Personnel). This emphasis on divisional management, with minimal corporate functions, followed the practice of Tenneco companies in the US and served to centralise and shorten lines of authority, to aid the rapid implementation of Tenneco's new policies and to minimise resistance from those managers who preferred traditional A & W practices.

The other objective of management reorganisation was to remove duplication of functions, to reduce staffing and save costs in administration. The management structure of A & W had reflected its past, as an accumulation of previously separate businesses that had been bought over many years but not effectively integrated. Attempts to rationalise the structure of management had caused almost continuous disruption since 1967.[16] Tenneco took a number of decisions to simplify and reduce management, especially corporate management.[17] The main London office was merged with the office at Warley, near Oldbury and the Corporate Engineering Department was unified at Whitehaven, while the Merseyside area office was closed. Such mergers allowed substantial reductions in office staff and office overhead costs to be achieved.

This rationalisation of management and administration was to precede a similar rationalisation of the production sites themselves. A & W's acquisitions in the 1950s and 1960s had added many scattered plants to the original Oldbury works. Savings in costs from concentrating production plants onto a few multi-plant sites were clearly an attractive possibility. The number of products and processes included in the A & W group was large and their profitability and competitiveness varied greatly. The company was warned by the managing director in 1980 that Tenneco was determined to make a profitable asset of A & W, by discarding "any business which consistently makes a loss. If the only way we can save a leg is to cut off a foot, we shall do it."[18] This warning suggested that a large-scale elimination of unprofitable processes was imminent.

Another direction in which management and administration at A & W led production was in the introduction of new technology, especially computer-based "information technology." In 1980, the first word processors were introduced to the Warley office to raise the productivity of office staff, whose numbers had been severly reduced in the previous twelve months. A new central company computer was purchased and this was linked both to the word processors and to terminals in the scattered Finance Departments.[19] Stock management and order processing were also areas to which computer processing was introduced.[20] A micro-electronic private telephone network was installed to unify the geographically scattered offices and production sites and to provide a direct link to Houston. The new company computer was able to communicate with the Tenneco Computer Centre and thus provide access, for example, to Tenneco's standard computer model for financial forecasting. Those objectives which inspired the re-organisation of management, namely the achievement of rapid, centralised decision implementation and maximised productivity of staff, were also well served by the new communications and information processing technology adopted after 1979.

Examination of Tenneco's behaviour in the US must lead to an expectation that the application of computer automation to production processes was also going to form an important element of their policy for raising profitability at A & W. Indeed, the managing director described the company's objectives at this time as "higher productivity, better salesmanship (and) reliable plants."[21] Process automation was a very relevant tool for realising at least the first and third of these. It soon became apparent to A & W production management that, "the message is loud and clear. We must increase our productivity and automated systems can undoubtedly help us to do it."[22] This policy of adopting process control automation at A & W and the manner in which it was implemented by Tenneco will be described later in this Chapter. Firstly, however, it will be necessary to describe and explain the state of process control methods as they existed on A & W plants at the time of Tenneco's takeover, in order to understand the nature and extent of the changes which were implied by Tenneco's new policy for computer automation.

Conservatism in the Technology of Process Control at A & W.

At the time of Tenneco's takeover of A & W, the British company had no plants under computer control. This was almost twenty years after the first applications of computers to chemical processes in Britain. The entire development of process control computers, as it has been described in Chapters 2 and 3, did not result in a single application at A & W, which in consequence failed to participate in the experience gained by the chemical industry, in the 1960s and 1970s, of operating computer controlled plants.

A & W production sites in the late 1970s revealed a generally backward state of process control techniques in use. No plants were under computer control and furthermore, electronic instrumentation, the necessary precursor of computer control, was also absent. Plants remained overwhelmingly committed to pneumatic instrumentation and controllers - what could be described as an improved version of the control technology of the 1940s and 1950s. No advanced control strategies could be implemented using such equipment and control depended largely on the skill and attentiveness of operators and supervisors. Furthermore, the actual level of functional instrumentation had declined on several plants,[23] where as a result of the unreliability of pneumatic equipment and inadequate maintenance, up to 50% of pneumatic controllers were functioning only as indicators, so that these plants had reverted to largely manual control. Tenneco's Operations Technologies Department, visiting the A & W plants in 1980, discovered a "primitive" level of control on some plants.[24] An example was a plant at which a vital stage of the process relied on one operator's recognition of a colour change, such that his failure to observe this change would result in the wastage of a whole batch. Some 19th century equipment was actually still in use at this plant.[25] A comparison with the description of the advances in process control technology given in Chapters 2 and 3, indicates that by the late 1970s A & W plants were far behind the level of technical sophistication achieved elsewhere in the chemical industry. A & W's non-adoption of the process control computers which existed in the 1960s and early 1970s can be explained to a considerable extent by the unsuitability of those computers for the A & W plants. As seen in Chapter 2, early computers were economic only on large scale continuous processes, whereas the majority of A & W plants were small or medium sized batch plants, making specialised phosphate chemicals. The high cost of computers was cited by A & W's Central Engineering Department in 1979 to explain its previous non-adoption of computer control.[26] However, as Chapter 3 showed, the progress of electronic systems during the 1970s, from integrated circuits to microprocessor technology, drastically reduced this problem by lowering the cost of purchasing and operating digital computers. Chapter 4 discussed the contribution which computer control might have made to the vital Longharbour project, where the cost of a computer would have been relatively insignificant within such a huge investment but the benefits would have been appreciable.

Unreliability was also cited previously as an area of weakness of process control computers and this was certainly a relevant factor for A & W, since many of its processes involved toxic, inflammable or explosive materials. A danger of sparking from electronic equipment existed but this was later much reduced by the availability of low-voltage signalling equipment. The improved reliability of computers was demonstrated by examples such as Tenneco's computer control of its hazardous PVC process, which was described earlier. That was a case where computer control was found to be more reliable and precise than manual operation. Tenneco had also moved, in the mid-1970s, from controlling continuous plants by computer to the control of batch plants - another indication that A & W's technical objections to computer control were of decreasing validity.

To fully understand the origins of the conservatism in process control technology displayed by A & W, it is necessary to recall the long-term trends and traditions in the company which were analysed in Chapter 4. For much of its history, A & W had operated in a monopolistic position in its established product and geographical markets. Its progress had been built by supplying new chemicals and opening new markets, without a severe pressure of competition to make the efficiency of the production process crucial. This position had altered radically in the mid-twentieth century, but certain traditions derived from the more favourable conditions of the past continued, especially a tendency to under-rate the importance of process engineering and its contribution to cost-effective production. This complacency was, as the Longharbour experience demonstrated, essentially unrealistic and led to disastrous results. Its neglect of process engineering left the company quite unprepared to respond to the sudden need to raise substantially the level of technical performance of their plants which became apparent in the late 1960s.

A crucial factor in A & W's conservatism in relation to process control was undoubtedly the lack of sufficient available investment funds. During the 1970s, when important progress in process control technology should have taken place, the company was experiencing low profitability and only investments with a high and certain return received approval from the Board. In part, this can be seen as a continuation of the long-standing under-capitalisation of A & W, which was identified in Chapter Four, but this was made particularly acute by the decision to concentrate investment in the Longharbour project, whose subsequent losses drained finance from the company's other operations throughout the 1970s. Since the failure of Longharbour was to a large extent the result of inadequate expertise in process control, the lack of progress in the technology of control can be veiwed as both a cause and an effect of the shortage of investment capital.

This failure of A & W to plan for adequate progress in process control was apparent not only in the allocation of investment but also in the organisation of A & W's technical resources. The emphasis on corporate management led to a concentration of the company's engineering expertise in its Central Engineering Department

(CED), which accumulated features that made it slow to respond to new control technology. The relationship between CED and plant management was crucial to any efforts to improve plant performance but this relationship seems to have compared unfavourably with that of the OTD and the Tenneco companies. The fact that, unlike OTD, CED charged A & W plants a fee for its advice in selecting new control technology also contributed to the distant relationship which it had with plant management. It is significant that the few proposals for computer control which did arise within A & W at the end of the 1970s, came from individuals at the production sites rather than from CED.[27] The only advanced electronic controller installed by 1979 was the outcome of the initiative of the Rainham plant manager and engineer, without reference to CED (see Chapter 7). Whereas OTD had a tradition of seeking actively to spread computer automation in Tenneco companies, A & W's CED retained a commitment to pneumatic systems of control. CED's direct responsibility for control equipment was confined to that on new plants and these were few during the 1970s, when investment was being absorbed by Longharbour. As will be described later, even when given control over a large new plant construction project CED demonstrated a continued commitment to pneumatic controls and an unwillingness to consider digital electronic alternatives.

The conservatism shown by CED was hardly surprising, when the unwillingness of the company to invest in new expertise by recruiting new engineers is considered.[28] In the case of OTD, a pool of expertise in the selection and implementation of computer systems had been accumulated, by hiring engineers with experience of such systems from other companies, paying for them to attend further courses and training and paying attractive salaries to retain their services. CED, on the contrary, had been subjected to a long period of restraint on recruitment and so continued to be led by men trained before the advances in electronic control systems, whose whole experience was of the pneumatic controls used in A & W. Expertise in electronic engineering or computers remained lacking. The position at plant level was worse, with plant managers more usually trained in chemistry than in process engineering or control[29] and lacking accessible advice to make new departures in this area, thus prefering to continue with technology which had at least the advantages of familiarity.

Another factor which contributed to conservatism in process control on A & W plants was the character of the workforce at the UK sites. Especially at the Oldbury site, A & W was making use of a reserve of skills accumulated through generations of employment by the company, in that local area. From its Quaker founders, A & W had inherited a tradition of paternalistic treatment of its workforce, based on stability and continuity of employment.[30] The skills of the workforce in operating and gaining satisfactory performance from the A & W plants could be relied upon and a high standard of motivation and initiative among operators was expected.[31] Chapter 4 has mentioned the problems experienced when A & W tried to transplant these methods to a remote area of Newfoundland, where such skills were totally absent and the plant was of a new design.

The skills of the workforce constituted a factor in the commitment to traditional control methods, in the same way that the training and experience of engineers and managers did. Managers expressed fears about a mismatch between new sophisticated equipment and their "unskilled" operators.[32] The trade unions did in fact resist proposals made by the company to create an elite of operators, retrained to work with the planned automated phosphine plant at Oldbury.[33] In Tenneco, considerable signs of such polarisation of the workforce were visible, for example at the computer-controlled Pasadena PVC plant where only the most experienced operators were allowed to work at the computer inter-face.[34] Potential labour resistance at A & W, both to changes in grades, rewards and working practices and to redundancies, acted as a deterrent in the minds of management to the introduction of advanced control systems.[35] From an industrial relations view-point, familiar techniques were to be preferred, since they minimised the potential for conflict. If benefits in labour productivity could not be achieved because of resistance to reductions in the workforce, then investment in new controls might not show a satisfactory rate of return. Also, fears were expressed that new equipment might actually increase wage costs, by requiring additional maintenance workers.[36]

A & W's conservatism in control technology can, therefore, be understood as the outcome of the company's generally exhausted state, since resources were lacking to embark on a successful adaption to new control technology in the 1970s. All the elements which have been described, combined to produce the inadequacy in this vital technical area, examples of which have been given. One final example of conservatism remains to be described. It was the last project on which Tenneco allowed A & W to pursue its traditional policies for process control and its results were sufficiently disturbing to produce a strong intervention from Tenneco, to ensure that in future its preferred policy, based on digital electronics, would be followed at A & W.

The last example of conservative control technology policy, at A & W, was the new "wet acid" plant which opened at Whitehaven in 1980. After the disaster of the huge thermal-acid plant at Longharbour, the new wet process plant represented a crucial last chance to avoid the problems of high energy costs in the UK, by establishing a source of phosphoric acid, based on a process with a low energy requirement. By building a large wet-acid purification plant on the site, it was intended to supply acid, not only to the detergent and non-food phosphate plants, but also to food-grade phosphate production. Therefore, the project was vital to A & W's future UK operations and formed the largest-ever UK investment (£20 million). At an output of 160,000 tons per annum this wet-acid plant ranked as "one of the largest in Europe."[37]

Despite the great importance of the new plant's performance, it was equipped entirely with pneumatic controls, characterised by OTD's director as "the technology of 30 years ago."[38] The original decision to employ such technology had been made several years previously, when it could be argued that proven alternatives were not available. However, this cannot explain why the decision was not reviewed, in the light of the subsequent improvements in electronic control systems. The control system employed was actually highly idiosyncratic, since pneumatic controllers were superimposed on electronic instruments, the reverse of usual practice. No advanced control strategies would be possible using these devices and computer control could not be added to them.[39]

The acid plant suffered similar kinds of process problems to those at Longharbour, especially difficulty in relating the composition of feed to conditions inside the reactor. The pneumatic controllers proved quite unsatisfactory and by the end of 1980 only 50% of control loops were under their control.[40] In another parallel with the Longharbour experience, the possibility of re-opening the old wet-acid plant on the site was considered. The problems of the new plant were, however, diagnosed by Tenneco's OTD, during their visit in 1980, to be mainly due to the inadequate control system and a decision was quickly taken to abandon the pneumatic controllers and replace them with direct digital control, based on microprocessors.

This experience probably played a part in the new company policy decision, which was made known to staff during 1980, that henceforth the standard approach to process control would be to employ electronic, digital, multi-loop controllers in almost all cases, except on the smallest plants.[41] The change from the previous policy of using pneumatic controls was abrupt and the direct result of Tenneco intervention, after OTD's tour of the UK sites in 1980. The methods by which Tenneco implemented its policy objective, of adopting new control systems in A & W, will be described in the next section.

The Organisation and Implementation of Advanced Electronic Control Technology in A & W.

Earlier, it was suggested that a degree of uncertainty characterised Tenneco's intentions with regard to A & W. Previous experience suggested that Tenneco would demand an effort by the company to modernise its plants and raise the efficiency of production, using process control automation as an important tool, but on the other hand the very poor profitability of A & W left doubts as to whether Tenneco would agree to sufficient investment for this modernisation to be implemented.[42] The nil rate of return from UK operations in 1980 led to the imposition of severe restraints on all expenditure at A & W. It seemed that Tenneco required A & W to mobilise from its own resources the necessary initiative for a programme of adoption of new control technology, which demanded a very substantial change from the conservative attitudes described in the previous section.

A powerful motive for engineers and managers to show a new concern for control automation was provided by the insecurity and fear generated by the widespread redundancies that resulted from management re-organisation and Tenneco's declared willingness to close loss-making businesses.[43] It became clear that individuals who showed readiness to adapt to the new policy, by educating themselves about process control computers, would have a much more promising future in the company than those who did not associate themselves with this trend.

Tenneco's OTD played an important role in changing attitudes towards computer automation in A & W. Within a year of Tenneco's takeover, the OTD began a series of seminars and courses, designed to spread awareness of the new technology and of Tenneco's policy for its adoption. The staff in production management were invited to a conference which aimed, not to produce "instant experts" but, according to OTD, to "demystify" computers and make A & W personnel "more objective" about their benefits.[44] In 1980, OTD gave their "applied automation course", which had previously been offered at the US subsidiaries of Tenneco and, later in 1980, was taken to ERCO staff at Longharbour. Soon afterwards, a seminar on the same subject was given to A & W's Italian and French managers.

The content of these seminars and courses was designed to introduce staff to the basic concepts and forms of technology of computer control for chemical processes and to discuss the examples already in operation at Tenneco's US plants. General advice on how to select and plan an automation project was given and this yielded results, in the shape of proposals for new control systems for three plants at Whitehaven and one at Oldbury.[45] OTD's role then changed to the giving of more specific advice, and the courses in 1981 involved representatives of the equipment suppliers and some discussion of specific A & W plants suitable for advanced electronic controls.[46] The new climate of encouragement for such proposals in the company, combined with the educating role of OTD, succeeded in raising, rapidly, the level of activity concerned with computer automation within A & W.

The Whitehaven instrument development engineer, an early proponent of computer control in the company, observed at a meeting on computer control,"how interesting it was to see so many people attending the convention. Three or four years ago, hardly anyone here today would have been involved with computers."[47]

In addition to its educating activity, through OTD, and encouragement for automation proposals, Tenneco acted to re-organise the company's technical expertise and to effect changes in the roles of technical staff. The Central Engineering Department, previously divided between the Oldbury and Whitehaven sites, was unified at Whitehaven. This resulted in the loss of some older and perhaps more conservative engineers, while early retirement also acted to reduce the numbers of technical staff and their average ages, leaving an instrument department at Whitehaven that consisted mainly of men in their thirties.[48] The re-organised CED was led by the former head of its Whitehaven branch, a man with a strong interest in microcomputer application. By these changes, the former leadership and traditions of CED, that had committed it to pneumatic control, were disrupted and it was re-oriented towards the use of digital electronic control systems. From its previous caution in this area, CED was forced by the lack of new plants after 1980, resulting from Tenneco's strict controls on investment, to seek a new role in preparing proposals for microprocessor-based automation, to be applied to A & W's existing plants.

A degree of rivalry developed, within A & W, as to where the focus of expertise in the new skills of selecting and implementing computer automation projects, should be situated. One proposal, that a new team of three engineers, trained in these skills, should be formed under the Director of Corporate Development, was rejected because it involved the expense of new staff recruitment.[49] The company preferred to make use of talent already within A & W, most notably the individuals at the Rainham phosphates plant, who had been involved in the only pre-1981 application of advanced electronic control. This project will be discussed in some detail in Chapter 7. The Rainham staff became very enthusiastic over the benefits derived from advanced control at their plant and were used as advocates of such control equipment to other plant managers and engineers, so that their example played a leading role in encouraging automation proposals elsewhere.[50] Furthermore, the engineer at Rainham was appointed, in 1981, to be the company's first Senior Process Control Engineer, based at Whitehaven and employed exclusively on the selection and design of new computer control applications for A & W plants.

Although A & W policy became concerned to create a pool of relevant expertise within the company, an important role continued to be played by OTD, based on its knowledge of control technology available in the US. It attempted to bridge the "technical gap" between Britain and the main equipment manufacturers in the USA, where in its view, almost all the equipment needed to give computer control to the A & W plants was already available,[51] so that experimentation should be abandoned, in favour of the transfer and application of proven technology. Efforts to develop a single-chip instrument at Whitehaven and to use a British computer to solve Longharbour's control problem, were stopped because American devices for these tasks already existed. There was other evidence that Tenneco had decided to terminate technical experimentation in A & W, notably the loss of separate status for the Research Department, (which had been founded by Sir Richard Threlfall), and a prohibition on funding for ambitious research proposals.[52]

The results of all the new initiatives towards applying computer control technology were plans for adoption and implementation of such equipment at a number of A & W plants. The phosphoric acid plant at Whitehaven was rapidly re-fitted with a microprocessor-based control system.[53] The thermal acid plant at Oldbury, for which computer control had been suggested in 1978,[54] finally received approval following Tenneco's intervention, allowing improved performance from the old plant and saving the cost of a new plant. Also at Oldbury, a phosphine plant became, in 1981, the first new plant to be designed with computer controls, "potential process hazard" being an important justification for the automated control strategy.[56] Other batch plants at Oldbury were found to be suitable for computers and plans were prepared for them. At the same time, a process of piecemeal adoption of electronic equipment began on the site, from the replacement of obsolete pneumatic controllers, as they became inoperable. Between 1978 and 1981, A & W had moved from a long-standing commitment to pneumatic controls, with digital electronics being viewed with great caution, to a firm commitment to digital electronics as the basic equipment for control, with computer control seen as an attractive option wherever it was practicable.

Conclusions and Future Prospects.

Inadequate performance in the use of process control technology, with a strong tendency to remain committeed to increasingly obsolete methods of control, which relied upon pneumatic equipment, was both an important cause of A & W's decline as an independent company and also a consequence of that decline. Therefore, Tenneco policies to restructure A & W, for increased profitability, inevitably involved decisive intervention to change the direction of A & W's control technology policy towards the use of computer automation. Essentially, A & W were given the alternative of acting to raise efficiency through new control systems, or of having its plants closed by Tenneco, as unacceptably uncompetitive.

Considerable progress was made, in the required direction, by A & W between 1978 and 1981, but various factors combined, also, to delay the adoption of new control technology. The deepening of recession in 1980, led to a very poor financial performance from many A & W businesses and the imposition by Tenneco of severe restraints on expenditure. This affected A & W's ability to employ relevant expertise for computer projects, as well as the availability of investment funds for new equipment. Also, the recession in markets made it difficult to justify expenditure on systems which provided higher output, as is usual from computer control, at a time when sales were depressed. In this environment, proposals for computer control needed to demonstrate a substantial rate of return from improved quality of product, or safety of operation, or labour productivity.

The probable outcome of this period, characterised by economic stringency and efforts at A & W to automate its plants, will be a company which has fewer plants, concentrated on fewer sites, producing fewer products and employing less labour, but with enhanced competitiveness, at those plants to which new electronic control systems have been applied, and considerable margins of spare capacity, in case markets should re-expand.

In order to see what the costs and benefits of adopting new control systems are, at the level of the individual plant, the reasons for choosing particular forms of technology, the extent to which expected benefits are realised and the impacts on the output and input requirements of production, it is necessary to consider an example of one such plant. The following Chapter consists of such a plant-level study, covering the first plant at A & W to be controlled by a central, multi-loop, electronic controller, based on a micro-processor and considers the conclusions for the future applications at other A & W plants, to be drawn from this first experience.

CHAPTER SEVEN

The First Adoption of a Microprocessor-based Control System at an A & W Plant : A Case Study.

Introduction.

Albright & Wilson's first microprocessor-based control system, which was installed in 1979 on the site at Rainham, Essex, to control an aryl phosphates plant, was important because it was the only proposal for adoption of such technology to have been approved by the A & W board prior to the takeover by Tenneco. It formed an exception to A & W's existing policy of commitment to pneumatic controls and it is, therefore, important to examine this exception in more detail, to discover its significance for the changes which occured in A & W policy for control technology, between 1978 and 1980.

Because it was the first adoption of a microprocessor-based system and was thus the precursor of the widespread adoptions that were encouraged after the Tenneco takeover, the case of Rainham can give some indications of what may be expected to occur at other A & W sites. It was the first available plant at which a decision to adopt an advanced control system could be studied in detail and a visit to the plant was undertaken, immediately prior to the installation of the new control system, to provide the basis for the analysis given in this Chapter. The visit allowed the existing control techniques and performance of the Rainham plant to be recorded and compared with operations at a second visit, two years after the installation of the new controls. Thus the Rainham plant allowed a detailed case study of the consequences of a radical change in control technology, for output, product quality and the size and nature of the workforce.

The decision to adopt.

The explanation of Rainham plant's status, as the first in A & W to adopt a microprocessor-based control system, derives from the relatively isolated situation of the plant, far from the main company sites at Oldbury and Whitehaven. This geographical separation reflected the nature of aryl phosphates production which, unlike most of A & W, formed part of the organic chemical industry and used phenol, an oil-derived raw material.[1] Its products were also very different from the major A & W product areas, being sold as plasticiser,[2] hydraulic fluid or lubricant.

Since the plant's construction in 1948, the Rainham management appeared to have acquired rather different attitudes from A & W management generally, describing themselves as "an insular lot."[3] The phosphates plant manager was responsible for his own budget and business, and showed a strong sense of identification with "his" plant. He was accustomed to diagnosing and solving the plant's problems, with little reference to A & W corporate management. This tradition of autonomy and self-sufficiency at Rainham, does much to explain its pioneer role in proposing, selecting and implementing the first advanced electronic plant controller. While Central Engineering remained committed to pneumatic controls, the Rainham management, which was separated from this cautious tradition, acted to educate themselves in the available technologies of control and chose equipment best suited to the needs of their plant.

This plant had used a relatively sophisticated control philosophy since 1958, when it had been equipped with what was then an advanced system of automatic local pneumatic controllers. This system was a reflection of the complexity of the process and the need for precise control of quality, features that required effective control equipment. The situation was contrasted, by the plant manager,[4] with the much cruder, manual control which was traditional at some other A & W plants. As a result, the Rainham management had always tended to give importance to good control technique.

The small size of the Rainham management had the effect of freeing them from the divisions between engineers and production staff, that characterised management elsewhere and impeded the application of new technology to production sites. One small group of men was responsible, at Rainham, for the profitability of the business and the organisation of production and the maintenance of the plant. Its members were able to determine objectives, diagnose technical problems and develop appropriate changes on the plant, in an integrated manner and with minimum delays. The project thus avoided the problem of the poor relationship between Central Engineering and plant management, which was identified in Chapter 6. A pocket of independent engineering expertise developed at the plant, with two men who were allowed to spend considerable time in looking at the possibilities of new electronic equipment. In the mid-1970s, an instrument engineer investigated available electronic instruments and controllers. He was succeeded by a chemical engineer who selected, with the plant manager, a central, multi-loop, digital controller based on a microprocessor.

The small size and isolated position of the Rainham plant seems to also have had significant implications for industrial relations at the plant. These were conducted at a very personal level, with a closer and less formal relationship between shop stewards and management than on the large sites.[5] Management was therefore confident that the planned changes in control technology could be implemented without significant resistance from the labour force. By stressing continuities with previous equipment and working practices, acceptance of the changes was gained. This confidence contrasted markedly with the fears expressed by other plant managers[6], that worker suspicion of new control equipment might be a serious deterent to their introduction. The Rainham management's confidence that such problems could be avoided was a significant factor in the decision to make use of an advanced digital controller..

Having educated themselves in the new control technology, selected equipment for their plant and satisfied themselves that workforce acceptance could be assurred, the plant manager and engineer submitted a proposal for investment funding to the company.[7] This met with some criticism from corporate engineers who believed that this first,complete plant control system was too ambitious and suggested instead a piece-meal approach,using discrete controllers,which would be cheaper, entail less risk of failure and be less likely to arouse fears of redundancies.[8] That this more cautious approach did not prevail,seems to have been due to the Rainham management's confidence in their preferred solution,which was approved by the company as being "seen as the most effective means of improving process control by

those individuals normally charged with this responsibility."[9]
A & W was prepared to give funding, at this time, for a convincingly presented plant-level initiative, even though it was not yet organised to initiate on a company level the adoption of microprocessor-based automated control for its plants.

Expected Benefits of the new Control System.

The economic conditions in which the Rainham plant was operating determined the priorities for production and hence the objectives to be considered when choosing a new control system. The Rainham plant had been one of A & W's most profitable operations, owing to the specialised markets for its products and a lack of competition. Its process utilised phosphorus oxychloride for which the only UK source was A & W's Oldbury works and thus the Rainham business benefitted from A & W's historic monopoly position in phosphorus chemicals. However, in the late 1970s, Rainham began to encounter problems of increased competition and rising costs, in a generally stagnant market. In these conditions, the existing performance of the plant became inadequate, both in terms of its unit costs and the reliability of product quality.

In order to respond to competition, it was necessary to reduce costs, which at first was achieved by enlarging the plant to gain economies of scale. However, by 1977 the space for expansion had reached its limits, while a new plant was not an attractive option on cost grounds. Attention therefore turned to possible ways of increasing its throughput, by eliminating the lost capacity resulting from inadequate process control. The plant chemical engineer examined the causes of lost capacity[10] and found them to include: slow startup, so that full-rate working took several hours to be regained after any stoppage, losses during product changeovers, and downtime resulting from control failures affecting the pump for coolant. All these control problems led to a loss of capacity which was estimated at 5%,[11] although in the light of the improvements later achieved with new controls, this seems to have been a modest estimate.

A more important consequence of poor control was unreliable quality of the product. Loss of control over either the reactor or the washing plant was liable to result in a product of high acidity, that needed to be reworked. Also, the slow changeover to a new composition of product resulted in some intermediate quality product.[12] In an increasingly competitive market it was essential to offer a reliable quality of product from the plant.

To achieve the objectives of improved quality, increased throughput and reduced unit costs, a control system was needed which could overcome the weaknesses of the existing system of pneumatic controllers. This had been an advanced system in 1958, since it promised a degree of automaticity, from discrete local controllers, each able to automatically control one loop, and used the advanced feature of "three term" control. However, the technology of pneumatics proved too unreliable for this task. By 1978, none of the controllers was using three term control and many of them were missing, not functioning or operating only as indicators. The cause of this "deinstrumentation" was the high maintenance requirements of pneumatic equipment. Pneumatic bellows and pipes were liable to freeze and block or leak, mechanical linkages to bend, break and corrode. Repair was difficult because of the range of sizes and ages of the controllers and the difficulty of obtaining spare parts, since manufacturers were beginning to discontinue pneumatic controllers. Besides these costs and difficulties associated with the unreliability of pneumatic devices, the skilled nature of maintenance work presented further problems. The work of the instrument mechanics was, for management,[13] characterised by low labour productivity, and was difficult to supervise and expensive to train. From the point of view of the maintenance department,these problems appeared to be the result of inadequate commitment,by management,to fund training and provide rewards needed to retain skilled staff for instrument maintenance.[14] Probably the neglect of the maintenance function was an outcome of an earlier decision by management to choose new electronic equipment for the future instrumentation of the plant, so it is probable that deinstrumentation was both a cause and a consequence of management disenchantment with pneumatic equipment. The result was that,by the late 1970s,the pneumatic controllers had suffered an irreversible decline in operational effectiveness.

The result of this poor state of the control equipment was that control had largely reverted to manual techniques. In 1978, the controller for feed to the reactor, the most crucial stage in the process,became unusable and control was by use of a manual cock. The control strategy for the plant had come to be entirely based upon empirical knowledge and the experience of supervisors and charge-hands, who understood how changes at one point in the plant would affect its downstream behaviour. Regular and somewhat labour-intensive sampling of the reactor, the product and by-product was the full-time task of one operator, to check the actual composition at these points.

Control based on the skill and experience of operating teams, gave more flexibility than the pneumatic controllers and so was preferable, although it was not very amenable to management supervision. The objectives of management were to achieve optimum performance by constant adjustments to the process, whereas supervisors tended to aim for an equilibrium in the plant, which gave less-than-optimum performance but was safe and required few adjustments.[15] For this reason, management at the plant hoped to install control equipment which had a higher degree of automaticity and so would be able to achieve a better performance, while requiring less intervention from operators and supervisors.

Given these somewhat varied technical and social objectives, management at the plant considered three broad possible options:[16] to renew the pneumatic controllers with more modern equivalents; to adopt discrete electronic controllers; or to centralise control functions in a single, multi-loop, electronic controller, based on a microprocessor. These three possibilities are represented diagrammatically in Figure 27 .

To renew the pneumatic controllers would have entailed

re-expanding the maintenance department, which had been reduced in numbers over several years, as the de-instrumentation process had proceeded. That this rundown had been allowed, suggests that management decided, several years prior to 1978, that the pneumatic system would not be renewed. In fact, a local electronic temperature controller had been introduced, experimentally, on the reactor in 1976, to test its reliability and acceptability to operating and maintenance staff. Having trained as a television engineer, the plant manager was well aware[17] of the reduced maintenance requirements of integrated circuitry, which cannot be repaired by mechnical skills but must be replaced and is constructed in a modular manner to facilitate this. Deskilling of the maintenance function and preventing unauthorised adjustments to controllers by the operators were the two major reasons for the decision to discard pneumatic equipment and explore the possibilities of electronic controllers.[18]

The second choice to be made, having realised the advantages of electronics, was between individual electronic controllers and a single multi-loop controller. The logic of minimising maintenance problems suggested a central controller, in which electronic circuitry was centralised into a single, compact device, composed of miniturised, integrated circuits which would be inaccessible to the plant's maintenance staff. This option avoided any need to replace the mechanical skills that would be lost through the disappearance of the pneumatic controllers, by electrical repair skills.

Management also carefully considered its control objectives on the plant, when choosing the new equipment. Renewed pneumatic controllers "would not significantly improve the control or the reliability of the process and would not provide any increase in output."[19] Electronic controllers would have given more accurate control, being digital rather than analog, but would not provide flexibility, since each would have been preprogrammed to control each loop in a fixed manner. Once all control was centralised in a multi-loop controller, however, management realised that whole routines such as start-ups and batch changes could be automated. If the plant could be run by a controller that was programmed by plant management, they could see the possibility of "regaining a more direct and more scientific control over the whole process."[20] Just as this technology could remove much of the dependance of management upon maintenance staff, so also it could reduce the role of operators in determining the operating strategy of the plant.

These considerations led management at the Rainham phosphates plant to explore various options for centralised, programmable, electronic control. The eventual choice was the "Diogenes" controller, manufactured by the Rosemount Company of the USA. The reasons for this choice are interesting, since they related more to the social organisation and control of production than to the technical goals of optimising plant performance. Indeed, when Rainham's proposal for funding for the Diogenes was put to the company,[21] it was suggested that a more highly powered "real computer", capable of fully automating control and optimising overall performance of the plant, should be considered instead,[22] but Rainham management preferred their less sophisticated choice. Diogenes[23] used packages of fixed, standardised software,which could be configured by positioning pegs in a panel that linked certain functions to certain channels. This panel provided a visual map of the control strategy in use and allowed the plant management,without needing programming skills,to have immediate control over the plant's operation. On the other hand, this board could be made inaccessible to the operators,who could make only minor changes via the operator's panel. The plant manager[24] found this separation of decision-making and the reduced role of the operators,to compensate for any benefits lost through not using a more sophisticated computer system,which would have required new skills and not matched existing relations of authority on the plant.

Changes to the Organisation of Work on the Plant.

Diogenes was installed in early 1979 and by 1981 it was possible to identify the changes which had resulted from its introduction and to assess whether the benefits expected by management had,in fact,been realised. Broadly, the level of skill and knowledge required of the operators and maintenance staff was reduced,compared with the pre-Diogenes plant, while the degree of control excercised by management had increased.

The disappearance of the pneumatic controllers removed much of the work of maintenance workers. Two years after their removal,the mechanical skills associated with pneumatic equipment had declined among the instrument mechanics,to the point that the engineering supervisor felt a return to pneumatic equipment would be impossible.[25] New recruits no longer learned the previous skills and replacement of faulty electronic parts had taken the place of the previous activity of the workshop, which had repaired, and even made, parts for pneumatic controllers. The need for maintenance labour was reduced and the number of instrument mechanics was allowed to decline by natural wastage, from five in 1978 to three by 1979.

A similar reduction in the contribution of the plant operators took place, as revealed by comparing their tasks on the pre-Diogenes plant with the abilities of the new control system and the tasks which it left for operators after its installation.[26] Owing to the gradual disintegration of the pneumatic controllers, the plant had been working almost entirely by manual operation prior to Diogenes. The shift team as a whole needed to be aware of the status of the plant by monitoring it at various points, to act to control flows, pressures and temperatures at correct levels and to make such adjustments as were needed for start-ups, shutdowns, batch changes or a satisfactory rate of normal, equilibrium operation, producing the correct quality of product. This overall task was subdivided between the various operators but co-operation and communication remained very important at all times.

One part of the control task was to directly adjust key actuators on the plant. The most crucial direct control task was control of the reactor and this was the main responsibility of the chargehand, who set and maintained the feeds of phenol and oxychloride, at an appropriate speed and ratioed them to determine the composition of the product. Automatic, accurate ratioing of these feeds was a prime objective of management's installation of Diogenes. Once the appropriate ratio had been keyed in as a set point, Diogenes could automatically maintain this ratio and simultaneously the level of "scrubber" and flows of catalyst and recycled phenols. These functions could not then be changed by operators, since the channels were isolated from the operators' panel, by a key switch.[27]

A similar automation of control occured on other parts of the plant, with operators restricted merely to introducing set points. Diogenes allowed management to restrict the operators' input, by locking the set points in selected channels or by restricting the possible relationships between functions, using channel interlocks, or by automatically deriving one channel's set point from the status of other channels.[28] Sound safety reasons existed for some of these restrictions but the overall effect was to greatly increase the extent to which plant operation was fixed by management and to reduce the role of operators. At first, operators thought that constant adjustments, via the operators' panel, were necessary but slowly they discovered that, during normal running, Diogenes could operate the plant almost entirely without their intervention. Management at first tended to stress the need to confirm that actuators on the plant were in fact implementing the instructions from Diogenes, but gradually the reliability of the control system was proved and the plant manager observed that two years after Diogenes' installation operators had "far more time than they used to have."[29] Even during start-ups and shutdowns, which previously had demanded most activity from the operators, Diogenes enabled these routines to be accomplished by issuing commands from a centralised position, via the operators' panel.

Not only was the absolute level of activity required from the operators substantially reduced, but so too was the degree of knowledge and understanding of the plant required of them. Before Diogenes, the training of an operator consisted largely in gaining an appreciation of the plant's behaviour, the significance of changes in pressure, temperature or colour of the materials at various points and an ability to compare this actual status with a conceptual model of the ideal, equilibrium operation of the plant. After 1979, however, the relevant model of plant operation was that which had been configured into Diogenes by management and remained "a closed book as far as the operators are concerned."[30] Diogenes generated numbers, with which operators compared other numbers, so that, according to the plant manager, they "no longer need to worry about what should be happening, only whether it is happening."[31] Therefore, new operators have not needed to acquire a full understanding of plant operation but only how to interact with Diogenes. This has effectively changed the relationship between management and operators, so that management is not longer as dependant on operator skill and attentiveness as previously, thus operators can be replaced more easily, since long experience of controlling the plant is no longer as important. These changes to the role of operators have resulted from a conscious pursuit of management's objectives at the plant and from the design of Diogenes, which enables the overall control task to be divided and allocated between operator and management inputs, in a manner decided by management.

This important dimension of power and authority on the plant, as it affected the use of the new control technology, is well illustrated by the changes to the role of the shift supervisors between 1978 and 1981. They combined the technical function of organising operators and plant to achieve production goals, with their position as a representative of management authority - the only representative during the night shifts. Their position rested on long experience of the process and they were all men in their fifties or sixties who had been promoted from operator grade, through chargehand, to supervisor. Supervisors represented the traditional approach to plant control and they had built up their own strategies for its operation over many years. Their objective was to achieve and keep a satisfactory equilibrium in the plant, as one of them expressed it "once this plant is running well, the less you do to it the better."[32] This approach clearly conflicted to some extent with management's desire to increase the throughput of the plant, which implied making sufficient adjustments to maximise the speed of operation, compatible with safety. Management tended to feel that supervisors were interested largely in "an easy life," for example they tended to slow down production towards the end of a shift, in order to leave the work of starting a new batch to the following shift. Supervisors, on the other hand, tended to resent management's "interference."[33]

Diogenes enabled management to take a decisive step towards gaining direct control over plant operation and ensuring the predominance of their objective of faster production. The new

Channel/Function Matrix board enabled the plant manager and engineer to permanently configure the operating strategy of the plant. This was done in a few days in early 1979, and thereafter only they had access to this matrix board. Although, for the time being, the speed of operation could be adjusted by the supervisors, management felt hopeful that Diogenes might in the future be programmed to run the plant at its maximum speed, continuously, automatically and safely, so that the plant might be self-maximising as well as self-optimising in its operation.[34] In 1981, Diogenes had already displaced, to an important extent, the role of supervisors as the planners of operating strategy and the appointment of two graduate supervisors from other plants in 1978 indicated that supervisors future role would be to organise production, unequivocally according to management's objectives and around the capabilities of the electronic controller, without the old reliance on tradition and experience.

The second function of supervisors, to be representatives of management's control over the operators' behaviour, was also displaced to a substantial degree by Diogenes. Previously, they had excercised an important leadership function, acting to gain "motivation" from their shift team, but Diogenes, by reducing the need for operator attentiveness and initiative, made the supervisors' role less necessary. Diogenes collected and displayed information in easily-understood bar charts and sounded alarms at excess deviations from set values, it automated some functions and limited others by interlocks, thus acting to a degree as an automatic supervisor of the operators' work. In addition Diogenes provided automatic logging and printouts of all changes to the plant and this gave managment a direct record of events during the night shifts, instead of relying on the verbal and written reports of supervisors. This was a very attractive feature of the system for management,[35] giving them an exact, impartial means of monitoring both the plant's operation and the work of operators and supervisors. These changes made intensive human supervision less necessary, since management's control of work was to a considerable extent built into the new plant control system and as a result the number of supervisors was reduced, by merging the previously separate supervision of operators, mechanics and ancilliary workers.

Changes to the Costs and Efficiency of the Process.

Within a few months of its installation, the new control system on the Rainham phosphates plant had more than fulfilled its promise of improvements to plant performance. The original primary justification for Diogenes had been the need to improve the reliability of the quality of product, through more precise control.[36] A satisfactory degree of control over quality was achieved using Diogenes, allowing aryl phosphates to be produced which were competitive with both the other producer in Britain and with importers. Because the changeover of batches, shutdown and start-up could be accomplished much more rapidly, the problem of intermediate quality product was virtually eliminated, as were the former causes of acid product.

The actual increase in capacity proved to be much larger than the 5% which had been predicted and was estimated, by the ex-Rainham chemical engineer involved in the project, as an additional 20%.[37] Evidence for such an increase is provided by the output of the plant during the first half of 1980, (see Figure 28) which, if it had continued at such a rate for the second half, would have produced approximately 20% more product than the previous best year (1979). Partly, this increased capacity came from rapid startups and shutdowns, so that the plant was able to work a very high proportion of the time at full rate but also it was found that Diogenes allowed the plant to be run at a faster speed than before, during normal running.

The increase in capacity should have resulted in lower unit costs through scale economies, but before these could become apparent, the market plunged into recession in mid-1980, causing the plant to be shut for two six-week periods (Figure 28). These shutdowns were useful for maintenance purposes and cleaning and painting the plant but it became clear that its increased capacity and the recession in sales had created a more permanent state of overcapacity. 1981 began with the plant working for three weeks in each four. The plant manager estimated that, due to Diogenes, the plant could now produce in three weeks what it had produced in four but that the market was $\frac{2}{3}$ of its pre-1980 size.[38] In the second half of 1981, output was 80% of output in the same period of previous years, although the plant was shut for 50% of those last 6 months of 1981. This experience caused the plant manager to estimate the potential maximum output of

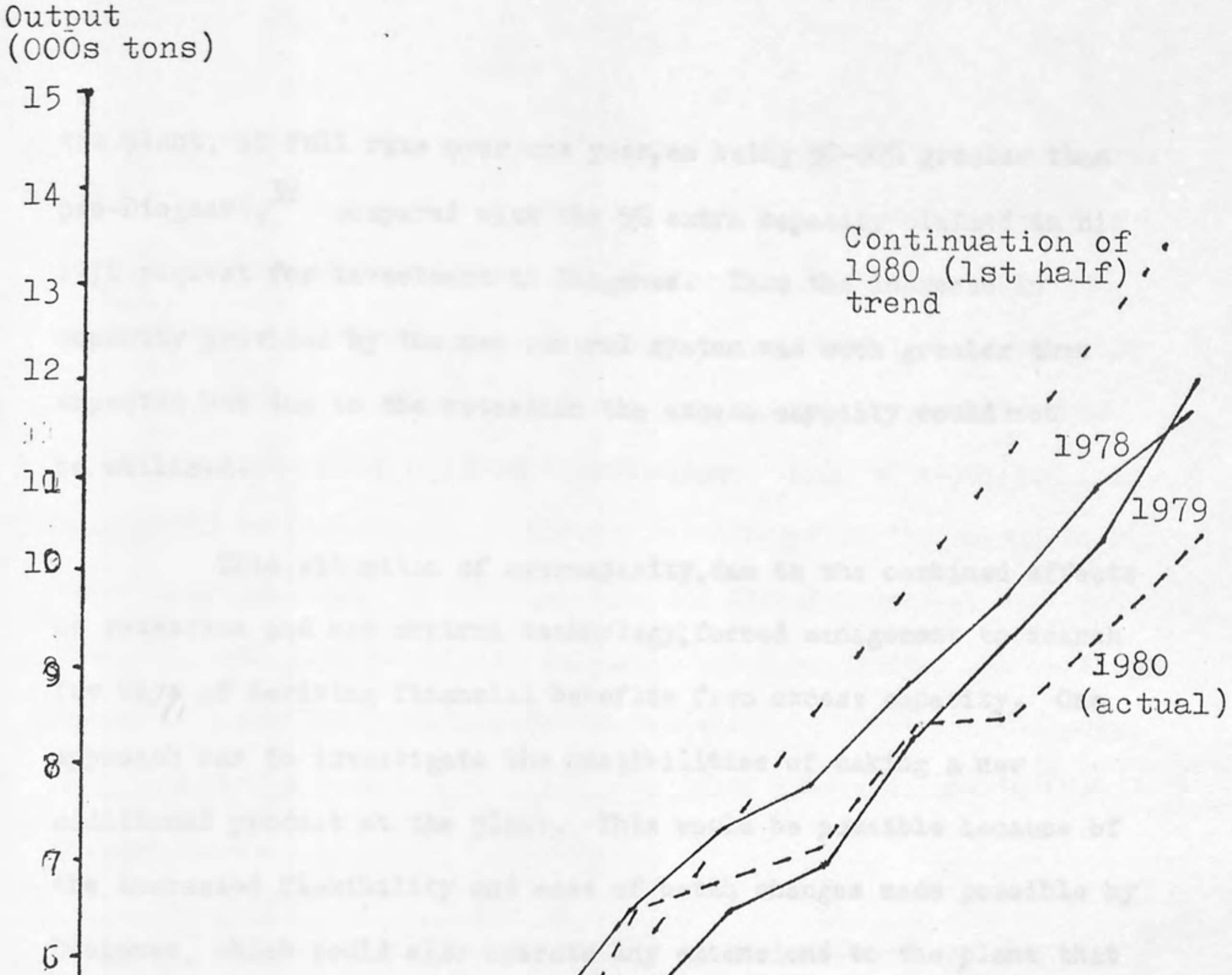


Fig. 28. Output of the Rainham phosphates plant (1978-80).
Source: Plant management data.

the plant, at full rate over one year, as being 50-60% greater than pre-Diogenes,[39] compared with the 5% extra capacity claimed in his 1978 request for investment in Diogenes. Thus the increase in capacity provided by the new control system was much greater than expected but due to the recession the excess capacity could not be utilised.

This situation of overcapacity, due to the combined effects of recession and new control technology, forced management to search for ways of deriving financial benefits from excess capacity. One approach was to investigate the possibilities of making a new additional product at the plant. This would be possible because of the increased flexibility and ease of batch changes made possible by Diogenes, which could also operate any extensions to the plant that would be required. The immediate savings from the excess capacity, however, came from part-time working, which allowed large savings in plant overheads, energy and labour costs, while producing any required output.

The original proposal for Diogenes did not include savings in costs from labour displaced by the new controls, but as outlined above, the requirements for operators and maintenance staff was found in practice to be substantially reduced. A few months after installation, it became apparent that the plant was over-manned. The fifth operator on every shift, who was in reserve to help with start-ups and shutdowns, was no longer needed and was made redundant in 1979 - a 20% reduction in operator numbers. With the depening recession in 1980, part-time working at the plant made one whole shift redundant, together with one supervisor. The monthly shutdown allowed much more time for maintenance work on the plant and that allowed a reduction in the numbers of the engineering department. Since the part-time working was made necessary by an excess capacity that was the result of approximately equal contributions from decreased sales and from the increased capacity provided by Diogenes, half of these redundancies could be regarded as indirectly resulting from the change in control technology. In practice, the two effects, recessionary and technological displacement of labour, occured together. The recession acted to inhibit any resistance which might have prevented the gains in productivity, from Diogenes, being realised as reductions in the labour force.

The potential for automating control, offered by Diogenes, was far from exhausted in 1981. It was able to control many more loops than were being utilised, so plant management retained much scope for further extensions of the system. The possibility of producing an additional product has been mentioned. If an appropriate sensor to measure product acidity could be found, one additional operator on each shift would become spare and these spare operators could be reformed into a new shift, if full-time working is again resumed. The potential 50-60% increase in output previously mentioned would then have required no increase in operating labout. Diogenes could also extend its control beyond the phosphates plant, to automate the effluent plant and storage tanks, perhaps also the neighbouring plant of A & W's subsidiary Bush, Boake, Allen Ltd. Future additions and extensions to the site will probably be accomplished using static or reduced numbers of operators, as the 50 spare control loops in Diogenes are utilised.

The other direction for extending the Diogenes system would be to link it to a new supervisory computer on the site, which could truly automate the operation of the plant. A single cable link would allow a new computer to "do anything to any channel that an operator can do through the Operators' Panel"[40] of the existing Diogenes. A supervisory computer would develop a strategy for overall optimisation of plant performance that would remove the supervisors' control over its speed of operation and obviate the need for operators to input set point values.

This option was enthusiastically recommended by Tenneco's OTD[41] but the Rainham plant manager remained cautious. Diogenes had required no new expertise in management and no new skills in the operators, but a fully computer-controlled plant might be imcompatible with the existing workforce. This expectation would seem to be supported by comparison with Tenneco's computer-controlled PVC plant at Pasadena, which was described in Chapter 5. Whereas at Rainham the operators had minimal educational qualifications and were regarded as unskilled workers, at Pasadena all were high school graduates and were only allowed to interact with the computer after a period of training in its operation.[42] Most work with the computer was done by young graduate supervisors who were very different from the middle-aged and traditionally-minded supervisors at Rainham. By 1981, Rainham phosphates plant had neither a trained chemical engineer, nor instrument engineer. The ex-Rainham chemical engineer doubted whether the Diogenes system would be fully utilised, even without supervisory control by a new computer.[43]

Conclusions.

This Chapter began by asking why the Rainham plant was the only A & W plant, before the Tenneco takeover, to propose and receive company approval for a microprocessor-based control system. The answer has been found to lie in the relative isolation of the plant from A & W management and engineering organisation and from their traditions of conservatism towards process control which were identified in Chapter 6. Pursuing their objectives for improved control, the Rainham management were led towards electronic, digital, centralised, programmable control. Their control objectives were essentially to seek an improvement to product quality and an increase to the capacity of the plant, but it became apparent to them that a new control system would also be relevant to their problems of inadequate management control over the work of operators, supervisors and maintenance workers. Diogenes offered a direct, programmable control over the plant by management and tended to deskill the workforce.

Diogenes allowed all the benefits which had been anticipated from an improved control system to be achieved. Improved control had important benefits, from improved reliability of the quality of product and unexpected increases to the capacity of the plant, through greater speed of operation. A major reduction in the necessary contribution of operators resulted from Diogenes and this led to unexpected opportunities, provided in part by the recession, for achieving actual savings in labour costs and a permanent change in the productivity of labour on the plant.

The benefits which derived from the new control system at Rainham helped to encourage a new enthusiasm for microprocessor-based controls, which spread through the company after 1980. It is, therefore, important to consider the consequences of this first example of the adoption of such technology, since it was soon to be imitated at other plants. The unexpectedly large increase in capacity that resulted at Rainham, from the improved control by Diogenes, was a doubtful benefit in the recession. Investment in new controls would not be approved for other plants with an objective of creating excess capacity. However, the increase in competitiveness resulting from the improvement to Rainham's product quality was a highly desirable result, which it would be important to achieve also on other A & W plants and the savings in labour of different kinds had positive implications for cost reduction, wherever such control systems were to be introduced. Anxiety expressed within corporate management that the Rainham experience might provoke trade union resistance elsewhere,[44] has not generally proved well-founded, since the severity of the recession has weakened the trade unions in A & W, as in British industry generally, and caused them to welcome rather than to resist new investments that enhance the competitiveness of A & W plants.

The Rainham experience has, therefore, tended to re-inforce the company's view that investment in new control technology has a vital role in solving technical and labour problems in plant operation and greatly improving the cost structure of production and the competitiveness of A & W's products. The appointment of the Rainham chemical engineer as Senior Process Control Engineer for the company, showed its desire to repeat the Rainham experiment elsewhere, with similar results.

This study of A & W's first plant to be controlled by a microprocessor-based system, ends the case study of A & W which occupies Chapters 4 - 7 of this thesis. At the time of writing, it represents the farthest point reached by the company in its policy of adoption of new control technology. The findings of the whole project and its implications for the study of new microprocessor technology in industry and of technical change generally, will be the subject of the concluding Chapter which follows.

CHAPTER EIGHT

Conclusions.

This Chapter has two functions; to summarise the empirical findings of the thesis and to discuss their significance for the general problems of studying technical change in industry, which were identified in the Introduction to the thesis. Firstly, a recapitulation of the conclusions of Chapters 2 - 7 will be given, to provide both an analysis of the diffusion of microprocessor-based control systems in the chemical industry and a summary of the case study in adoption of this technology at Albright & Wilson Ltd. Secondly, this Chapter will consider the implications of these empirical findings for the study of diffusion and adoption of process innovations, with particular reference to an understanding of the significance of microprocessor-based technologies for change in British industry.

The Introduction identified a need to re-examine computer control of chemical plants, in the light of the change in technology associated with microprocessors and the change in the economics of chemical production which took place during the 1970s. Part One offered an explanation of the diffusion of the new control technology, as a response to new production needs which have been imposed by the transition from economic expansion to recession. The process control computers of the 1960s and 1970s were limited in their diffusion, within the chemical industry, by their high costs, which made them economic only on large plants. It was a technology applicable to the new complexity of the control task on large plants, which resulted from the competitive pursuit of scale economies during the period of rapid growth in markets for chemical products.

Microprocessor-based control equipment, by contrast, is applicable to almost all control tasks and all kinds of process and sizes of plant. It allows the precision, sophistication and programmability of computer control to be applied to raising the efficiency of chemical plants generally and so counteract the effects of recession, by reducing unit costs through raising the productivity of plant and labour. These benefits are obtainable at a cost much below those of previous control computers and unlike them, the new technology is compatible with existing skills on chemical plants.

The combination of a general need for increased efficiency of operation of chemical plants, with the suitability of microprocessor-based systems to provide such improvements, is the qualitative basis of a very rapid quantitative increase in the number of process control computer devices, which are being applied to an expanding range of processes and control tasks. The diffusion of this technology can, therefore, be understood in terms of industry-level conditions but its actual pattern will be determined by the response of individual chemical companies to the new economic and technical demands. In order to understand the nature and timing of this response, it is necessary to examine the behaviour of individual firms and the determinants of company-level control technology policies, which result in early or late adoption or non-adoption of microprocessor-based control systems.

Chapters 4 - 6 of this thesis have provided analyses of two contrasting companies, with very different policies and performance with regard to the adoption of computer controls on process plants. Albright & Wilson Ltd. had no computer controlled plants in 1978, no experience of computer control and a long-established commitment to pneumatic control equipment which was incompatible with advanced electronic controls. By contrast, Tenneco Inc. had almost ten years of experience with computer control of processes, had installed such control on batch as well as continuous operation and was conducting a planned diffusion of automated control equipment, in both the processing and discrete manufacturing operations of its companies.

These very different company policies and achievements have to be explained in terms of the different nature, context and history of the two firms. Albright & Wilson originated in the British industrial revolution of the early 19th century and had gradually accumulated various anachronistic features since then, as technology and industrial organisation had changed more rapidly than A & W could adapt. Most important of these inherited structural weaknesses were its location of production, relative to the location of cheap energy sources and its small size in an area of production requiring very large capital investments in large scale plant and resources, to manage successfully the changes in technology needed for continued competitiveness. Tenneco's success in exploiting new control technologies must be seen as the outcome of its strengths in these same areas. It benefitted from a location within the US economy, the centre of post-1945 economic growth. Oil and natural gas production gave it a cheap and readily available source of cheap energy and a source of surplus capital, which it had used to grow into a giant conglomerate with financial resources many times greater than that of A & W. Its active posture in technology reflected its generally expansionary nature as an enterprise, whereas A & W's conservatism in control technology was part of a generally cautious and defensive tradition.

The context and history of these two firms can, to a large extent, explain the differences in their internal organisation which affected their success in exploiting new control technologies. Albright & Wilson's undercapitalisation led to inadequate investment in modernising its plants, especially during the 1970s, a key decade for progress in process control, when A & W had to concentrate its financial resources into one large project at Longharbour. Tenneco on the other hand, could plan on an assumption of large capital resources and was therefore able to undertake long-term programmes of investment in new technology, to raise the profitability of its companies, even where losses had to be tolerated for a considerable transitional period, for example in its shipbuilding business.

The sige of Tenneco also gave it vital advantages in the key area of the expertise needed for planning and implementing computer automation projects. Many companies, operating across various industries, were able to make use of a small group of experts in automation technology. A & W could not support such a team and its reluctance to recruit new engineering talent left it with an increasingly obsolete commitment to pneumatic controls, which tended to inhibit investigation of the potential benefits of advanced electronic systems. The British company's small size and confinement to one area of production was another vital limitation, since it lacked large-scale continuous processes on which experience with the computers of the 1960s and 1970s might have been gained. Tenneco, however, gained such experience on its gas transmission operations and then transferred its competence to projects for computer control of batch chemical production and the automation of its manufacturing operations. This inter-industry diffusion also allowed Tenneco to manage relatively easily the transition from large computers to microprocessor-based systems, whereas A & W had a larger technical gap to bridge from pneumatic equipment to microprocessor technology.

Different competence in control technology had important consequences for the two companies. Failure to control its major investment at Longharbour was crucial to A & W's general commercial failure, loss of profitability and loss of financial and managerial independance. Its "rescue" by Tenneco may yet lead to widespread rationalisation of its operations, entailing the closure of many plants and substantial redundancies. For Tenneco, with its policies, organisation and expertise aimed at wide-scale application of micro-processor-based automation in its companies, new technology represents an opportunity rather than a threat, by which it may restructure the costs of production to raise productivity, save energy and combat the effects of recession by continued growth and competitiveness.

After its takeover of A & W in 1978, Tenneco used its new control over company policy-making to impose the adoption of computer control, or electronic devices compatible with computer control, upon its new subsidiary. Through its Operations Technologies Department, Tenneco performed an educational role in A & W, by acting to transfer knowledge of Tenneco's own experience and of new control automation equipment available in the US, to A & W production and engineering staff. Fear generated by Tenneco's drastic re-structuring of A & W's businesses and management helped to overcome previous conservatism towards new technology within the company. Tenneco's impatience with progress in this area then led to the imposition of an explicit new policy in A & W from 1980, that compelled abandoning of pneumatic controls and rapid introduction of digital electronics for plant control. Re-equiping with computer automation was introduced as an externally-managed change, closely associated with rationalisation of production and administration, and shedding of labour by redundancies.

The examples of computer controlled plants, both implemented and proposed, which have been examined in the thesis, allow various observations to be made of the costs and benefits obtained from advanced control systems, which are apparent at plant level. Whereas previously, the high initial cost of computers had made them inapplicable to small or medium plants, especially batch plants, such as those forming a majority of A & W plant, by the late 1970s microelectronic technology had reduced the costs of such control equipment to a small consideration relative to other capital costs. This was particularly true where new controls allowed an existing plant to substitute for a new plant, for example with the Oldbury thermal acid plant. The cost of new controls was also less significant since they were often substituting for existing pneumatic equipment which had become inoperable and would have been expensive to replace. Piecemeal introduction of electronic control systems was beginning to convert A & W plants to a computer-compatible control configuration, even where the cost of full computer control could not be justified. The experience at Rainham phosphates plant was that microprocessor-based equipment could allow advanced control without making significant new demands on the skills of management and operating staff, while effecting a cost reduction in the maintenance function. A significant constraint, however, was the specialised expertise needed to select and design new control applications. This was an important element in Rainham's status as A & W's first plant with advanced electronic controls and its absence has acted to delay their more rapid diffusion in the company.

When the benefits from new control systems are considered, it is clear that enhanced technical efficiency was not the only goal. Increased automation of control was found to be important as a means of increasing management's direct control over the plant and the workforce. At Rainham, considerations of management authority and power to realise its objectives were important in both the decision to adopt an electronic, programmable controller and the design which was chosen.

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Product quality was seen as an important element in competitiveness during recession and precision and reliability of operation were significant benefits sought from advanced controls at A & W. They also promised to improve the performance of existing plants, with the result of increasing capacity by faster average running speed. The Rainham example showed that this could be achieved simultaneously with reduced operating and maintenance labour, so lowering unit costs substantially.

Tenneco has been able to invest much beyond the level which A & W's own earnings as an independent company would have allowed but the low profitability of the UK operations resulted in reductions to their programme of investment. In these conditions, a convincing case needed to be made for each automation proposal, in terms of a return from reductions in energy or labour, or improvements to product quality or safety of operation. The recession has therefore, acted to delay the diffusion of computer control systems in A & W but a steady process of piecemeal introduction of micro-electronic instruments and controllers was visible by 1981. Once plants have been converted to digital electronics, they will be compatible with computer control, if it becomes economically attractive. Between 1978 and 1981, therefore, A & W moved irreversibly towards a transition to digital electronic controls from pneumatic equipment and into a new era in process control technology.

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In the Introduction it was argued that studies of the diffusion of process innovations need to be complemented by case studies of the adoption of the technology by individual firms. This thesis has provided such a detailed study, relating it to the general factors which are encouraging and inhibiting the diffusion of microprocessor-based technologies in chemical process control applications. By this linking of a study of industry-level factors to a study of policy-making and implementation at the level of the firm, an exploration of the behaviour of two different firms has been possible. Only against the background of general economic and technical change, which was given in Part One, is it possible to separate the features of Tenneco and A & W that resulted in such different attitudes and accomplishments in process control. It is suggested that the development of a conceptual framework, able to integrate industry-level diffusion studies with studies of the adoption of new technology at firm or plant level, is a fruitful direction for future work in the study of technical change in industry.

There has been much discussion of the relationship between the economic recession and its effects and the new wave of micro-electronic technology, especially as applied to the automation of production. This discussion needs to be informed by specific, empirical studies of this interaction of recession and new technology, as it is occurring in British industry in the late 1970s and early 1980s. It is therefore interesting to record the effects of recession in encouraging or inhibiting adoption of new control technology, which have been observed in the present work. These examples have been at least suggestive of more general connections between economic conditions and process innovations.

The new control technology in the chemical industry can act to counter the effects of recession in a number of ways. It is input-saving, since more precise control allows for savings in energy and labour, therefore by reducing unit costs it can enable firms to sell more product even in depressed markets. By increasing the quality and range of products, it allows new markets to be developed for chemical products and, of course, enables more efficient firms to take the markets of less efficient producers. The enhanced competitiveness of firms which can exploit the new control technology, can encourage a concentration of production within the static markets, as overcapacity in the chemical industry is rationalised, through the closure of the less cost-efficient plants.

These benefits are obtainable from a technology which has other substantial advantages over previous control equipment. It has a low cost to purchase and maintain and can be fitted to existing plant in a piecemeal fashion, if necessary, so its demands upon scarce capital are not prohibitive, even in recession. Its tendency is to be inherently labour-displacing, both in the operation of plants and in their maintenance requirements. More subtly, it advances the automation and programmability of control and so reduces management's need to obtain co-operation and motivation from operators, whose contribution to safety, quality and output can be made less crucial.

On the other hand, the recession does act to delay the diffusion of new control technology in the chemical industry. The investment required, although modest compared to other capital costs, may be beyond the resources of companies which are suffering reduced profitability or even losses, in the recessionary environment. Lack of markets for chemical products means that many plants are working below existing capacity, therefore the benefits of increased output, usually obtainable from computer control, will not contribute to the rate of return from new applications during a recession. Finally, a constraint on more rapid diffusion has been the scarcity of expertise in applying new control technology. Despite efforts to simplify the use of microcomputers and similar systems and to provide contract expertise in applying and maintaining systems, by their manufacturers, the high cost of expertise has acted as a deterrent to firms which are reducing, rather than expanding, their staff numbers.

The thesis has dwelt at some length on the problem of conservatism and dynamism in companies, with regard to new process technology. In this context, the importance of changing sources of energy, geographical factors and stages in the scale and organisation of industrial capital have emerged as crucial to any exploration of the contemporary situation of the firms that have been studied. By putting individual firms into such a context, it is possible to relate their present performance to more general ideas about the progress of industrialisation. To the extent that A & W is typical of long-established British firms, it may exemplify the problems encountered by British industry in adopting new production technologies. The suggestion is that historical and geographical factors should be considered, when seeking for significant differences between successful and less successful adopters and when predicting the likely relative performance of British firms in implementing technical change.

The experiences of A & W and Tenneco have also focussed attention, in this thesis, upon the consequences of adoption and of failure to adopt new control technology. The conventional model of diffusion sees most potential adopters deferring a decision to adopt until the technology is quite proven, but in a situation of recession and strong competition, firms which delay adoption of a technology with a strong competitive advantage, may face total failure and the choice of A & W, between takeover and extinction. The role of company failures in increasing the proportion of potential adoptors using the new technology, should, perhaps, be a subject for further study. On the other hand, the thesis suggests an intimate connection between competence in managing the adoption of new technology and success in growth and accumulation, which could also be a focus for studies of technical change at the level of individual companies.

Finally, the study of the relationship of Tenneco and A & W has provided an example of one method whereby adoption can take place. Conventional diffusion theory has imagined adoption as being the result of an imitation of early adopters by other firms, who see the advantages obtained by the pioneers. Another possible process, however, is the planned transfer of technology, imposed through a takeover of a non-adopting firm. The case of A & W and Tenneco cannot easily be categorised as either intra or inter-firm diffusion, since the transfer took place within the Tenneco corporation. Tenneco acted as an agency for a conscious diffusion of computer control, from the US to its foreign subsidiaries, partially overcoming the gap in knowledge and practice of control technologies, existing between Britain and America. It would be of considerable interest to explore how widespread is this role of multi-national companies in stimulating the diffusion of new technology. The conventional model of diffusion, by imitation among a large number of independent firms, may need to be expanded to include trans-national, trans-industrial transfers of technology within the large corporations. Certainly, from a British perspective, the experience of A & W and Tenneco emphasises a need to abandon any view of Britain as an independent industrial economy. The role of foreign capital and management in implementing the adoption of new technology, where British management has failed to modernise its production facilities deserves further study. The implications for technology policy, whether by governments or firms, of this activity of multi-national companies in planning technical change, are likely to be far reaching.

N O T E S

A N D

R E F E R E N C E S.

P R E F A C E

1. MacTaggart, K. Technical Innovation in Industrial Production (Ph. D. thesis, University of Aston, Birmingham, 1981 - restricted until 1983.)
   and
   Zermeno-Gonzalez, R. The Development and Diffusion of Industrial Robots, vols 1 & 2, (Ph. D. thesis, University of Aston, Birmingham, 1980.)

2. A study of automated production facilities at British Leyland was begun simultaneously with this project and the findings appear in Scarbrough, H. The Control of Technological Change in the Motor Industry : A Case Study, (Ph. D. thesis, University of Aston, Birmingham, May, 1982.)

   A number of case studies, mainly in the West Midlands engineering industry were undertaken also at this time, see Wilkinson, B. Technical Change and Work Organisation, (Ph. D. thesis, University of Aston, Birmingham, 1981.)

CHAPTER ONE

Notes and References.

1. Some technical clarification is needed here. One form of microelectronic circuitry is the microprocessor, which is programmable and processes information. It can be used as the central element in an automatic controller which can respond to signals from one part of a plant with commands, so as to regulate the operation of valves, motors etc. A microprocessor can also be used as the central processor unit in a "microcomputer," which has memory storage and an operator interface, usually a screen and keyboard. A microcomputer, or several linked together (a "distributed" control system) will be able to control the operation of the whole plant according to a pre-specified operating strategy. In this thesis, the term "microprocessor controls" is used to refer to all microprocessor-centred control elements, both those introduced piecemeal onto parts of a plant and those used as complete plant control automation systems. Chapter Three elaborates on the characteristics of this technology.

2. This literature is very large and most of it rather weak, especially the earlier contributions which were necessarily mainly speculative. It has been listed and reviewed by:
Bassant, J.R., Bowen, J.A.E., Dickson, K.E and Marsh, J. The Impact of Microelectronics: A Review of the Literature, (London, 1981);
and The British Computer Society (Computers and Employment, Specialist Group), Computers and Employment: A Selected Bibliography, (London, 1982);
and Braun, E.& Senker, P. (for Manpower Services Commission), New Technology and Employment, (London, 1982), especially Chapter 4.
It is significant how much of the literature attempts to estimate the likely diffusion of microelectronics technology, as a step to the prediction of employment impacts.

3. The first regional study is:
Green, K., Coombs, R., Holroyd, K., The Effect of Micro-Electronics Technology on Employment Prospects: A Case Study of Tameside, (Farnborough, Hants, 1980).

4. A study of book length is:
Swords-Isherwood, N. & Senker, P. (eds), Microelectronics and Engineering Industry, (London, 1980).
No similar study exists for the process industries generally, nor for chemicals particularly.

5. Some examples of this view and its validity are considered in Chapters Two and Three. Two expressions of it are:
Evans, L.B., "Impact of the Electronics Revolution on Industrial Process Control," Science, 195, (March, 1977), "this industry is already highly automated."
and Manpower Services Commission, The Manpower Implications of Microelectronic Technology, (London, 1980), says the process industries "are already highly capital-intensive and the scope for further manpower savings as a result of applying new technology is minimal", (p. 29-30.)

6. See Chapters Two and Three.

7. Woodward, J., Management and Technology, (London, 1958), was an influential study exploring this relationship between organisational structure and "automated" technology.

8. Especially Blauner, R., Alienation and Freedom: The Factory Worker and His Industry, (Chicago, 1964). Other references are in Chapter 3.

9. See Chapter 2, Ref. 1 for a list of relevant journals.

10. Schumpeter, J.A., Business Cycles: A Theoretical, Historical and Statistical Analysis of the Capitalist Process, (New York and London, 1939).

11. Mensch, G., Das Technologisch Patt, (Frankfurt, 1975), translated as Stalemate in Technology: Innovations Overcome the Depression, (Cambridge, Mass., 1979).

12. The literature on economic long waves has been surveyed by Barr, H., "Long Waves: A Selected, Annotated Bibliography," Review, II (4), (Spring, 1979), p. 675-718.

13. Theories of the relationship between long waves in economic activity and long waves in technology are summarised and classified by Delbeke, J., in "Recent Long Wave Theories: A Critical Survey", Futures, 13, (4), (August, 1981). The August and October 1981 issues of Futures contain twelve original contributions to the debate, including papers by Mensch, Freeman and Mandel.

14. Mensch, G., "1984 - A New Push of Basic Innovations?" Research Policy, 7, (1979), p.109-122.
Freeman, C., Clarke, J. & Soete, L. - Unemployment and Technological Innovation - A Study of Long Waves and Economic Development, (London, 1982).

15. Some of the standard texts in this area are:
Mansfield, E., The Economics of Technological Change, (New York, 1968).
Parker, J.E.S., The Ecomomies of Innovation, (London, 1974).
Norris, K. & Vaizey, J., The Economics of Research and Technology, (London, 1973).
Freeman, C., The Economics of Industrial Innovation, (Harmandsworth, 1974).
Rosenberg, N. (ed.) The Economics of Technological Change, (Harmandsworth, 1971).
The literature on technical change has been critically surveyed by Kennedy, C. & Thirlwall, A.P., "Surveys in Applied Economics: Technical Progress," Economic Journal, (March, 1972), p. 11-72.
Utterback, J.M., "Innovation in Industry and the Diffusion of Technology," Science, 183, (1974), p. 620-626.
Ray, G.F., "Innovation in Industry - the State and Results of Recent Economic Research in West European Countries Except the Federal Republic of Germany," Research Policy, (3), (1975), p.338-359.

16. Nabseth, L. & Ray, G. (eds.) The Diffusion of New Industrial Processes, (London, 1974).

17. Davies, S., The Diffusion of Process Innovations, (Cambridge, 1979).

18. The model first appeared in Mansfield, E., "Technical Change and the Rate of Imitation," Econometrica 1961.) It was retained in his later articles and developed by other writers on diffusion, whose work is reviewed in Davies's book, Ibid. p.13-25.

19. Gold, B., "Technological Diffusion in Industry: Research Needs and Shortcomings," Journal of Industrial Economics, XXIX (3), (March, 1981), p.247-269.

20. For example Barron, I.& Curnow, R., The Future with Microelectronics, (London, 1979).

21. Parker, Economics of Innovation, op. cit., Ref. 17, Chapter 6.
Mansfield, Economics of Technological Change, op. cit., Ref, 17, p. 119-123.

Such explanations are criticised by Gold in his section "On the Superficiality of Common Explanatory Variables," p.257-261 in "Reaearch Needs and Shortcomings," op.cit., Ref.21.

22. Stoneman, P., Technological Diffusion and the Computer Revolution; The UK Experience, (Cambridge, 1976).

23. Fisher, L.V., The Diffusion of Technological Innovation with Special Reference to the Application of the Digital Computer in Process Control, (Ph. D thesis, University of London, 1974).

24. Gold, "Research Needs and Shortcomings," op. cit., Ref. 19, p. 253-5.

25. Tivey, L., The Politics of the Firm, (Oxford, 1978), Chapter 1.

26. Gold, "Research Needs and Shortcomings," op. cit., Ref. 21, p. 248-250.

27. Threlfall, R.E., The Story of 100 years of Phosphorus-making - 1851-1951, (Oldbury, Staffs: 1951).

28. Davies, Diffusion of Process Innovations, op. cit., Ref. 19, p.34.

CHAPTER TWO

Notes and References.

1. The leading technical journals in this field have been: for the USA, Control Engineering (1954-); for the UK, Control (1958-69), continued as Control and Instrumentation (1969-) and Chemical and Process Engineering (1952-72), which was continued as Process Engineering (1972-) and also, Process Control and Automation (1954-66), continued as Instrument Practice (1966-72), further continued as Process Instrumentation (1972-).

2. Mensch, G. Stalemate in Technology - Innovations overcome the Depression (Cambridge, Mass 1979), p. 178-181.

3. Mensch, (Ibid., p.xvii-xviii) defines "basic innovations" as those "which establish new branches of industry" and "radical improvement innovations" as those which "rejuvenate existing branches". These are distinguished from "improvement innovations" that allow "further development in established areas of activity which were once established by a basic innovation." (p.47).

4. Reuben, B.G. and Burstall M.L. The Chemical Economy (London, 1973), chap. 2.

5. Ibid. Table 22, p.31.

6. Mensch, G. Stalemate in Technology, op. cit. ref.2, Table 4.7, p.132.

7. Reuben, B.G. and Burstall M.L. The Chemical Economy op. cit. Ref. 4, p.34 and Fig. 2.3, p.36.

8. Beeching, Lord "Economic Developments affecting the Chemical Industry", Chemistry and Industry, 3 (32) (1967), p.1340.

9. Different kinds of competition, "cost minimising", "performance maximising" and "sales maximising" are related to different kinds of industrial sectors in de Bression, C. and Townsend, J. "Inter-industrial flows of technology", Research Policy, 7 (1978), p.49-60. and

in Meyer, F.V., Corner, D.C. and Parker, J.E.S., Problems of a Mature Economy, (London, 1970), p.308. Both characterise chemical production as "performance maximising", together with other new industries such as electronics and aerospace.

10. Reuben, B.G. and Burstall, M.L. The Chemical Economy, op. cit. Ref. 4, p. 33-34.

11. "Commodity" phase of production is defined by Beeching as "freely competitive, large-scale production ... with a variation of profitability about a generally modest level", in Chemistry and Industry, op. cit. Ref. 8, p.1340.

12. Economies of scale for process plant are discussed in Freeman, C. The Economics of Industrial Innovation, (Harmondsworth, 1974), p.63-69, and in Reuben and Burstall, The Chemical Economy, op. cit, Ref.4.

13. Reuben, B.G. "Economies of scale or diminishing returns"? Process Engineering, (Nov. 1974), p.100.

14. Needham, M.V. "Electronic systems for Industrial measurement", Control, 1 (1), (1958), p.4.

15. Anon, "ICI set the pace in direct digital control of chemical plant" in Process Control and Automation, 11 (11), (1964) p. 498-501.

16. Braun, E. and MacDonald, S, Revolution in Miniature: the history and impact of semi-conductor electronics, (Cambridge, 1978, 2nd Edition, 1982), Chap. 5.

17. In his discussion of the economies of scale, Reuben notes that "Instrumentation and Control equipment show the largest savings, in that their cost is virtually independant of plant size". Process Engineering, op. cit. Ref. 13, p.102.

18. Anon. "Computer runs refinery for Texaco", Business Week, (April 4th, 1959), p.44-54.

19. "ICI set the pace etc." op. cit. Ref. 15.

20. Stoneman, P. Technological Diffusion and the Computer Revolution - the UK experience, (Cambridge, 1976), Table 8.1, p.167.

21. For example, Scott, M.J. of Taylor Instruments, Europe interviewed in Process Instrumentation, 1 (6), (1972), p. 275-7.

22. Gold, B. "Technological Diffusion in Industry: research needs and shortcomings", The Journal of Industrial Economics, XXIX (3) (March 1981), p.265.

23. *Ibid.*, P.252.

24. ICI's first computer-controlled plant was only economically feasible because the ammonia-soda reaction was regarded as not hazardous enough to need back-up controls, "ICI set the pace, etc", *op. cit.* Ref.15.

25. Scott, M.J., *Process Instrumentation*, *op. cit.* Ref. 21, p.275.

26. The scarcity of trained instrument artificers has been examined in *Department of Employment Gazette*, (May, 1979), p.433.

The serious consequences of the shortage of artificers for ICI plants on Teeside are described in *Financial Times*, (April 5th, 1979), p.6.

CHAPTER THREE

Notes and References.

1. Mensch, G. Stalemate in Technology: Innovations Overcome the Depression, (Cambridge, Mass., 1979(, Chap. 1-3.

2. Ibid. Gives S-shaped curves for Gross National Product of the US in Figure 2.6, p.71 and for West Germany in Figure 2.7, p.72 (1947-1975).

3. Ibid. Chapter 2.

4. Chapter 2, Section 2.2, Notes 4-6.

5. The effects of simultaneous maturing of product life cycles in the chemical industry, is described in Bradbury, F.R. "Changes in the Chemical Industry," in Edge, D. and Wolfe, J. Meaning and Control, (London, 1973), p.181-192.

6. Ibid. p.191-2.

7. Ibid.

8. Chapter 2, Section 2.2.

9. Mandel, E., The Second Slump, (London, 1978).

10. Reuben, B.G., "Economies of Scale or Diminishing Returns," Process Engineering, II (1974) p.100-103.

11. Wood, R., "Technology Beaten in Battle to Cut Costs," Process Engineering, 10 (1975), p.38-41.

12. Ibid. p.39.

13. Reuben, "Diminishing Returns?", op.cit., Ref.10, p.101.

14. Ibid. p.101.

15. Cost curves for 19 chemical products, all exhibiting the same U-shape, with a steady reduction until 1973, showing sharp rises thereafter, are reproduced in Wie, J., Russell, T.W.F. and Swarzlander, M.W., The Structure of the Chemical Processing Industries, (New York, 1979), Figures 6.4 and 6.13 to 6.16.

16. "Survival, let alone expansion, is dependant on the evolution of new technology," according to Dr. J. Howard in "Chemicals Seek a New Technology Mix,". New Scientist, 81 (1143), (22nd Feb. 1979), p.570-572.

17. The history of integrated circuits is related in Braun, E. and MacDonald, S., Revolution in Miniature: the History and Impact of Semiconductor Electronics, (Cambridge, 1978), Chapter 8.

18. McGowan, M.J., "Process Control is Distributed to the Valves," Control Engineering, 25 (Sept. 1978), p.41-46.

19. Bond, A., "Distributed Control - the 2nd Generation," Process Engineering, (August, 1980), p.70-71.

20. Kompass, E.J., "A Microprocessor in Every Control Loop," Control Engineering, 23 (Sept. 1976), p.123-6.

21. The advantages of microprocessor control systems are discussed in McLaren, G., "Why Use Micros?", Control and Instrumentation, 13 (Feb. 1981), p.60.

22. Friedman, A., Industry and Labour : Class Struggle at Work and Monopoly Capitalism, (London, 1977), p.78.

23. The literature has been critically reviewed by Child, J. in "Technical Progress," in Barrett, B. et. al. Industrial Relations and the Wider Society, (London, 1975), and by Wedderburn, D. and Crompton, R., Workers Attitudes and Technology - a Case Study, (London, 1972).

24. Blauner, R., Alienation and Freedom: the Factory Worker and His Industry, (Chicago and London, 1964).

25. Ibid. p. 6-7 and 124.

26. Ibid. p. 128-30, US Department of Labor, Outlook for Computer Process Control (Washington D.C., 1970).

27. Crossman, E., Automation and Skill, (London, 1960). Gives the duties of an operator on a "automatic"plant as (1) Control (2) Recording and Reporting (3) Special Procedures,for startup, shutdown and (4) Routine Maintenance.

28. Blauner, Alienation and Freedom, op. cit., Ref. 24., p. 133 and 169.

29. US Dept. of Labor, Outlook for Process Control, op. cit., Ref. 26.,

> though the computer eliminated some duties of these employees, the same size crew generally was retained to cope with any emergency arising from the malfunction of the computer or process equipment ... operators were required to perform manual operations which duplicated automatic computer operations, to retain skills needed for emergency manual control.

30. Blauner, R., Alienation and Freedom, op. cit., Ref. 24, p. 131 and 168-9.
Lowe, E. and Hidden, A., Computer Control in Process Industries, (London, 1971), p. 253.
Hunter, L.C., Reid, G.L. and Boddy, D., Labour Problems of Technological Change, (London, 1970).
For a criticism of this upgrading thesis see
Braverman, H., Labour and Monopoly Capital: the Degredation of Work in the 20th Century, especially p. 220-224, for maintenance workers and p. 224-227 for the skill status of chemical operators.

31. Manpower Services Commission, The Manpower Implications of Microelectronic Technology, (London, 1980), p.88-89.

32. Hunter, Reid and Boddy, Labour Problems of Technological Change, op. cit., Ref. 30, p.186.
Blauner, Alienation and Freedom, op. cit., Ref. 24, p.128.
US Dept. of Labor, Outlook for Process Control, op. cit., Ref. 26.

33. Blauner's description of the position in 1964,

> Because of the high degree of responsibility that continuous-process technology demands, management is particularly interested in a permanent, stable workforce ... employment in the oil and chemical industries is often for life, (Ibid. p.130),

may be contrasted with the Chemicals Officer of the General and Municipal Workers Union in 1977,

> There are those who seek to exploit our record by means of a "hatchet job" on manning levels and who seek our compliance with indiscriminate redundancy plans ... The social consequences of investment policies coupled with the export of capital could quickly transform industrial relations in the chemical industry into a quagmire of disputes and confrontation,

Chemistry and Industry, (5th March, 1977), p.162.

34. Hunter, Reid & Boddy found that no direct redundancies followed the ten examples of technological change in chemical companies that they studied in the 1960s because of redeployment and natural wastage. Labour Problems of Technological Change, op. cit., Ref. 30.

35. Blauner, Alienation & Freedom, op. cit., Ref. 24.

36. Ibid.

37. Mallet, S., The New Working Class, (Nottingham, 1975), saw chemical workers as characterised by solidarity and militancy as a result of process technology which reintegrates work. The premises are the same as Blauner's but the conclusion is that workers are not integrated into the firm but together against the firm's capitalist objectives. The technological determinism implicit in this was challenged by Gallie's comparison of French and English chemical workers in In Search of the New Working Class, (Cambridge, 1978) which found that militancy among French chemical workers was the result of cultural factors, not process technology.

38. Friedman, A., Industry and Labour: Class Struggle at Work and Monopoly Capitalism, (London, 1977), p. 78-101.

39. Ibid. p.101. The argument that indirect methods of control over workers have been characteristic of the post-1945 economic expansionary period is put by Clegg in "Political Economy of Organisation", Chap. 13 in Clegg, S., & Dunkerley, D., Organisation, Class and Control, (London, 1980). The increasing strains in industrial relations in the chemical industry have manifested themselves in increasing numbers and duration of strikes shown in Gill, C., Morris, R. and Eaton, J., Industrial Relations in the Chemical Industry, (Farnborough, Hants., 1978), Table 1.2.

40. Mensch, G., Stalemate in Technology, (Cambridge, Mass., 1979), p. 103.

41. Control Engineering, (September, 1976), p. 124 and June, 1978, p.49.

42. Gold, B., "Technological Diffusion in Industry: Research Needs and Shortcomings," The Journal of Industrial Economics, XXIX (3), 1981, p. 247-269.

43. Ibid. p. 250-252.

CHAPTER FOUR

Notes and References.

1. Threlfall, R., The Story of 100 years of Phosphorus-making, (Oldbury, Staffs., 1951)

2. Anon. "The beginnings of phosphorus manufacture," Endeavour, XX, (Jan. 1961), p.40-41, discusses the roles of the various contributors to the development of a successful process for phosphorus production.

3. Ibid. p.41.

4. To whom Arthur Albright had in fact sold his patent rights in France. Threlfall, 100 years of phosphorus, op. cit., Ref. 1., p.245.

5. Arthur Albright, quoted in Ibid. p.58.

6. Chambers, J.D. The Workshop of the World : British Economic History from 1820-1880, (London, 1961) p.1.

7. Threlfall, 100 years of phosphorus, op. cit. Ref. 1., p.50, he was quoting G. S. Albright.

8. The process is described in "Beginnings of phosphorus manufacture," op. cit. Ref. 2., p.40.

9. Threlfall, 100 years of phosphorus, op. cit. Ref. 1., p.54.

10. Ibid. p.74.

11. Ibid. p.52.

12. Ibid. p.58.

13. Ibid. p.89-90.

14. Ibid. p.74, White phosphorus output rose from 54 tons in 1855 and 446 tons in 1881.

15. Described in the first part of Ashworth, W., An Economic History of England, 1870-1939, (London, 1960).

16. "As the vacuum of demand was filled, markets tended to be glutted, for though they obviously increased, they had not increased fast enough ... to keep pace with the multiple expansion of output and capacity in manufactured goods." Hobsbawm, E., Industry and Empire : an economic history of Britain since 1750, (London, 1968), p.106.

17. Ibid. p.106.

18. Landes, D.S., The Unbound Prometheus : technological change and industrial development in Western Europe from 1750 to the present, (London, 1969), p.247.

19. Threlfall, 100 years of phosphorus, op. cit. Ref.1., p.260.

20. Ibid. p.115.

21. Reader, W.J., Imperial Chemical Industries : a history (Vol. 1), (London, 1975), Chapter 1.

22. Threlfall, 100 years of phosphorus, op. cit. Ref. 1., p.94.96.

23. G. S. Albright, quoted in Ibid. P.245.

24. "Distillation took about 16 hours", Ibid. p.52. The coal-fired retort and electrothermal processes are compared on Ibid. p.93.

25. Ibid. p. 99-101. This was "Phosphorus Electric Old", which operated from 1893 to 1902.

26. Wallace, W., "Oldbury Electrochemical Co., " Ibid., Chap. XV, Six 50 KW units were opened at Niagara in 1897.

27. Hambly, F.J., "The Electric Reduction Company of Canada Ltd.," Ibid. Chap. XVI.

28. Ibid. p.211.

29. Ibid. p. 115-116.

30. Sir Richard Threlfall, F.R.S. (1899-1932) was a theoretical and practical chemist, physicist and chemical engineer. He was Professor of Physics at University of Sydney, N.S.W., and then, in 1899 became A & W Director of Research, founding the Research Department. Previously "the application of physical chemistry to commercial processes had been

virtually unknown" at Oldbury. He designed and built new, larger furnaces and a gas-fired generator plant and made improvements to other processes. Further details of his life, by his grandson, are given in Threlfall, 100 years of phosphorus, op. cit. Ref. 1., Chap. X.

31. Ibid. Chap. XI., White phosphorus production in England fell in 1920 to ¼ of the 1918 output, p.189.

32. The loss was £43,000 in 1921, Ibid., .193.

33. Reader, ICI : a history, op. cit. Ref. 21., p.170.

34. Especially the Safeguarding of Industries Act (1921) and the Import Duties Act (1932. Their significance for the chemical industry in outlined in Hardie, D.W.F. & Pratt, J.D., A History of the Modern Chemical Industry, (Oxford, 1966), p.110-111.

35. "Rationalisation" is "a new-fangled term to describe the old-fashioned device of eliminating competition." Meakin, W., The New Industrial Revolution, (London, 1928), p.131.

36. Hardie & Pratt, Modern Chemical Industry, op. cit., Ref.34, p.115.

37. Ibid. "At the time of its formation, ICI enjoyed a monopoly of alkali, chlorine, hydro-chloric acid, nitric acid and metallic sodium manufacture, as well as in the production of nitro-explosives and many of the principal types of dyestuffs."

38. Haber, L.F., The Chemical Industry, 1900-1930, (London, 1971), p.292.

39. Threlfall, 100 years of phosphorus, op. cit., Ref.1., p.178.

40. Ibid. p.239-240.

41. Burnham, J., The Managerial Revolution, (New York, 1941), and Berle, A. & Means, G., The Modern Corporation and Private Property, (New York, 1932).

42. Galbraith, J.K., The New Industrial State, (Boston, 1967).

43. W.B. Albright, who remained as a part-time member of the board until 1980. Since he, his father and grandfather were each in the company for 50 years, they spanned the whole history of the company in 3 generations, Albright World, (January, 1980), p.1 and 4.

44. This situation of a breakthrough in technology creating a product, for which markets develop only slowly, is not confined to phosphorus. M. B. Hall has found the same in the cases of celluloid, polyvinylchloride and aluminium, see "The strange case of Aluminium," History of Technology, 1, (1976), p.143.

45. Threlfall, 100 years of phosphorus, p. 194-205. A chart of A & W phosphorus -derived chemicals is given on p.256-257.

46. Childs, A.F., "Phosphorus, Phosphoric Acid and Inorganic Phosphates", in Thompson, R., Modern Inorganic Chemicals Industry, (London, 1977), p. 375-402.

47. Anon. "ISMA forecasts long-lasting world phosphate surplus", European Chemical News, 28, (21 May, 1976) p. 12.

48. Childs, "Phosphorus, phosphoric acid and Inorganic Phosphates", op. cit. Ref. 46, p. 380.

49. Information on the technical problems of the Portishead plant is from an interview with A & W Director of the Central Engineering Department, (12th December, 1980).

50. The Times, (6th May, 1967), p.15.

51. Comparative costs for UK and Newfoundland production are given in the discussion of the Longharbour project in European Chemical News (5th July, 1968), p.30.

52. Threlfall, 100 years of phosphorus, op. cit. Ref. 1., p.139.

53. Cockman, D.P.,"The Albright and Wilson Phosphorus Venture in Newfoundland,"(unpublished paper, University of Liverpool, 1976). Synthesises a variety of published sources prior to 1976.

54. European Chemical News, op. cit. Ref. 51.

55. Interview with C.E.D. Director, op. cit. Ref. 49.

56. Edney, M. "At last - after the long hard slog - the success story of Longharbour", (Albright World, (January, 1979), p.10-12.

57. Robbins, B. & Hyde, M., "The Technical Problems at Longharbour", A & W Annual Report, (1970) p. 13-15.

58. Interview with C.E.D. Director, op. cit. Ref. 49.

59. Interview with Tenneco Director of Operations Technologies Department, (May, 1980).

60. Edney, "Story of Longharbour", op. cit. Ref. 56.

61. Interview with C.E.D. Director, op. cit. Ref. 49.

62. Warren, K., "Growth, technical change and planning problems in heavy industry with special reference to the chemical industry", Chap. 7., in Chisholm, M. and Manners, G. (eds) Spatial Policy Problems in the British Economy (London, 1971), p.201-202.

63. Ibid.

64. Edney, "Story of Longharbour", op. cit., Ref.56.

65. Ibid.

CHAPTER FIVE

Notes and References.

1. The company journal Tenneco has produced two reviews of the company's history:
   Anon. "25 remarkable years of Tenneco", Tenneco, II, (Autumn, 1968), p. 2-27.
   Anon. "Tenneco's first 35 years," Tenneco, XII, (Autumn, 1978), p. 8-22.

2. See chapter 2, Figure 2.

3. "25 remarkable years," op. cit. Ref. 1., p.2.

4. Energy Institute, University of Houston, Texas Energy, (Houston, Texas, 1978).

5. Texas Employment Commission, Houston Labor Market Review (March, 1980).

6. "Tenneco's first 35 years," op. cit. Ref. 1., p.8-10.

7. Tenneco Annual Report (1979) p.12.

8. Ibid.

9. Anon. "The 50 largest industrial companies in the world," Fortune (13th August, 1979), p.208. The rankings are by sales.

10. Some books dealing with this phenomenon are
    Sobel, R., The Age of Giant Corporations - a micro-economic history of American business, 1914-1970, (Eastport, Conn., 1972).
    Rumelt, R., Strategy, structure and economic performance, (Boston, Mass., 1974).
    Examines the link between conglomerates, diversification and profitability.
    Hannah, L., The Rise of the Corporate Economy, (London, 1976).
    Barber, R., The American Corporation, (London, 1970).
    Galbraith, J.K.L., The New Industrial State, (Boston, Mass., 1971).

11. Tenneco Annual Report, (1979) and Albright and Wilson Annual Report, (1979).

12. The history of Tenneco's acquisitions and diversification is briefly recounted in "25 remarkable years of Tenneco," and "Tenneco's first 35 years," op. cit. Ref. 1.

13. 1953 Tennessee Life Insurance Company, 1978, Philadelphia Life Insurance Company, 1980, South-Western Life Insurance Company.

14. Interview with Tenneco Director of Operations Technologies Department, (May, 1980).

15. Monroe Auto. Equipment Company was merged with Tenneco's subsidiary Walker Manufacturing Company, which manufactures exhaust systems, to form Tenneco Automotive Division.

16. The Tenneco takeover of Albright and Wilson and the motives behind it will be discussed in chapter 6.

17. Deisel, J., "A Decade of Progress - Newport News," (Newport, Virginia, 1978).

18. <u>Ibid</u>. The general validity of profitability as a yardstick of performance was expressed by Tenneco President W. E. Scott to the Racine, Wisconsin Chamber of Commerce.

> "And what is the assigned role of business? To provide necessary or desirable products and services at reasonable prices. I used eleven words to define our role. Let's shorten it to four. The assigned role of business is ... <u>to make a profit</u> ... Therefore, when someone asks you whether business is living up to its social responsibilities, you tell them ... <u>damn right we are</u>. <u>By trying to make a profit</u>." (original emphasis). <u>Tenneco</u> (summer, 1975).

19. <u>Financial Times</u>, (27th July, 1979), p.14.

20. Interview with Director of OTD, <u>op</u>. <u>cit</u>. Ref. 14.

21. Deisel, "A Decade of Progress," <u>op</u>. <u>cit</u>. Ref. 17.

22. <u>Ibid</u>.

23. <u>Ibid</u>.

24. <u>Ibid</u>.

25. <u>Ibid</u>.

26. <u>Ibid</u>.

27. <u>Ibid</u>.

28. <u>Wall Street Journal</u>, (31st January, 1979), p.1.

29. <u>Wall Street Journal</u>, (2nd February, 1978), p.3.

30. Wall Street Journal, (8th February, 1978), p.20.

31. Business Week, (4th April, 1959), p. 44-54.

32. Chemical Engineering Progress, 56 (May, 1960), p.63-67.

33. Gardiner had essentially a financial background, rather than an engineering one, Tenneco, II (Autumn, 1968) p.8-9.

34. Lane, J., "Process Control at Tenneco", A presentation to A & W company conference on automation (March, 1979). Gave an outline of Tenneco's first computer applications.

35. Ibid. and interviews with Director of OTD, op. cit. Ref. 14.

36. Interviews with Group Manager, Tenneco Chemicals at Pasadena plant (May, 1980) and Director of OTD, op. cit. Ref; 14.

37. Lane, J., "Computer impact on the Petro-chemical Industry," Presentation to the International Micro and Mini Computer Conference of the Institute of Electrical and Electronic Engineers, (Houston, Texas, 14th November, 1979).

38. For an example of automation of control to reduce hazard for PVC at a British plant see, Spear, M., "Safety in control of PVC resin plant", Process Engineering, (April, 1980), p.93.

39. Interview with Director OTD, op. cit., Ref. 14. The title "Industrial Automation Department" was changed from 1979 to "Operations Technologies Department", to reflect the widening of its scope to include work on energy production and conservation and environmental control.

40. Industrial Automation Department Functional Plan (1980).

41. Lane, "Computer impact on Petro-chemicals", op. cit. Ref. 37.

42. The Director of OTD has been "closely involved in the implementation of computer-based process control systems continuously since 1958". Ibid.

43. IAD Functional Plan, op. cit. Ref.39.

44. Ibid.

45. *Ibid.*

46. Marsh, P., "America's factories race to automation", *New Scientist*, 90 (25th June, 1981), p. 845-7.

Lists General Electric, Westinghouse and International Harvester as among companies "establishing centralised automation teams", p.846.

CHAPTER SIX

Notes and References.

1. Tenneco (Summer, 1973), p. 6 and p.12-17.

2. Albright World, (July, 1979), p.1.

3. Tenneco's acquisitions in Britain were described in Tenneco, op. cit., Ref. 1., p.6-11.

4. Meason, G., quoted in Albright World, (November, 1978), p.1.

5. Sunday Times, (4th June, 1978), p.53.

6. Meason, G., interviewed in Chemical Age, (16th March, 1979) p. 8 and 9.

7. Ibid.

8. Meason, G., op. cit. Ref. 6.

9. Albright World, (May, 1979), p.2.

10. Financial Times, (11th February, 1982), p.10.

11. Albright World, op. cit. Ref. 9.

12. Albright World, (January, 1980), p. 1 and 4.

13. Meason, G., op. cit. Ref. 6.

14. Ibid.

15. Internal A & W memorandum, "Reorganisation of Management," (March, 1980).

16. Published material describing these re-organisations between 1967 and 1976, has been summarised and referenced by Cockman, D.P., in "The Albright and Wilson Phosphorus Venture in Newfoundland", (unpublished paper of University of Liverpool, 1976).

17. "Re-organisation of Management", op. cit. Ref. 15., and interview with Production Co-ordination Manager, (5th March, 1980).

18. Livingstone, D., quoted in Albright World, (September/ October, 1980), p.2.

19. Albright World, (January, 1980), p.6.

20. Albright World, (March, 1981), p.4 and Bainbridge, B, "The Computerised Stock Management Systems within Bush Boake Allen", (presentation to the Advanced Control Systems Seminar, A & W 8th & 9th March, 1979.

21. Livingstone, D., op. cit. Ref. 18.

22. A & W Director of Corporate Development introducing the Advanced Control Systems seminar (8th-9th March, 1979) quoted in Albright World, (June, 1979), p.8.

23. This "de-instrumentation" was observed at Rainham (see Chapter 7), at Widnes (West Bank plant) during a visit in March, 1979, at Oldbury described by a corporate engineer interviewed at Whitehaven (12th December, 1980), for example, the new phosphoric acid plant described by the Senior Process Control Engineer interviewed at Whitehaven (12th December, 1980).

24. Director of OTD, interviewed in May, 1980, (interviews and conversations over a 2-week period.)

25. Ibid.

26. Peevor, D., (Senior Chemical Engineer CED, Whitehaven), "Advanced Automation of the Amines Plant at Whitehaven", (presentation to the Advanced Control Systems Seminar, 8th-9th March, 1979).

27. For example the proposals of the Senior Chemical Engineer at the Technical Services Department of the Phosphates Sector at Oldbury, who suggested computer control of the thermal acid plant before 1978 (interviewed March, 1979).

28. A limitation stressed by the Deputy Director of CED, interviewed 12th December, 1980.

29. The different relative status of engineers as compared with chemists at Tenneco and at A & W was seen as a significant difference by the Director of the OTD op. cit. Ref. 24.

30. Threlfall, R. E., 100 years of phosphorus-making, (Oldbury, 1951), p.375-380 gives details of the Oldbury Works Pension Fund (1895) and pensioners with 40 and 50 years service in A & W. Anecdotes of families with several generations employed at A & W are given in p.102-112.

31. Interviews with supervisors at Rainham, 16th December, 1978, and Widnes (West Bank) on 12th March, 1979.

32. A point strongly expressed by the deputy manager Widnes (West Bank), interviewed 12th March, 1979, and highly relevant to the choice of new controls at Rainham (see Chapter 7.)

33. Interview with Production Co-ordination Manager A & W op. cit., Ref. 17.

34. Interview with Group Manager, Tenneco Chemicals, Pasadena (2nd May, 1980).

35. A & W Training Officer interviewed 20th February, 1981, still felt that union resistance to redundancies would make agreement on the installation of new technology difficult to achieve.

36. Deputy Manager Widnes (West Bank) op. cit., Ref. 32., Supervisor at Rainham, op. cit.. Ref. 31.

37. Albright World, (April, 1980) p.1.

38. op. cit., Ref. 24.

39. Ibid. This was a cause of some tension between CED at Whitehaven and OTD.

40. Senior Process Control Engineer, interviewed 12th December, 1980.

41. Ibid.

42. The position was stated by the A & W managing director in the Albright World "Annual Report for Employees" (1980): "We must ensure, to protect the investments we already have in the UK, that we are as efficient as any producer in the world. This means that our plants must be modern and well run and our manning levels as slim as they can possibly be ... but we may find it more and more difficult to justify new capital investment in chemicals for export, which now account for 36% of our UK sales ... we shall have to confine expansionary investment in the UK to those projects which show a satisfactory return on the assumption of a pound reamining strong."

43. The A & W Managing director also warned, "In some areas, with the best will in the world we shallnot be able to reach the necessary standards to keep us in business and this will mean some further site closures." (Ibid.)

44. Albright World, (June, 1980), p.2. and "Applied Automation courses" (OTD Booklet) p.1.

45. Interview, Director of OTD, (May, 1980).

46. "Applied Automation" course at Kidderminster on 23rd-24th March, 1981 and "Small Computers for Process Control and Production" course at Coventry on 23rd-27th March, 1981.

47. Albright World, (February/March, 1981), p.5.

48. Interview with Senior Process Control Engineer CED, op. cit., Ref. 40, and Instrument Engineer Whitehaven (13th December, 1980).

49. Interview with Production Co-ordination Manager, May, 1979.

50. Rainham phosphates Plant Manager, interviewed 18th February, 1981.

51. Interview with Director of OTD, op. cit. Ref. 24.

52. Interview with Corporate Research Manager (19th December, 1980).

53. Interview with Director of OTD, (28th February, 1981) and interview with Senior Process Control Engineer, op. cit. Ref. 40.

54. Kent, A., (Senior Chemical Engineer, Phosphates Sector Technical Services Dept.), "Phosphoric Acid Storage, Blending and Deorsenification - Computer Control", (internal memo., 26th June, 1978).

56. Robbins, B., "Advanced Process Control in A & W", (presentation to the Advanced Control Systems seminar, 8th-9th March, 1979.

57. Interview with Deputy Director of CED, op. cit. Ref. 28.

CHAPTER SEVEN

Notes and References.

1. For an account of the end uses of phenol see Reuben, B.G. & Burstall, M.L., The Chemical Economy, (London, 1973), p. 263.

2. Phosphate plasticiser is a small part of the total plasticiser market, used for purposes where fire-proofing is important e.g., in coal mine belting. Ibid., p.249-253. The same chemical substance is varied in its acidity, colour etc. for the other uses.

3. Interview with Rainham phosphates plant manager, 15th & 16th December, 1978.

4. Ibid.

5. Ibid. and interview with operators' Shop Steward, Rainham plant, 16th December, 1978.

6. Interview with Widnes (West Bank) Deputy Plant Manager, 12th March, 1979. Accredited to other plant management's by Rainham Plant Manager, 28th January, 1981.

7. Lewis, J.T., "Capital Authorisation Request, Instruments - New Control System, Phosphates Plant, Rainham", (Organics Sector internal document, 1978).

8. Interview Production Co-ordination Manager, A & W, 5th November, 1979.

9. Lewis, "Capital Authorisation Request", op. cit. Ref. 7.

10. Barrett, D., "Control System Survey", (Rainham, phosphates plant document, 1978).

11. Lewis, J.T., "Capital Authorisation Request", op. cit. Ref.7.

12. Ibid.

13. Interview, Plant Manager, op. cit. Ref.3.

14. Interview, Engineering Department Supervisor, Rainham Plant, 28th January, 1981.

15. Interviews with Rainham Phosphates Plant Operating Supervisor and Rainham Bush, Boake Allen Plant Supervisor, 16th December, 1978.

16. Lewis, "Capital Authorisation Request", *op. cit.* Ref. 7., p.14-15.

17. Interview, Plant Manager, *op. cit.* Ref. 3.

18. Brod, L. "Rosemount Diogenes at Rainham", (Presentation to Advanced Control Systems Seminar, 8th-9th March, 1979.

19. Lewis, "Capital Authorisation Request," *op. cit.* Ref. 7., p.14.

20. *Ibid.* p.10.

21. *Ibid.*

22. By the Corporate Development Department. Interview with production Co-ordination Manager, *op. cit.* Ref.8.

23. Anon. "Diogenes Process Controller," (Information booklet, Rosemount Inc., 1977).

24. Interview, Plant Manager, *op. cit.*, Ref.3.

25. Interview, Engineering Supervisor, op. cit., Ref.14.

26. Borrett, A. "Diogenes Operator's Manual," (A & W Rainham, 1979), and
Borrett, A. "Introduction to Diogenes Control System," (A & W Rainham, 1979).

27. *Ibid.*

28. "Diogenes Process Controller", *op. cit.* Ref.23.

29. Interview with Rainham Phosphates Plant Manager, 27th January, 1981.

30. *Ibid.*

31. *Ibid.*

32. Interview, Rainham Supervisor, *op. cit.* Ref. 15.

33. *Ibid.*

34. Interview, Plant Manager, *op. cit.* Ref. 29.

35. *Ibid.*

36. Lewis, "Capital Authorisation Request", *op. cit.* Ref. 7.

37. Interview, ex-Rainham Chemical Engineer (Senior Process Control Engineer, CED), 12th December, 1980.

38. Interview, Plant Manager, op. cit. Ref. 29.

39. Ibid.

40. "Diogenes Process Controller", op. cit. Ref. 23.

41. Interview with Director of OTD, 28th February, 1981.

42. Interview with PVC Plant Supervisor, Tenneco Chemicals, Pasadena, May, 1980.

43. Interview, ex-Rainham Chemical Engineer, op. cit. Ref. 37.

44. Interview with Production Co-ordination Manager, 5th March, 1980.

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