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A CASE STUDY IN THE MANAGEMENT OF TECHNICAL INNOVATION - NEW FERMENTED FOODS IN WESTERN EUROPE

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ABSTRACT

The thesis is a case study of innovation within the firm and is based on novel food fermentation innovation. Novel food fermentation innovations were based on technologies that fermented microorganisms to provide a new source of protein for animal and human consumption and this protein is sometimes referred to as single cell protein. The research uses a qualitative method to investigate project managers' perceptions of the process of innovation in a group of Western European firms. 32 semi-structured interviews with selected managers were transcribed and then analysed using grounded theory (Strauss, 1987) to develop a set of categories which represent patterns in the responses of the managers. These categories include the market, the firm environment, firm culture and strategy, competition and cooperation between firms, product champions and technical decision making. Concepts are developed from the material in each category, such as the idea of a "reference market," (see chapter 4) which show how technology is socially structured within the firm. In the conclusions all the categories are used to suggest a model of the process of innovation decision making.

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ABBREVIATIONS

BOD	Biochemical oxygen demand
BP	British Petroleum plc
BMFT	West German Technology Ministry
DNA	Deoxyribonucleic acid
ICI	Imperial Chemical Industries plc
IFP	French Petroleum Institute
LQ	Liquichimica
MAFF	Ministry for Agriculture, Fisheries and Food
RHM	Rank Hovis McDougall plc
RNA	Ribonucleic acid
SCP	Single Cell Protein
t/a or tpa	Tonnes per annum
T&L	Tate and Lyle plc

GLOSSARY

Alkane	Any saturated aliphatic hydrocarbon
Causal map	Weick's (1979) term for the retained, linked cognitions which form an individual's set of causal relationships
Cognition	Knowledge that is comprised of elements of perception
Cognitive mapping	A process of constructing a mental map of one's environment
Comparative analysis	The examination of similarities and differences based on the categorisation of the text by the researcher
Empirical	Relating to experiment and observation rather than to theory, based on practical experience
Enactment	The process by which certain cognitions are selected and then retained into the causal map, ie they become part of an individual's experience
Fermentation	The growth of microorganisms on an organic substrate which they metabolise
Grounded Theory	The process of the discovery of theory from data using a method of comparative analysis
Hydrocarbon	Any chemical consisting of hydrogen and carbon alone, eg alkanes
Innovation	A novel product or device or idea, not necessarily commercially successful
Methane	The simplest alkane and the main constituent of natural gas
Methanol	The simplest alcohol, the first stable oxidation state of methane, highly soluble in water, toxic.
Network	The set of personal relationships between the scientists and managers who were interviewed
Quorn	The trade name used by RHM to describe their texturised mycelial fungus grown on a glucose substrate, (mycoprotein)
Reference market	A market for an innovatory product based on an existing market, (see chapter 4)
Substrate	Substance upon which microorganisms feed, breaking it down by enzyme action
Technology	Knowledge related to the use of physical objects or artefacts, (see chapter 10)

INTRODUCTION

This thesis arose out of the researcher's interest in technical innovation and its relationship to long term economic change. Research into technical innovation has tended to concentrate on its macroeconomic features and it was felt that more case studies of innovation within the firm were needed. These should be as recent as possible and analytical in nature rather than distantly historical and over conditioned by pre-existing ideas.

A case study of innovation based on the semi-structured interviewing of managers would fulfil these criteria. The case study chosen was that of novel food fermentation innovation because it was a recent, radical innovation and the constraint of secrecy would not inhibit managers from being interviewed since many of the projects had failed commercially. A large number of firms had developed projects in this technology and the case study therefore offered the chance to compare the approaches of the companies to what appeared to be the same technology. This technology is described in chapter 3.

A network of managers in the innovating companies was built up through personal contacts which reached across firms and to an extent across countries, with potential interviewees located and approached by telephone to assess their suitability for interview. Thirty two managers were interviewed in France, Belgium, Denmark, Norway, Switzerland, Italy and West Germany, with all the interviews being tape recorded then transcribed. The semi-structured interview (see chapter 2 for explanation) was chosen as the method of interviewing managers because it allowed the managers to refer to a variety of influences on innovation. Transcripts were analysed in detail and patterns of manager responses were identified in accordance with the method of grounded theory. These patterns or categories of response then became the chapter titles under which the transcript material was organised. These categories represent the principal origins of the managers' perceptions of influences on the fermentation innovations. Such influences range from those external to the firm, such as the regulatory environment and the market, to those internal to the firm which include firm culture, strategy and product champions.

Chapter 4 explores various conceptions of the market used by managers to guide the development of their technology. The idea of a "reference" market is developed to model the reciprocal influence of markets and technology.

Chapter 5 looks at examples of inter-firm cooperation and competition within novel food innovations as a group of projects. It suggests that managers had to judge when to cooperate and when to compete with other firms because a range of influences affected the projects.

Managers perceived certain attributes of firms to have affected firm behaviour. Many of them identified the same characteristics in the same firms and to this pattern the research gives the name of firm culture, which is the title of chapter 6.

In chapter 7 the research examines how senior management, and possibly firm strategy may have affected the projects. In some cases, but without a clear pattern between the firms studied, senior management did have a role to play. This is developed in chapter 9 where the role of key individuals or product champions is discussed.

Chapter 8 looks at how technical decisions were taken which were critical to the differences between the projects and finds that even here non-technical considerations affected the choice of technology.

The conclusions use the idea that technology is socially constructed to suggest a model of innovation within the firm that is consistent with the ideas developed in the thesis and also with some of the features of the long wave models of technical and economic change.

CHAPTER 1 TECHNICAL INNOVATION AND THE ECONOMY

Introduction

This chapter will examine models of the economy which take technical change as the major source of long term economic development and will suggest that case studies of technical innovation within the firm can contribute to an improved understanding of how technical change occurs in the economy. There is then a selective review of innovation case studies and some conclusions are drawn about how these might be improved upon. The chapter ends by preparing a loose and provisional "conceptual framework," which is a collection of possible innovation influences that will be used to guide the initial interviews.

1.1 The Existence of Long Waves in the World Economy

World economic development has not been a smooth and continuous process, but rather periods of economic growth have alternated with periods of slower growth. Prices and employment have shown a variation in the long term, with an apparent cycle of approximately 50 years between peaks in the indices. These variations are often referred to as "Kondratiev waves", although the Russian economist Kondratiev was not the first to pay them attention, (see Duijn van (1983) or Freeman (1984) for more on long waves.) These waves have prompted a search for an explanation of their existence and some possibilities are reviewed by Delbeke (1984). The explanations have in common that the "cause" of the long waves must vary on the time scale of near 50 years. Possible candidates are the changing structure of capital investment and long term shifts in demand, but those that are of the greatest interest here use technical change as the source of long wave variations and can be termed "structuralist" explanations or models.

Almost all the structuralist models refer to Schumpeter (1942) as the first writer to link these waves to technical and structural change. One of Schumpeter's most frequently quoted passages suggests that he made this link because of his observation of the dynamics of firm competition in his contemporary economy. The most powerful type of firm competition was,

> "the kind of competition from the new commodity, the new technology, the new source of supply, the new type of organisation... competition which commands a decisive cost or quality advantage and which strikes not at the margins of the profits and the outputs of existing firms but at their foundations and very lives." (Schumpeter, 1942 p84).

Schumpeter contrasted this powerful form of technical and organisational competition with the interests of mainstream economists who were interested in essentially static forms of competition, or as Schumpeter puts it,

> "competition within a rigid pattern of invariant conditions, methods of production and forms of industrial organisation...that practically monopolises attention." Schumpeter (1942).

Schumpeter (1942) suggested a model where the capitalist entrepreneur was responsible for the innovations associated with each long wave.

More recent developments of the structuralist model have moved away from Schumpeter's formulations, (see Freeman and Perez, 1988) but it is nevertheless instructive to consider how each wave has been associated with particular innovations and has had its own characteristics.

1.2 Characteristics of Long Waves

The long wave literature cited above usually refers to four distinct long waves that have occured since the industrial revolution. Each of these has been based on a set of core technical and organisational innovations. A simplified list is shown in table 1.1, but see Freeman and Perez (1988) for a more detailed description of the characteristics of each wave.

The structure of the economy changes as the group or "cluster" of innovations linked to a wave diffuse through a major part of the economy. For example, the early and late phases of each wave will be associated with a different employment and investment situation. (See Freeman, Clark et al (1982), and Rothwell and Zegveld, (1979) for a "neo-Schumpeterian" explanation of observed changes in employment patterns in OECD countries since the war.)

An example of a "cluster" of innovations which Freeman (1982) takes as part of the 4th Kondratiev are those associated with the production of synthetic oil-based materials. One part of the cluster was basic polymer chemistry which was developed in the 1920s and was a useful tool in the development of the plastics and synthetics fibres industry[1]. However, the industry in its modern form was only possible once certain high pressure chemical engineering innovations (materials and techniques) were developed. These were essential to enable the construction of experimental and later full scale synthetics materials plant. Commercial synthetics were only possible once a range of technical and scientific innovations were established and brought together.

Different models have emphasised the different social origins for the innovations. Freeman (1982) describes how in the 1920s Schumpeter believed the entrepreneur was the driving force who pioneered and then exploited technical innovation[2]. By the 1940s Schumpeter recognised that an increasing proportion of innovations were conceived and developed in the corporate R&D department. Freeman refers to the R&D department as one of the major industrial organisation innovations of the 3rd Kondratiev, with increased diffusion of this organisational form occurring during the 4th Kondratiev. The growth in the role of the R&D laboratory has been accompanied by the increased role of science as an input into innovation.

There are many features of the technical change-economy relationship that have been well researched, there is no complete "theory" which adequately represents this complex interaction, but there are a

[1]Although polymer science was developed after the discovery of the early synthetics, ie this is another case where the science came after the technology, (Pavitt, 1986)

[2]See chapter 9 conclusions for a discussion of this idea in relation to the findings of the research.

KONDRATIEV		TYPICAL INNOVATIONS	LEADING COUNTRY
Early Mechanisation Kondratiev From 1770s to 1830s	1	Textiles Textile Chemicals Textile Machinery Water Power Potteries	UK France Belgium
Steam Power and Railways Kondratiev From 1830s to 1880s	2	Steam Engines Steamships Machine Tools Iron Railway Equipment Railways	UK France Belgium Germany USA
Electrical and Heavy Engineering Kondratiev From 1880s to 1930s	3	Electrical machinery, Heavy Engineering Steel Ships Heavy Chemicals Synthetic Dyestuffs Electricity Supply and Distribution	GERMANY USA UK France Belgium
Fordist Mass Production Kondratiev From 1930s to 1980s	4	Automobiles Trucks Armaments Aircraft Consumer Durables Process Plant Synthetic Materials Petro-chemicals Highways	USA GERMANY Other EEC Japan
Information and Communication Kondratiev From 1980s to ?	5	Computers Electronic Capital Goods Software Telecommunications Optical Fibres Robotics FMS Ceramics Digital Telecommunications Satellites	JAPAN USA Germany Sweden Other EEC

Table 1.1 Kondratiev Waves and Associated Technical Innovation

number of models of the general interaction of technical change and the economy in the long term. These use metaphors and analogy to emphasise particular features of the innovation-economy relationship over others and three of the more recent models will be briefly discussed.

1.3 Some Models of Structural Change in the Economy

Nelson and Winter (1982) suggest the idea of "natural trajectories" to represent technological change, where a trajectory represents an inherent logic and direction for technical change. They use the Boeing 707 as an example of such a trajectory in the aerospace industry. As the industry developed some core features of modern design, exemplified in the Boeing 707, came to dominate. With this "core" established, technical innovation became directed towards marginally improving the core features rather than providing radical alternatives to them. Nelson and Winter suggest the production and distribution of electricity, plastics and electronics as three other examples of trajectories. Nelson and Winter's metaphor of a trajectory carries a suggestion that the trajectory is an optimal path of development and that there is a sense in which the eventual technical form is predetermined.

Dosi (1982) takes the idea of a technological trajectory and integrates it into a more wide-ranging model. He suggests that the Kondratievs should be seen as corresponding to the development of "technological paradigms", after the scientific paradigms of Thomas Kuhn (1981). The paradigm idea helps to "build in" to his model the idea of uncertainty and the possibility of technical choice. A technological paradigm is a "pattern" of solution of certain technical problems. The solution of a particular problem , such as the design of the Boeing 707 is based on "selected" principles derived from the natural sciences and material technologies. These selection rules are chosen and learned by technical people over a period of time and are market related. These rules guide technical development for a time but there are periodic changes in the "set" of rules, as a new technical form becomes taken as standard in an industry. This model, unlike the Nelson and Winter model, does focus attention on a process of decision making by technical and commercial personnel. The model suggests follow-up research on who selects these rules and how they do so.

Freeman and Perez (1988) build on Dosi's ideas when they add a taxonomy of innovation to the paradigm idea and when they stress the interaction of technical and non-technical innovations as the base of each period of economic restructuring, hence their description of the paradigm as "techno-economic". They also introduce a "taxonomy" of innovation, since innovation varies enormously in its technical and economic impact and this is summarised below.

INCREMENTAL These are innovations which modify a part of a production process. They are common in all branches of mechanical engineering and often result from individuals working on the production process. They are limited in their economic impact although their cumulative impact may be large in some industries, such as those based on chemical and refining plant.

RADICAL These innovations may be new products or production processes, examples being the invention of nylon or other synthetic fibres. They require substantial investment to bring the innovation to market and their economic impact may be considerable but is localised. An example would be nylon, which radically altered the market for natural fibres for selected products, but did not enter into a substantial proportion of the total of manufactured goods. A similar example would be ammonia.

CHANGE IN TECHNICAL SYSTEM These innovations can include organisational or management innovation and change the technical basis for production in an industry or for a significant range of products, but fall short of changing the entire economic structure. An example would be the collection of synthetic fibre innovations.

CHANGE IN TECHNO-ECONOMIC PARADIGM These innovations have the potential to change the basis for production throughout the economy. They may require vast investment in a new infrastructure to support the new economic base. Electricity is one example.

Dosi (1982) describes the idea of a technological paradigm as a "metaphor" for the process of incorporation of knowledge and technology into industrial growth. This is an equally valid description of all these models. They all use metaphor to link observed patterns in industrial development, the Kondratievs, to more familiar patterns of change. In doing this they attempt to make the complexity of the relationships between innovation and industrial growth easier to conceptualise.

In an earlier work where Freeman and Perez were developing these ideas, they suggest that future research should,

> "...use our framework to study discrete innovation diffusion." (Freeman and Perez, 1986 p25).

They stress that such research should place particular emphasis on the role of institutional factors, policies which enable or retard diffusion and "managerial attitudes." This is because the diffusion of technical innovation through the economy is not spontaneous. It is most often the firm which innovates and then attempts to help the process of diffusion through the economy and research should focus on how and why the firm innovates.

There are many attempts to incorporate technical change into the theory of the firm (see for example, Coombs and Saviotti, 1987) and an interesting one is that of Teece (1988), who has begun to introduce some of the properties of technical knowledge into his model of firm behaviour. In this model, "A firm's core business...stems from the underlying natural trajectory embedded in the firm's knowledge base." (Teece, 1988 p264)

Teece links the idea of a technological trajectory to the firm's core business. Firms will "specialise" in certain products because they possess the requisite technical knowledge base to produce them. It also follows that the technical innovation that they would introduce would tend to match the capabilities of their knowledge base. The knowledge base would constrain the field of possible innovations and individual firms would appear to "move" along a trajectory in time.

If this were to be related to the entire economy, one could imagine firms to be arrayed on the technical trajectories that make up the current techno-economic paradigm.

Teece also discusses some of the properties of technical knowledge to explain some features of firm behaviour. Here he draws on Polanyi's ideas of the nature of knowledge and technical knowledge in particular, (see Polanyi, 1958 for detail). Technical knowledge is characterised by its tacit nature; that is it exists only partly as written work, but also as "practical" knowledge possessed by technicians, engineers and scientists. The tacit nature of technical knowledge results in the difficulty of transfer of skills and knowledge between firms without a transfer of technical personnel. Firms will tend to want to stay within their core business based on proprietary technical knowledge, because of the costs and difficulties of changing their technical knowledge base.

Of course the technical base of the firm does change through time as technical innovation is introduced. Metcalf (1988) develops the idea that the firm's competitive decisions are responsible for its introduction of technical innovations. He stresses that these decisions mould the development of their technical base.

> "Technologies do not compare in the literal sense. Only firms compete, and they do so as decision making organisations articulating a technology to achieve specific objectives within a specific environment. The outcome of their decisions is what determines the economic significance of rival technologies and how this changes over time." (Metcalf, 1988 p568)

A study of how technical innovation is created and then propagated within the economy must therefore take account of relevant decision-making within the firm. Metcalf (1989) has referred to how these decisions give "structure" to firm technology. A study of decisions will involve talking to the people who were involved in those decisions, the managers of the firm. The question of how best to accomplish this is dealt with in chapter 2.

Metcalf's ideas can also be used to suggest that the change from one techno-economic paradigm to another is the result of competitive decisions made by firms. There must be a patterning of the competitive decision making process in all firms over long periods of time to give rise to the techno-economic paradigms. It may even be possible to find evidence of the shift from one techno-economic paradigm to another by studying how the firm innovates.

A case has been made for research on the innovation process within the firm. The next section supports this case through a brief survey of the work on innovation at an aggregate level, ie work concerned with innovation within the economy as a whole. This work is useful to the thesis because it contains many of the established characteristics of technical change in the economy. These give significance to the choice of novel food fermentation innovations as a vehicle of study for the thesis.

1.4 Some Empirical Studies on Technical Innovation

Much work has been done on innovation inputs and outputs such as aggregate R&D spending and patents, but less on the process of innovation itself which is internal to the firm. This work establishes the pattern of spending on innovation in the economy by governments and firms and some of these results can be summarised in note form.

1 Large firms spend more R&D per successful innovation than small firms. (Mansfield, 1977)

2 There is no tendency for R&D spending to be proportional to the size of the firm. (Scherer (1984))

3 Patents registered per qualified scientist and engineer, (QSEs) have been declining since the late 1960s in 50 of the industrialised countries, despite an increase in the number of QSEs in industrial employment. (Griliches (1984))

4 The proportion of R&D spending by government as opposed to industry varies greatly between countries and by industrial sector. See for example Coombs (1987)

5 Industrial R&D spending is concentrated by industrial sector, with the chemical and electrical engineering and defence, aerospace industries absorbing the greater proportion in all OECD countries, (eg Freeman, 1982)

6 Industrial R&D spending is highly concentrated by firm. The top 20 firms in the US control over 50% of private R&D spend, (eg Freeman, 1982)

These results are brought together in numerous general texts on technology and the economy such as Freeman (1982) and more recently Coombs (1987). Many of these writers are economists who have become interested in technical change and have applied an economists' approach to its study. By contrast, political economists who are interested in the international role of technology tend to explain the inter-country differences in terms of government policy and historical national experience, (for example, Williams (1984) on international "technology gaps" and technology and the arms trade, and Clark (1987) on political economy.)

Authors that attempt to explain the inter-industry differences in innovation spending sometimes use inter-firm manager behaviour differences. For example Kay (1979) interprets the differences in R&D spending between firms to infer that there are "meta-rules" suitable for each corporation's circumstances that managers use to set levels of spending on innovation. However, there is little empirical work on what have been called meta-rules (by Kay), selection rules (from Dosi, 1982) or rules of thumb (Simon, 1959) which are so often assumed to exist by authors making external observations of firm behaviour. All these authors believe that firm behaviour can be understood in terms of rules which are used by managers to guide decisions and behaviour in specific circumstances in the firm.

However, there has been a reluctance among economists to choose research methods which would examine these "selection" rules in any detail and the decision making process inside the firm. The problem has been recognised repeatedly by researchers into innovation, as the following quotations show.

> "We must learn to understand the forces that motivate firms and individuals to innovate, to take the risks that bring about technical change and to compete successfully." (Landau and Rosenberg, 1986 p6)

> "Many of the interesting questions and decisions are taken at the "project" level, but little data are available on this level." (Griliches, 1984 p15)

The partial "exhaustion" of some of the most promising research hypotheses may be responsible for these demands for an increase in attention to the internal dynamics of the firm. Nelson and Winter (1982) consider the "Schumpeterian hypothesis", to be an example of this effect. They consider that the law of diminishing returns set in years ago with the large research effort going in to testing the validity of the hypothesis that "larger firms have an increased propensity to innovate over smaller firms."

Another theme in the innovation literature which may be considered "exhausted" has been whether market pull or technology push have been the prime factors responsible for the production of successful innovations. The large interest in the theme may be due to the provocatively interesting study by Schmookler (1962), who studied four industries for the relationship between their patents and investments. In the railway industry he found that swings in the number of patents issued followed swings in capital investment. This was evidence that technical change was not a product of science alone, as suggested in the synoptic model (see below), but could be the result of market demand. A review of the literature by Mowery and Rosenberg (1979) concluded that both technical push and market pull were important and that especially the science and technology base of a company limited the types of innovation it chose to develop.

The market pull, technology push debate is an example of a class of debate where a simple and clear hypothesis can be postulated, of the sort "market demand is the principal cause of technical innovation." Methodologically respectable research can then take place and can attempt to verify or disprove the hypothesis in specific circumstances. The conclusions one can draw from such bodies of literature are frequently those that Mowery and Rosenberg draw in this instance, that there is no single general cause, but a complex of causes in which market and technical factors interact.

In summary there have been a plethora of comments by innovation writers that there is a need to look inside the firm at the process of innovation and the people involved in it. It was suggested here that this is due to the exhaustion of some typical macro-economic innovation research problems, such as the Schumpeterian hypothesis. This is not to doubt the value of macroeconomic data, but to suggest that it could be complemented by research into the people who take the decisions which result in innovation. This would be directed towards the managers and scientists inside the firm. The next section examines the potential of the innovation case study to yield new insights into the process of innovation.

1.5 Some Case Studies of Technical Innovation and Common Problems with Research Results

1.51 Gold and Criticism of Diffusion and Innovation Case Studies

Gold is an example of a writer who advocates detailed case study analysis of innovation after having criticised existing research, including existing case studies. Gold (1971 p21) has criticised the "synoptic model" that he believes is too often an implicit assumption in studies of innovation by economists. In this model the R&D department is where basic science is "applied" to produce new technology. The technology is then matched with market needs and innovation produced. This linear model is not "wrong," but is rather guilty of gross oversimplification of the complexity of the innovation process. When Gold considers how managers make decisions on innovatory projects he characterises decisions as, "elements in a stream of temporary successive commitments." Gold (1971 p222)

This contrasts with what might be termed a "rational" view of decision making where decisions occur at well defined points in time and represent optimal choices based on full access to information.

In a critical review of diffusion case study literature, Gold (1981) has criticised the innovation literature for its inarticulate and limited assumptions of how innovation and innovation diffusion occurs. His criticisms, which could apply to many examples of the innovation case study, can be summarised as follows:

1 Innovation is rarely discrete and does not develop in isolation from other innovations and products - it has a "technological context."

2 Innovation often arises because of other, larger aims, such as an attempt to produce a novel product or process.

3 The innovation and its environment are not static during the period of development and diffusion in the environment, as many models implicitly assume.

4 There are few studies of failed innovation and therefore little chance of an informed debate on the reasons for innovation success and failure.

5 There are few studies which compare reasons for the adoption of the same innovation in different companies.

6 There are few studies of the early part of the innovation generation process and of the reasons why managers and scientists pick one innovation over another for development.

One conclusion to be drawn from Gold's criticisms of this literature is that case studies need be no more informative about their subject than other research methods. As Burke (1970) observes, a typical study might be read in a period 1000 times shorter than the time span of the original series of events. The few events which are selected for the written case study depend on the precise concerns of the case study author. That this is a feature of all case studies is shown by Adelman and Jenkins (1977) who make the same point with regard to case studies in education and Hannah (1984) who makes it again for business history. The author of a prospective case study of technical innovation within the firm must be aware of the assumptions made as research begins.

1.52 Historical Case Studies of Innovation

In an attempt to increase the detailed knowledge of all innovation development in one industry over time, Gold et al (1984) has produced an edited collection of historical essays on innovation in the US steel industry. The detail of the work shows how the innovation environment of the steel industry was constantly modified by the adoption of innovations. It also shows that innovations slowly changed form through the period of their diffusion, but it fails to relate these observations to decisions managers took. Questions concerning manager intentions and reasoning cannot be answered directly in historical case studies, only deduced. The managers are dead. They rely on historical material which is largely statistical and designed to meet the needs of the firm or government in the past, and is not designed to reveal manager reasoning.

This is a limitation common to all historical case study work, including economic history to which one might hope to turn for informed case studies of technical change. Economic historians generally acknowledge the importance of technology over periods of time in entire economies and industries. However Freeman (1982) has noted that economic historians rarely take a technology orientated perspective at firm, R&D department or single innovation level. In a critical review, Alford (1976) describes mainstream economic and business history as either following the "great man" (entrepreneurial) or "classical economics" perspectives. Supple (1977) in another review believes business historians are preoccupied by "remote" studies, ie pre-world war 2, which are rarely relevant to modern business practice. There is a need for technology centred case studies which choose contemporary examples.

In one of the few exceptions to these criticisms of business and economic history, Graham (1986) has written an applied history on the research and development of the videodisc in the company RCA, (Radio Corporation of America). This study does examine innovation in the firm and at the R&D department level. It is also contemporary and shows little sign of being preconditioned by simplistic perspectives. As a result it is highly informative about innovation in modern corporations. It is true that Graham obtained an extraordinary degree of access to RCA internal documents and managers at all levels, something which might be difficult to repeat. She makes some interesting observations on the process of innovation,

> "the choice of technical approach to a given innovation often relies more on the internal needs and preferences of various parts of the corporation than on a sense of a need in the market place. Jobs, key skills, use of readily available equipment, shared characteristics with other projects and fulfilment of individual organisational goals are all legitimate internal needs that can influence choices made about a technology as much as, or more than information about the market." (Graham, 1986 p3)

Graham is therefore able to list some of the management values that conditioned the development of the technology in the case of the videodisc. Many of these values derived from RCA managers' experience of past projects. One of the uses of this study is that Graham is able to show how values and attitudes were formed in the past and how these set the context for debate over RCA's videodisc innovation.

1.53 R&D and Project Management Literature

There is a literature which aims to produce research useful to active managers in R&D departments, the R&D and project management literature. Perhaps typical of the kind of results this literature produces are 7 pieces of advice to managers that Mansfield (1977 p6) has abstracted.

1 Research should be related to a company's goals.

2 Relate research to competitors, customers and the scientific community.

3 Do not underestimate the uncertainty of projects.

4 Ensure proper transfer of new technology to operations

5 Do not allow research to become isolated from development

6 Do not allow degeneration of R&D to a "technical servicing department."

7 Do not focus solely on R&D - use innovation in other firms and industries and avoid the "not invented here" syndrome.

The list represents a summary of what Mansfield considers to be the most common R&D management problems. It is not very useful as advice to firms because it is difficult to form the judgement that these "faults" apply to a firm's activities. There must be other "rules of thumb" that led Mansfield to make such judgements in the case of particular firms and it is these that would be useful to firms. Such rules should be revealed by comparative studies of the decision making process in the R&D department, in the firm.

As has been said before, there are few such studies. The R&D management literature is the obvious place to look for insights, but unfortunately few insights are forthcoming. A review of the management of R&D literature by Radnor and Rich (1980) reinforces this criticism. They emphasise that studies of the management of R&D suffer from a lack of empirically based work, a neglect of integrated theory production and give little consideration of changes occurring through time. Small and limited areas for study are chosen such as "career ladders", which are so disaggregated that,

> "point to point linearity assumptions and a static view" are encouraged, (Radnor and Rich, 1980 p115).

Winkofsky and Mason (1980) come to similar conclusions in their review of the budgeting and project selection literature. In their view project selection is not a "constrained optimisation problem", as is commonly thought, but rather a,

> "highly diffuse and heuristic process carried out by many individuals and groups within a firm." (Winkofsky and Mason, 1980 p12)

These heuristics are used by a firm's managers. To find out what they are and how they differ between firms, it would be reasonable to interview the managers and give them the opportunity to express their priorities and values in managing their R&D department or a project, and this will be part of the approach in this thesis. This is in contrast to a survey technique which might ask managers for the degree to which they support statements which are not their own, but which are derived from a static neo-classical economic model.

Rosenbloom and Abernathy (1982) have written a case study which links management belief and consequent behaviour to the decline of the US consumer electronics industry. US management believed that consumer electronics was a "mature" industry and so they relied on advertising rather than technical excellence to sell VCR products. In contrast the Japanese were not deterred by market rejection of their prototypes and concentrated on improved product quality through production process innovation. The Japanese effectively captured the US market for VCR products as they had done for other consumer electronics products.

Rosenbloom and Abernathy's case study is interesting because the source of their chosen explanation for the decline of the US consumer electronics industry is a difference in management culture and belief, which results in a different approach to the development of technology. In this example, technology is something that a firm may choose to create and use competitively. A methodological feature of this study is that rather than use a model and a hypothesis to guide their research, they sought to understand a problem: why the US consumer electronics industry had declined and one of their main methods was talking to living managers in the countries concerned.

Another highly relevant study has been done by Langrish et al (1972). Langrish and his co-workers investigated every firm that had won the Queen's Award for Industry over a period of 2 years, and attempted to understand why their innovations had been successful. He stresses the complexity of factors that affect innovation:-

> "new productive process is the historical outcome of many strands of events." (Langrish et al (1972 p7))

This conclusion that no single factor governs innovation success is a common one, it is made by Rubinstein et al (1976) and Rothwell (1977) among others.

Thomas (1970) used participant observation to compare in detail some of the characteristics of two electronics companies' R&D departments. Unfortunately he constrained himself to,

> "assess information and economic needs of decision makers so that the decision-making function could be reduced to a logical evaluation of alternative outcomes." Thomas (1970 piii)

After having spent one day a week for 2 years and having written 204 000 words he concludes that more case study work within the firm is required and that,

> "The rational planner decision maker models are impracticable" Thomas (1970 p 598)

After having entered the firm and having been in a prime position to examine the complexity of the influences on innovation, he narrowed his perspective at the start of the study and so limited his conclusions. However, it is significant that empirical studies of manager behaviour in the firm, such as Thomas', frequently question the value of the rational planner model, and rational planning techniques. This suggests that these techniques and the model itself are of far more limited use than is commonly assumed.

1.6 A Conceptual Framework for Case Studies of Innovation

Chapter 1 has moved from looking at macro-economic models of technical change to technical change within the firm. It has shown that to examine technical change within the firm there is a need to understand how managers take decisions on innovation, which requires some form of interviewing of managers. This section develops a loose conceptual framework which will be used to structure the interviews of the research.

A useful "model" for the way managers deal with the large number of possible influences on the development of innovation is suggested by Braun (1981). Braun suggests what he calls "constellation theory" in an attempt to partially structure how multiple factors affect innovation. Managers' decisions to proceed with innovation development only occur when patterns occur amongst the relevant factors. In Braun's words, a process is developed only when the constellation of circumstances are such that managers recognise that a process should occur. Its most important feature is that it recognises that managers select and interpret factors which they believe affect the chances of innovation success. There is a need then, for an empirical study which allows for the managers' expression of the range of factors that they believe affect the innovation process.

This is an aim of this research and chapter 2 will argue that interviews with managers are necessary and that these interviews should be "semi-structured" and allow interaction between interviewer and interviewee. There is a need now to make explicit how such interviews will be partially structured.

Bessant and Grunt (1985) have culled a list of possible influences on the innovation process from their own and other case studies which they use in manager interviews. They are those concerned with personality, which are values, beliefs, experience and education and those concerned with the local environment, which are operating division and firm.

Bessant stresses the flexibility of this list and suggests that more "layers" can be added to this "onion" model if they are found to influence innovation development. For example, if the managers specify other influences, they can be incorporated into the list. His framework has been modified for this thesis by some of the additional influences that other writers have found to affect innovation in the firm, in the following manner:-

External Environment to the Firm	Markets for Innovation Other firm competition Other firm cooperation
Internal Environment of the Firm	Firm Division R&D Department Personality

This is a loose conceptual framework which makes no prior assertions about causality, but retains the possibility of many influences on innovation. The interactive nature of the interviews and the interpretive nature of this research allows these categories to be modified both during the collection of interviews and during interview analysis. These attributes of the research method will be discussed in detail in chapter 2.

1.7 A Focus for the Thesis - Novel Food Innovation in Western Europe

Novel food innovations were chosen as a group to be the vehicle for the case study because together they represent an attempt to produce a radical change in food production. They can be classified as attempted radical innovations which have the effect of substituting a complex industrial fermentation technology for agriculture as a means of producing protein. If they had been commercially successful on a large scale these innovations would have had a considerable economic effect.

Another feature which influenced the choice of novel food fermentation for the case study, was that a large number of firms had embarked on this research, so that there would be a common basis for comparison between firms.

It was initially thought that because most of these attempted innovations had been abandoned, managers would be more likely to speak freely about the influences on their past decisions. Since these innovation projects had been abandoned, mostly in the 1970s and early 1980s, they would also be fresh in the memory of managers interviewed. The tendency of firms to protect their interests through secrecy would probably be moderated if the projects no longer had much chance of successful commercialisation. However, one project was found to be experiencing commercial success; Rank Hovis with their human food product, mycoprotein, and another to be expecting such success, Dansk Bioprotein with an animal feed. The reasons for selecting novel food fermentation for this case study can be listed as follows:-

1 The innovations have a common base their use of fermentation technology to produce protein rich food or feed

2 Food, oil and chemical companies used fermentation technology to produce the innovatory food or feed products.

3 The projects were developed to various stages; full scale plant, pilot stage and only laboratory research.

4 The innovations as a group comprise both failures and successes.

5 There are a variety of market conceptions which developed with different projects

6 In the innovation taxonomy of 1.2, novel food fermentation would be classed as radical innovation, with all that that implies

7 These innovations represented the first attempt at commercial success in the industrial biotechnology field since the 19th century development of large scale brewing in the beer industry

The geographical boundary to this study is Western Europe due to limitations of finance and time, but reference is made to developments elsewhere, especially in Japan and the Soviet Union, (see appendices 3 and 6). The major commercial developments in the western world were all in Western Europe.

Within Western Europe the firms were selected for study if they had attempted to use fermentation technology to produce new foods or feeds. Within this group there is huge variation in the manner in which the technology is exploited, so much so that managers would sometimes regard other firms in the group as in another business. Paradoxically this variety of approaches to the technology provide one of the strengths of the study. The variety suggests something about the nature of technology itself, something that has been referred to in this chapter. It is given a structure, a detailed form by people and their organisations. It is the motivation and the perception of interests of these people in the novel food innovating firms that will be investigated in this study.

1.8 Conclusions

Chapter 1 has given reasons for studying technical change within the firm. A review of the literature established that a case study based on the people, the scientists and managers who make the decisions that create new technology should be of value. Whereas macroeconomic models of technical change are based on patterns of decision making which appear in the economy as a whole, microeconomic models of innovation should be based on patterns of decision making within the firm and it is a microeconomic model of this type that is the likely result of this research.

Chapter 1 has fixed some of the requirements of the research method during a survey of the innovation literature and these will be related to a research method in the following chapter.

CHAPTER 2 - METHOD OF DATA COLLECTION AND ANALYSIS

Introduction

Chapter 1 has argued that the process of innovation within the firm deserved more study and set out a loose conceptual framework to guide such a study. Those arguments were entirely based on an analysis of the innovation literature, but this chapter will describe an appropriate research method and will discuss methodological issues which arise.

The research is a case study of those companies involved in attempts to commercialise novel food innovation. The first section of the chapter therefore examines the status of case studies as a research tool. It is argued that case studies can be used to generalise and that their use is not solely restricted to the case that they use. In section four there is a development of the related idea that theory can be generated from a single instance to apply to a wider range of instances. In sections two and three it is argued that a study of managers through interviews needs to make assumptions about social psychology and these should be made explicit since they will guide the choice of interviewing technique and affect interpretation of the results.

2.1 The Value of Case Studies

The term "case study" covers a vast range of research forms. Education and business history researchers have long favoured the case study while economists appear to have dropped the case study from their research method armoury. Most discussion of the value of the case study is to be found amongst these two fields of research. A good starting point for a discussion is the definition of a case study by Adelman et al (1977 p140).

> "The case study is an umbrella term for a family of research methods having in common the decision to focus an enquiry around an instance."

So if research is described as a case study this does not imply the use of a standard research method. The "specific instance" may be examined through standard structured interviews or there may be a mix of methods, perhaps questionnaires and unstructured interviews. This definition also says nothing about how a case study may be used. The method and the use of the case study are both influenced by the assumptions and beliefs of the researcher.

In chapter 1 a variety of innovation case studies were referred to where the material and hence the value of the study was restricted to the questions with which the study was concerned. These questions also varied in complexity with consequent variation in complexity of material in the case studies. The more intricate case studies allow a number of interpretations of the events they describe, an effect that is considered as the equivalent to statistical degrees of freedom by Campbell (1975).

A range of case study "types" can be imagined from the simple use of anecdote to illustrate perhaps a single point, to a complex case study with a variety of possible interpretations. In the latter, to retain some complexity, material is collected with sensitivity to a variety of possible relationships between variables. However, the study is still directed - for example, in chapter 1 the use of the simple "synoptic model" of the innovation process was found to restrict the diversity of case studies.

At this complex end of the range, there is the case study where there is perhaps no formal theory or model predicting connections between variables. There will be a group of perhaps poorly connected, but independently valid interests and expectations of relationships which do not add up to something with the status of a "theory". In case studies of this type the problem becomes how to cope with the many possible relationships within the material of the case study.

It is this type that is favoured in this thesis, and for the following reasons. If what Gold (1981) refers to as the "synoptic model" is rejected as a poor representation of the innovation process, it is because innovation is a complex process although it does involve, as the synoptic model implies, some matching of technical and market opportunities. The requirement is not for more research which strains to constrain empirical evidence into the narrow waistcoat of available models. It is rather for the systematic sorting and display of the factors that affect the innovation process and the statement of likely connections between them. That is, there is a need for research which can help a move towards a better model of innovation. This is one of the aims of the thesis.

The work by Langrish and Gibbons et al (1972) is an example of this last type. The study was limited to the firms which won the Queens

Award for Technological Achievement in a period of two years and the reasons why they innovated successfully. The study did not predict precise relationships between innovation success and certain factors. They did pay particular attention to the relation between basic science and innovation and concluded that they could not identify basic science inputs as a major factor affecting firm innovation. However they did not restrict their study to this relationship and therein lies its strength and value.

Project SAPPHO is a study which began by making predictions about which factors would govern innovation in the firm, but it made over 200, which it then reduced to a small number through the study of many pairs of successful and similar innovations, (SPRU, 1972). This is an example of a study where the variety of the initial assumptions contributed to the validity and precision of the conclusions.

Authors from a number of social science fields have called for more case studies; Cronbach (1975) in psychology, Supple (1977) and Hannah (1984) in business history, Adelman et al (1977) in education research. The reason why these calls are resisted by many economists is that case studies are often associated with various methodological "evils." If these were to be listed they would certainly include the supposed "unrepresentativeness" of case studies and the use of inductive reasoning, which is the tendency to make generalisations based on the case study. An articulation of these beliefs can be found in Popper (1972) or Medawar (1979). Popper's work may even be partly responsible for the success of the view that the case study and induction are fundamentally flawed research tools. The reasons for these beliefs probably owe a great deal to what Kuhn (1970) calls "normal science" as the dominant form of problem tackled in the physical sciences. However, this chapter is not the place to continue a discussion on the origins of different disciplines' predilection for one methodological approach or another, although the effect of these widespread beliefs on the case studies that are undertaken is interesting. For example, Hannah (1976) describes the effect on business history case studies, where,

> "the absence of generality unnecessarily inhibited business historians in the rigorous development of causal interpretations." (Hannah, 1976 p6)

The result of this inhibition is that too often these case studies would be simply descriptive, so that insights and interpretation of case study material is minimal.

Hannah's "rigorous development of causal interpretations" of case study events is only a step away from advocacy of inductive reasoning. All that is missing is the suggestion that the explanations for the case study events might apply outside the specific instance. Such inductive reasoning from case studies is advocated by Mitchell (1983) who believes that,

> "...extrapolation is based on the validity of the analysis rather than the representativeness of the events."

More simply, arguments will be judged by common sense and their inherent likeliness. Clyde-Mitchell gives an example in the story of the psychologist who found a statistically significant correlation between stomach disorders and the tendency to perceive frog-shapes in Rorshach ink-blots. The psychologist's Freudian explanation was that the frog was anal-symbolic and demonstrated that the stomach disorders were linked to anal-obsessive personalities. This analysis was seen as inherently unlikely by his clinical psychologist colleagues and no follow up research was carried out, despite his impeccable statistics.

It was the validity of the analysis which was at fault, not the research method. Even with an "impeccable" methodological approach, ridiculous conclusions can be reached. Researchers can become obsessed with "scientific method" to the detriment of common sense[1].

Clyde-Mitchell's argument is supported by Adelman et al (1977) who also write of the difference between the type of generalisation that comes from experimental research and a case study,

"It might be asked whether the generalisations produced by case study are stronger or weaker than those of experimental research. Stronger or weaker they tend to be different...in practice the most important differences are in the way claims are made against truth and in the demands made upon the reader. Experimental research "guarantees" the veracity of its generalisations by reference to formal theories and hands them on to the reader; case study research offers a surrogate experience and invites the reader to underwrite the account, by

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1 Watson (1986) has a similar view when he advocates the use of "critical commonsense" in research

appealing to his tacit knowledge of the human situation." (Adelman et al, 1977 p143).

So far this discussion has made two points:-

1 The number of factors considered in the study and their interrelationships should reflect assumptions about likely influences on the process of innovation rather than be determined by a single model or theory.

2 It will be valid to make informed comment about the process of innovation in general, based on the case study.

The large number of innovation influences referred to in chapter 1 and all their possible inter relationships might be thought to pose a problem for the collection of data and its analysis. This is not the case since only a few of the possible relationships are likely to be valid and the selection of which ones are important in conditioning innovation is done by the managers themselves. Properly constructed interviews should yield the managers views on how innovation took place. The next section outlines a psychological model of social interaction which supports this approach and the choice of interview method.

2.2 People as their own Theorists

The problem of the last paragraph is only a problem if you believe in the "rational man" of classical economics origin. Only rational man would attempt to imagine the outcome of every possible permutation and combination of a given set of factors. When making decisions real people operate selection rules which strike out all but a small and manageable number of options. Elger (1975) describes the origin of such selection rules,

> "Conceptions and interpretations are products of past experience informed by ideology and preconception. There is no simple response to environmental stimuli (but) choice is exercised in the limiting assumptions and selective perception of key personnel." (Elger, 1975 p116)

In Elger's view individuals in industrial organisations have constantly fluxing attitudes in response to organisational experiences. When faced with major organisational crises there is a reorientation of their attitudes and beliefs, although the reorientation is conditioned by prior experience. Elger calls this view of organisations a processual perspective because there is a process of negotiation of the organisational reality that continues between all levels and individuals in an organisation.

Elger is also one of many critics of organisational and economic literature. Child (1972) is another author who has criticised organisational analysts for over-emphasising the determining effect of external factors such as firm size and technology on organisational form. Child points out that managers exercise a degree of choice within these external constraints.

However Weick (1979) is a critic who goes further than Elger or Child and develops his own model which describes what an organisational environment is and how causality operates in such a model. Weick broaches new and useful ideas as he combines psychological insights with organisational analysis. This social psychological model succeeds in being a coherent and self-contained alternative to the orthodox views of how organisations function. It is important to the thesis because it will be used to support the argument for semi-structured interviewing as a principal method of data collection.

By stressing that all organisations rest on personal interaction Weick, like Elger, diminishes the idea that organisations are somehow "real" beyond the interactions that make them up. An organisation is only the sum of the personal interactions of its members and these interactions are conditioned by the inability of people to process all of the information that they receive. They therefore selectively retain key events. In Weick's terms individuals use "causal maps", which are particular sets of causal relationships between remembered events. These causal maps are used to identify events of relevance out of the huge influx of information continually being received by the individual. This is the process of "enactment", through which some events receive conscious attention and others do not. An enacted event is a significant event and it is the past experience of the individual which affects which events are enacted. However, a set of events then has to be given meaning and there may be several ways of interpreting these events. This is where negotiation within an organisation may take place to reduce the equivocality of the events and enable a move towards their common understanding. The result of negotiation may be that selected events are incorporated into individuals' causal maps and so help to change the way in which future events will be perceived.

This process of internal negotiation results in the members of an organisation having a perceptible similarity of outlook to an outsider and it could be suggested that this similarity is the basis for saying an organisation has a "culture". It should follow that a culture will rarely be a unique and well-defined entity. It can be defined as far as the values chosen to define it by those inside an organisation are similar to the values chosen by people outside the organisation, but it will inevitably be perceived differently by people since they all have their own causal maps.

Weick's model depends on a reformulation of the psychological finding that sensory perception cannot be separated from mental preconceptions - belief has always been found to mediate perception and it follows that there is no such thing as "pure" observation. Yet the set of beliefs that mediate perception are themselves changed by the process of perception. There is therefore a process where the model which modifies perception, is itself updated, in Weick's terms an updating of the "causal map".

Weick also considers that firms operate in a "selection environment", in which the better adapted firms grow while others decline. However a consequence of Weick's model is that the environment has no "real" existence but is the causal map belonging to the members of a firm. The "environment" to individuals in a firm includes other parts of the firm with which they have to work. In contrast, the firm - environment boundary is frequently taken as a very real and absolute separation by other organisation analysts, for example, one thinks of Chandler (1962) and (1976) with his senior managers planning rationally in response to environmental change.

The idea of a "selection environment" requires that there is a sense in which some causal maps can be "better" than others at conferring competitive advantage on firms. This raises the question of to what extent there is an external and objective reality which the causal maps seek to understand, with the better causal maps having a better "fit" to the selection environment. The view adopted here is that "reality" is socially constructed rather than having an "objective existence" separate to people. Some causal maps can be better than others at conferring competitive advantage because they are better than others at interpreting events in order to understand other people's needs and expectations.

To examine the process of innovation we need to examine the relevant parts of the "causal maps" of the managers who were closely involved in the novel food projects. They themselves will have selected the events that they believed were major influences on the project and there is a need to understand their actions as they themselves understand them. This process of trying to understand thought through a process of "mapping" ideas has been referred to as "cognitive mapping" by Eden et al, (1983). Reed (1985) comments that a commitment to,

> "'cognitive mapping' indicates a concern with explicating the concepts which practitioners rely on to make sense of the practice in which they are engaged - that is, with

describing and reporting the framework of assumption, beliefs and ideas which practitioners develop." (Reed, 1985 p141)

This leaves the question of how to "cognitively map" and the next section argues that the use of semi-structured interviews are the most appropriate method.

2.3 Cognitive Mapping through Semi-structured Interviews

Although we have a collection of possible factors that influence the innovation process we have no theory predicting the relationships between these factors in particular circumstances. Therefore it would be quite wrong to use structured interviewing techniques because these assume the interviewer has a clear understanding (through theory) of what the possible (and limited number of) responses will be. Completely unstructured interviews are never truly possible since the interviewer is sure to be required to make some sort of an introduction of themselves, and by physical presence alone will affect the interviewee. One could try to minimise the interviewer-interviewee interactions and this may be appropriate in certain circumstances. The unstructured type of interview and the degree of interview interaction are discussed in detail by Spradley (1979).

Between the two extremes of structured and unstructured interviews, the term "semi-structured" covers interviews where there is a degree of interaction between interviewer and interviewee. In this thesis chapter 1 has set up a background of prior interests which will condition the questions asked in the semi-structured interviews and show whether the innovation influences are regarded by the managers as important influences and whether they comprise a near "complete set".

The questions also follow what Pettigrew (1979) refers to as an "event schema." For example there would be a series of questions about the firm's market conception at the stage when the project was first thought up and then at each successive stage of development. By working through the different innovation influences and how they may have changed through the lifetime of the project the interviews are given an initial structure by the interviewer. The open-ended nature of most questions allows the managers to express their own views on how their projects evolved. They tended to use these opportunities to spin their own "stories" of the project. In these stories, various project events are understood by anecdotes illustrating key influences on those events or general "truths" about personalities, organisations or the environment.

Piore (1979) has also remarked on managers' tendency to describe events in the form of such "stories." Piore attempted to ask structured interview questions but found that managers insisted on adding explanations that were not being covered by the structured questions. Since these were intrinsically interesting to the research, the experience led Piore to question the structured approach. He found that the econometric model of manning arrangements itself was called into question by the process that his interview "stories" revealed, something that could not have happened with the use of structured interviews alone. This has led him to appeal for the reintroduction of qualitative research techniques into economics.

Piore made another observation which was born out by the interviews for the present thesis. This was that even with official authorisation to interview lower officials in organisations, active cooperation was gained only when they were allowed to tell their stories of events. Their consequent enthusiasm was then very useful, for example in identifying other useful contacts in the organisation. In the case of this thesis there was rarely a need for official authorisation, but there were occasions when an insistence on a certain line of questioning began to be counter-productive. Appreciative listening rather than an insistence on the interviewer's preconceived notions of events tended to build a good relationship.

This approach is strongly supported by Hickson et al (1986), who compare an ethnographic study of a social setting with an attempt to understand the setting through selective semi-structured interviews. They comment that,

> "It was found that the essentials of problems, interests and processes could be gathered by interview. Interviews give an outline narrative of main events and participants through the answers to a series of questions about what happened, without it being necessary to discover every incident. The hindsight story that is forthcoming...is the same in main events and characteristics, just less cluttered with detail." (Hickson et al, 1986 p25)

Weick's model of people acting as their own theorists could lead to the same conclusion even without the Hickson evidence. In Weick's model the managers would have selectively retained the series of events that constituted a project. Their "story" in a semi-structured interview will therefore be their interpretation and particular selection of relevant factors contributing to those events. The Hickson evidence is equivalent to saying that had the researcher been present during the series of events themselves, their interpretation would have been similar to the manager's interpretation. Semi-structured interviews may not yield an account of what it is like to be a manager in a particular organisation, but they do identify the principal influences on events and the relationships between them.

2.4 Analysis of Data and Grounded Theory

It will be necessary to develop conceptual links during the analysis of the interview notes and transcripts that make up the qualitative data. Glaser and Strauss (1967) and Strauss (1987) developed a method of analysis of qualitative data that has acquired some of the reputation for rigour and formality that is usually associated with statistical analysis of quantitative data. They define the development of "grounded theory" as the process of discovery of theory from data using the method of comparative analysis.

Comparative analysis can be used to produce grounded theory in the following manner. The qualitative data is read carefully and notes are made in the margin of the text. These margin notes consist of any and every thought that the researcher has which is related to the material. A major function of these margin notes is to categorise the text and for this categorisation to enable a reordering of the text by the ideas and insights of the researcher. This requires the physical cutting up of the text and its reassembly in files headed with the dominant categories from the margin notes. Dominant categories are found by rereading the margin notes and identifying the more frequent categories and themes within categories.

An example in this study was the repeated references to a product champion by some interviewees. These references were frequent enough for a file to be started which was labelled "product champions" and into which all such references were inserted. By a process of continually comparing categories for their adequacy in representing the material within them, some of the weaker categories may be weeded out or merged with others. So where an incident suggested the significance of the power of one person and was headed "dominant personality", this became subsumed within the product champion category.

The dominant conceptual categories provide the grounded theory and this theory should be a valid way of interpreting the case study material. Glaser and Strauss (1967) argue that the comparative analysis used to produce this theory also makes it likely that it is useful in other cases, although here its validity remains to be tested. The production of grounded theory does not therefore contradict anything that has so far been said about case studies. It is useful in that it contains a systematic procedure for the production of insights, which can then be applied (using Mitchell's (1983) argument) in other situations, but dependent on the quality of the analysis.

In a number of ways grounded theory requires a different set of research skills to the survey and experimental methods of research (for which see Wilson, 1979). Perhaps one of the most important is the quality of reflexivity. This is the conscious cultivation of awareness of personal experience and the attempt to increase the sensitivity of the observer. This quality is frequently associated with the ability to do good qualitative research, for example by Wright Mills (1970), or even with good management skills (Mangham, 1986).

Grounded theory can be thought of as the formalisation of the "craft" of doing qualitative research. There are a number of more personal accounts describing the attributes and practice of a good sociologist for example Wright Mills (1970). These have in common the advocacy of some kind of system to enable the storage and retrieval of qualitative research data. Wright Mills advocates the use of a private journal, a filing system based on a lifetime research plan and the periodic resorting and reclassification of this filing system as interests and projects change.

It is therefore not so important to follow all the steps laid out as grounded theory by Glaser and Strauss as to have some systemised method of dealing with data. However, it is possible to be even more formal and "methodologically minded" than Glaser and Strauss. Turner (1981) interprets grounded theory production slightly differently to Glaser and Strauss. For Turner theory generation is the process of assembling new cognitions into a coherent framework, a useful idea that links grounded theory to the earlier references to cognitive mapping. The main advantage of grounded theory for Turner is that it brings the cognitive research process out into the open.[2]

It should therefore be possible to exhaust the "set" of cognitions pertinent to a particular case study. Comparative analysis is efficient at collecting cognitions and developing categories but there comes a point in a case study when these returns diminish. Glaser and Strauss refer to this as theoretical saturation. Once categories have become established they can be ignored and as the analysis proceeds only the novel insights and categories need to be noted.

This was the case with one of the last interviews of the fieldwork, with Gulbrandsen of Norsk Hydro. There were very few new insights and therefore his name does not show up often in the quotations of the text. The interview was most useful as a check on the conclusions drawn from the earlier interviews. This was an important feature of the interviewing method, that it was possible to cross check key statements and views by using early interviews to guide the questions of the later interviews.

2.5 Grounded Theory and Semi-structured Interviews in Practice

The previous sections have described much of the literature background for the research method of the thesis, but this section will describe the experience of using this research method.

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[2]However, Turner becomes too involved in describing the marginal merits of alternative grounded theory procedures, a criticism which also applies to Martin's (1986) appreciation of grounded theory.

The initial bounds of the project included all novel food and feed-from-waste projects in Western Europe. However it soon became clear that there were many yeast from waste projects running in Western Europe, more than it was feasible to visit. The interest in these projects became restricted to Tate and Lyle, Bel Industrie, Cellulose Attisholz and the Pekilo plants. Together these covered the major "types", based on different waste substrates. This group also covered the cases where there was a serious attempt to license the technology. The only waste processes that were omitted were the Swedish Sugar Company's Symba Yeast process and the Waterloo Process, the latter originating in North America.

However the decision to focus on the major SCP (single cell protein) projects plus RHM's fungal process was not taken at one point in time. The research followed a developing "network" of manager contacts, with one contact suggesting the names of several other managers who might cover, for example, the market or technical sides of the project in other companies. There was a degree of choice over who to see and this depended on what seemed to be the most important questions pertaining to a particular project. The result of following up the most interesting contacts was that the waste processes lost out by default.

Obtaining the necessary interviews for this research was more difficult than at first anticipated. Originally, a written approach to several firms was made by letter requesting interviews with managers, which met with a negative response. It was a personal contact between the head of life science at Trent Polytechnic and a former manager at ICI which brought the first interview. The network of interviewees was established as this contact provided further names, and they in their turn provided others. The origin of the manager network was their shared experience as microbiologists at university and the personal acquaintances they made on the fermentation conference circuit. This was sufficient for them to know the names and positions of many of their counterparts in other organisations. A glance at appendix 7 which lists those managers interviewed shows that many of those interviewed were scientists or R&D managers.

The network did not extend to all the continental companies, especially not the waste process companies. These were too small for individuals to be known to the "core" contacts in ICI, BP and T&L, but the company names were known. In these cases an approach through the switchboard was necessary; sometimes a telephone conversation took place rather than an interview. Notes from these telephone conversations produced useful data which was analysed in the same way as the transcripts.

Interview networks have been remarked on by Foot-Whyte (1960) in his unique work on interviewing in field research. This records many of the experiences of a researcher in qualitative interviews. Foot-Whyte notes that the informants at "connections" in the network are often especially valuable. In this research these connecting positions corresponded to one manager's opinion of another company's project. These short overviews were invaluable as a guide to the important issues and features of the projects, for example it was outside comment by Bu'Lock (ICI consultant) that identified the methanol nozzles of the

ICI fermenter as having been problematic. ICI were willing to talk about this matter, but they might not have raised it themselves.

Another feature of interviewing that Foot-Whyte comments on is the need for a relatively neutral subject matter with which to start the interview or to which you could return if the interviewee becomes touchy. This was not a problem in this research since the emotional quality of different relationships within the company were not felt to be highly important. However the research was aided by the developing knowledge of SCP which was gained by the researcher. This was useful in that it helped show interviewees that the researcher was not ignorant of their field. This was probably the reason why the use of personal contacts worked better than the cold written approach to potential interviewees; it helped to establish a rapport.

Another aspect of the interview relationship was to what extent one could be confident that the interviewee was not "distorting" the account for the interviewer's benefit. In this case and where sensitive topics were not raised, reading between the lines of technical papers and exploiting the individual differences in manager accounts over what was considered sensitive helped to cover these issues. (See earlier with reference to Bu'Lock). The interviews were aimed at understanding how the managers saw events and there is no problem with any other kind of "distortion" because our view of a socially constructed reality and multiple perspectives in any social setting make the notion of "getting at the truth" less important. There are no obvious reasons why the managers should have changed their stories, as Treeby (RHM) claims,

> "No part of the chain of historical decisions gives me any trouble, including identifying how the real decisions were made as opposed to what in retrospect we would like to perceive as decisions. The only areas where I would start to become more sensitive is any area regarding a commercial relationship which is current and very much under discussion."

Since many of the events were known to many managers it was possible to cross-check some of their interpretations. The reason for the Italian ministry of health refusal to approve Toprina was probably the issue that was checked most often because there was no consensus view amongst interviewees. However the result of a lack of consensus was interesting since the various interpretations of events could be contrasted. The desire to cross-check particular points had to be tempered by the need not to pressure the interviewees and to allow them to develop their own stories.

A tape recorder was used and interviews transcribed wherever possible. The advantage of this was that relatively long quotes were possible in the text of the thesis. This gives the thesis it's distinctiveness and something of the flavour of what it must have been like to have worked on one of these projects should come over to the reader.

For two of the early interviews notes were written up even though a tape recording had been made so that the two methods could be compared. The result was that although a remarkable amount of information could be retrieved from memory when writing notes immediately after an interview, this information was inevitably a selection of the issues raised. This selection occurred on the basis of what was thought to be important to the innovation process before the interview occurred. Since this changes over the period of the research, interview notes become less useful the earlier they are taken. A transcript can be returned to and reinterpreted, notes are already a partial interpretation of the interview. This was the case with one of the first interviews, with Peter Harwin, (ICI). The notes that were taken were useful in setting up questions for the next interview in ICI, but these later interviews superceded the Harwin interview in content.

In the later interviews the categories for grounded theory were sufficiently developed so that the responses to questions were increasingly repeats of earlier interviews. There was an effect, then, where the interviews became increasingly useful then began to decrease in value. The Gulbrandsen (N Hydro) interview has already been referred to earlier as an example of the later type of interview. Because the categories were no longer changing so rapidly note taking after the interview would have been a more efficient use of time. A mix of methods would seem most appropriate to grounded theory production of this type.

The development of fixed categories and therefore a focus for questions was accompanied by an increase in the sophistication of the questions. It was this that led to the most interesting responses and the greater yield of quotes than in the earlier interviews. This focusing on issues is something which is found in similar studies such as Graham (1988) and Bessant and Grunt (1985). It was found that the best way to take advantage of the later interviews was to prepare an advance list of questions and send it on to the interviewee. The advantage of the advance list was that the questions revealed to the interviewee how much was already known and so saved time working through established material. This evolution of the prepared questions can be seen in the samples in appendix 4.

As the interviews were recorded they were promptly transcribed and analysed as described above. This grounded theory analysis had the advantage that not only chapter titles but sub-headings were obtained depending on the frequency with which a topic recurred. The grounded theory analysis therefore effectively cut out much of the organising of material for the writing up tasks.

The development of conclusions or theory from the data was not quite as simple as Glaser and Strauss describe. Open ended conclusions, tentative generalisations and patchy new models are the likely result of grounded theory in practice, rather than final answers to important questions, or grand unifying theories. This does not reduce the value of the exercise provided there is an increase in understanding of issues.

The obvious route to improving the quality of analysis is to relate the grounded theory to bordering fields of knowledge, marketing, corporate strategy etc. The discussion does not pretend to be complete or to make due reference to all preceding work. It is likely that the researcher has some idea of the literature in these bordering areas where his grounded theory is making incursions and this should be made use of in conclusions.

2.6 Conclusions

This chapter has described a research method for the case study and a means of analysing qualitative data. It has justified the use of semi-structured interviews to investigate a case study and the use of grounded theory to analyse the interviews collected. Open ended conclusions, tentative generalisations and patchy new models are the likely result of grounded theory in practice, rather than final answers to important questions, or grand unifying theories. However, it will be valid to make informed comment about the process of innovation in general and to combine such ideas to form a model of the innovation process.

CHAPTER 3 SINGLE CELL PROTEIN AS THE PRINCIPAL EXAMPLE OF NOVEL FERMENTATION TECHNOLOGY

Introduction

In this chapter the history of the single cell protein projects is summarised and the technology and relevant science to one of the projects is described in some detail. This involves a description of the production process of one of the full scale plants which will be useful when managers come to talk about each step, as they do in chapter 8. For reference there are tables of the companies where interviews took place, length and number of interviews, size of plant built and names of the different protein products. Finally, there is also a summary of the decisions made in each of the four projects which progressed furthest.

This chapter should make the debates and references to technical issues intelligible and serve as an SCP primer to be referred to if the going gets tough in the chapters ahead.

3.1 A Short History of Single Cell Protein[3]

The name single cell protein or SCP was given to the industrial processes for fermenting microorganisms by Nevin Scrimshaw, an academic at MIT in the late 1960s. At this time many oil companies started research on the feasability of SCP processes based on yeast, bacteria

[3]Also see Marstrand (1981) for an overview of SCP development.

or fungi.[4] The aim was to produce novel foods or feeds through the industrial fermentation of these micro-organisms on some kind of hydrocarbon substrate.

Scientific papers were published as long ago as the late 19th century on the ability of certain bacteria to grow on methanol. Some sulphite liquor waste processes were installed during the 1920s to produce yeast as animal fodder and during the second world war both the Soviets and the Third Reich hurriedly constructed food yeast manufacturing plants to provide protein supplements to the diets of their industrial populations. Germany had also attempted to construct such plants in World War 1, based on Candida Utilis yeast. Solomons (1983) reports that production only reached half the German target due to technical problems.

At the end of the war the German food manufacturing technology was a priority interest for both the Soviets and the Western powers. Lewis (Shell) tells the story of how, besides cats, rats and dogs, the Soviets managed to feed yeast protein supplements to their troops during the defence of Stalingrad. Lewis suggests that yeast supplements can be added to the list of factors that "could have tipped the balance" during the second World War. It is from this time that the Soviet Union has been interested in single cell proteins and the Soviets continue to operate more plants than any other country in the world, (see appendix 3).

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[4]Fungi are multicellular but companies that fermented fungi attended the same conferences as those interested in yeast and bacterial fermentation. Their scientists also published papers in the same journals.

Immediately after the war SCP plants continued to be built for human food supplements. For example, in 1948 Candida yeast was grown on waste sulphite pulp liquor and using German-type technology in the US, later a second plant was built of 5 000 t/a capacity which has only recently ceased operation. In 1947 the British Government financed a project to grow Candida Utilis on sugar-cane molasses in the West Indies as a protein-vitamin supplement for the indigenous population. The project eventually failed, apparently due to technical problems and under-capitalization, Solomons (1983).

Once the food shortages of the War and the immediate post-War years had passed, interest dropped away in yeast as a food. Not until Champagnat, working for BP, announced his team's succesful cultivation of yeasts on petroleum did general interest increase again. Solomons (1983) comments that at the time it was known that micro-organisms could grow on water insoluble substrates such as petroleum, but there was an assumption among scientists that these organisms would be rather specialised and would grow only slowly. The BP announcement stimulated world wide interest in these organisms, particularly among the oil companies.

During the 1960s oil was cheap and protein, in the form of soya meal, was relatively expensive. More important, the trend in the oil price was downwards, that of soya stable or expected to be upwards. Chemical companies with access to cheap hydrocarbon substrates also began research programmes into SCP -ICI and Norsk Hydro took North Sea gas as their starting point for manufacture. The expectation of an increasing protein "gap" was a further reason for developing the technology. In the late 60s to early 70s world population and therefore demand for food was expected to grow faster than conventional agriculture could expand its output. It was thought that there would be a specific shortage of protein in many third world diets. These forecasts of world-wide protein shortages seemed to guarantee the economic success of a novel protein manufacturing process. It was this expectation of a food shortage that encouraged some of the food companies into novel protein manufacture. The food companies used non-oil derived substrates, such as starch and glucose where these were being produced as surplus to other food manufacturing processes. The fermentation of the substrates would enrich the protein content of these by-products and offer the prospect of turning them into complete foods with higher value.

Another group of companies manufactured SCP, but on a small scale and as a means to solve waste disposal problems linked to their principal activities. This group includes pulp, confectionery and palm oil producers. Most were uninterested in the SCP conference circuit, preferring to buy in technology from equipment manufacturing firms and it was the latter that tended to do the research, build the pilot plants and attend conferences on SCP. The largest capacity waste processing plant would be less than 10 000 t/a,limited by the volume of waste products, compared to target capacities for the SCP plants of around 100 000 t/a.

The oil price rise shocks of 1973 and 1979 overturned the economics of the hydrocarbon based SCP processes. During the period 73-82 research and development was abandoned by almost all the oil and chemical companies. The soya price fell in real terms where it had been expected to rise during the 1970s and this seemed to finish hopes of an economically viable process. However, with the fall in hydrocarbon and energy prices in 1986 the economics have once more become more favourable. There is now (1989) one project run by Dansk Bioprotein in Denmark which aims to produce SCP from North Sea Gas by late 1990. The food and waste-based processes were not severely affected by the change in oil price, but the cheapening of the price of soya in the 1970s and the development of new waste treatment technologies undermined the economics of some waste processes.

At the present time (1989) there is only one product on the market and this is "Quorn", which is a mycelium fungus grown on a glucose substrate by Marlow Foods, a company which is jointly owned by RHM and ICI. According to Spencer (1989), there are now over 40 prepared dishes which contain Quorn and which are being sold through various supermarkets and chain stores in the UK. It is the intention of RHM and ICI that Quorn will become a major, internationally traded foodstuff.

The success of any of these projects would mean the addition of a new food to the human food chain. Either animals would eat the novel proteins and people would eat the animals, or else people would eat the proteins directly. As one manager put it, the success of Quorn represents the first time since the potato that Western populations have begun to eat an entirely novel source of food.

The attempt to commercialise single cell protein can be seen as the first development in what would now be called biotechnology and some of the scientists who originally worked on the SCP projects are now to be found in small biotechnology companies. Some of the technology developed by the SCP projects has been applied to other projects in the bio-industrial field which are still current, but it is likely that much of the technology will never be used because it is too specific to a certain type of biological production; continuous fermentation to produce a low-priced commodity. At present, low-priced, biological commodities of all kinds are produced more cheaply through agriculture.

Between the time BP announced its interest until the present time, roughly £ 1 000 000 000 in today's money has been spent on SCP projects in the West. The three companies that built large commercial plants incurred most of this development cost, BP, ICI and Liquichimica. There have also been literally hundreds of small research groups, mostly in universities all over the world, who have investigated a wide range of possible organism and substrate combinations. These substrates include peat, all kinds of vegetable processing wastes, animal waste slurries, oxidised polyethylene and fish oil. Solomon (1983) lists 27 references to unusual substrate-organism SCP research. This research has now almost entirely faded away.

3.2 Companies

Table 3.1 shows which companies were involved in the technology and the stage to which they pursued development. Although there was variation in the technological complexity of the pilot plants and full scale plants, the table ignores this and serves as a rough guide as to how far each company progressed. It can be used to estimate the expenditure of the companies and the relative importance of the projects. If a pilot plant had been built, the cost would be of the order of £ millions, to arrive at a full scale, 100 000 t/a plant the cost in current pounds would be around £200 - £300 millions including all the development work

Company	Product	Pilot Plant	Full-Scale Plant	Number of Interviewees	Hours Inter
ICI	Pruteen	1000	70 000	8	13
BP	Toprina	4 000	100 000	4	7
Liquichimica	Liquipron	yes	100 000	1	3
Hoechst	Probion	yes		1	3
Shell		yes		4	7
T&L		yes		3	5
Esso-Nestle		yes		1	0.5
Pekilo		yes		3	2
RHM	Quorn	yes		1	2
Norsk-Hydro		yes		1	2.5
Unilever				1	1
Amoco	Torutein	7 500		0	
Philips Petr.	Provosteen	1 800		1	0.5
Swedish Sugar	Symba	10 000		0	
Cell. Attishlz		yes		2	2
Bel Industrie	Protibel	yes		1	1
IFP/ELF/CFG		yes		1	2
Rumania/Jap		yes		0	0

Table 3.1 Company, Product and Interviews

and pilot plant construction. This was how the managers estimated the cost of a project, exact figures rarely being available or easy to remember. Only 3 companies spent this kind of sum on SCP; ICI, BP-ANIC and Liquichimica. On the opposite end of the scale of expenditure are T&L and the waste substrate processes with an expenditure of a few £ millions on low capital intensity technology.

The micro-organisms could be grown in batches on agar jelly or shake flasks, but this yielded no sizeable quantities of product. To do nutritional and toxicological research a pilot plant of around 1000 t/a capacity had to be built. Liquichimica built a pilot plant with the sole purpose of training the technicians who would have to operate the full scale plant. The jump from a pilot plant to a full-scale plant of 50-100 000 t/a capacity assumes the larger scale fermentation will pose no radical engineering problems. Some companies built a semi-industrial plant to test the viability of fully scaling up production, others jumped to full-scale from pilot plant. The semi-industrial plants' product was meant to be sold on a continuous basis on the open market, their capacity was about 10 000 - 20 000 t/a.

The plant constructed for Cellulose Attisholz and the Pekilo plants are classed as semi-industrial in table 3.1. These had a different economic justification to the hydrocarbon based projects and a semi-industrial size plant was as large as a waste-based protein plant could hope to become, given its dependence on the quantity of waste or by-product produced by the primary process.

3.3 Science Base - Micro-organisms

The two types of single celled organisms used to grow protein were yeast and bacteria. Bacteria are of the order of 1-2 micrometres, or millionths of a metre and reproduce by binary cell division. Yeast cells are larger, have thicker cell walls, have a lower protein content and reproduce differently to bacteria. Their cell size ranges from 5-10 micrometres and they reproduce by "budding" smaller cells from the parent cell membrane. They are in effect species of single cell fungi. Fungi are multi-cellular and have a thread-like, filamentous structure. Bacteria grow most rapidly, with a cell division time of 1-2 hours. Yeast grow a little slower and fungi most slowly of all.

However, the faster the organism grows the higher the percentage of ribonucleic acid (RNA) in their cell mass. This is the cell nucleic protein which transmits genetic information to the DNA of a new cell splitting off from the parent cell. RNA and DNA have no nutritional value to mammals and are simply broken down by the liver to uric acid and excreted. If a human diet contains too high a percentage of nucleic acids the uric acid burden on the kidneys may be too great and it deposits out of the urine as small stones or crystals in the kidneys and joints - which is the cause of gout.

In a particular species of yeast or bacteria there are many strains. So Candida Lippolytica, Candida Albecans and Candida Tropicalis are all yeast species, but each contains many strains. Each strain has precise optimum growing conditions; pH, temperature, pressure, nutrient requirements and product concentrations. Even within the same species, different strains metabolise different products, so different strains may be toxic or non-toxic to animals and human beings. These strains may not even be named in the microbiological texts, if there has been no reason for scientists to take an interest in them. This was true of ICI's bacterium which they named Methylophilus Methylotrophus, a member of the Pseudomonas genus.

The equation for cell growth in a methanol solution can be simply stated as follows;

$CH_3OH + NH_3 + O_2 = \text{Cells} + CO_2 + \text{extra-cellular products}$

While the carbon dioxide bubbles out of solution, the extra-cellular products excreted by the cells stay in the methanol solution. They may contain growth-limiting substances and they also represent a loss of carbon from the cell mass. Differing growth conditions will change the cells' metabolism and they can be manipulated to minimise the production of these products and maximise cell weight-gain.

3.4 Substrates and How to Choose One

The substrate is the source of carbon and energy which the micro-organism will use to build its cells and metabolise proteins. Any substrate will require nutritive elements to be added to it, nitrogen, phosphorus and trace elements. All the companies were looking for a substrate which was available in large quantities, cheap and capable of being produced in a very pure form. The nutritive elements were supplied as aqueous solutions so the substrate needed to be water-soluble or, in the case of the n-alkanes, prepared as an emulsion. Nitrogen was generally supplied as aqueous ammonia and sulphur and phosphorus as sulphuric and phosphoric acid.

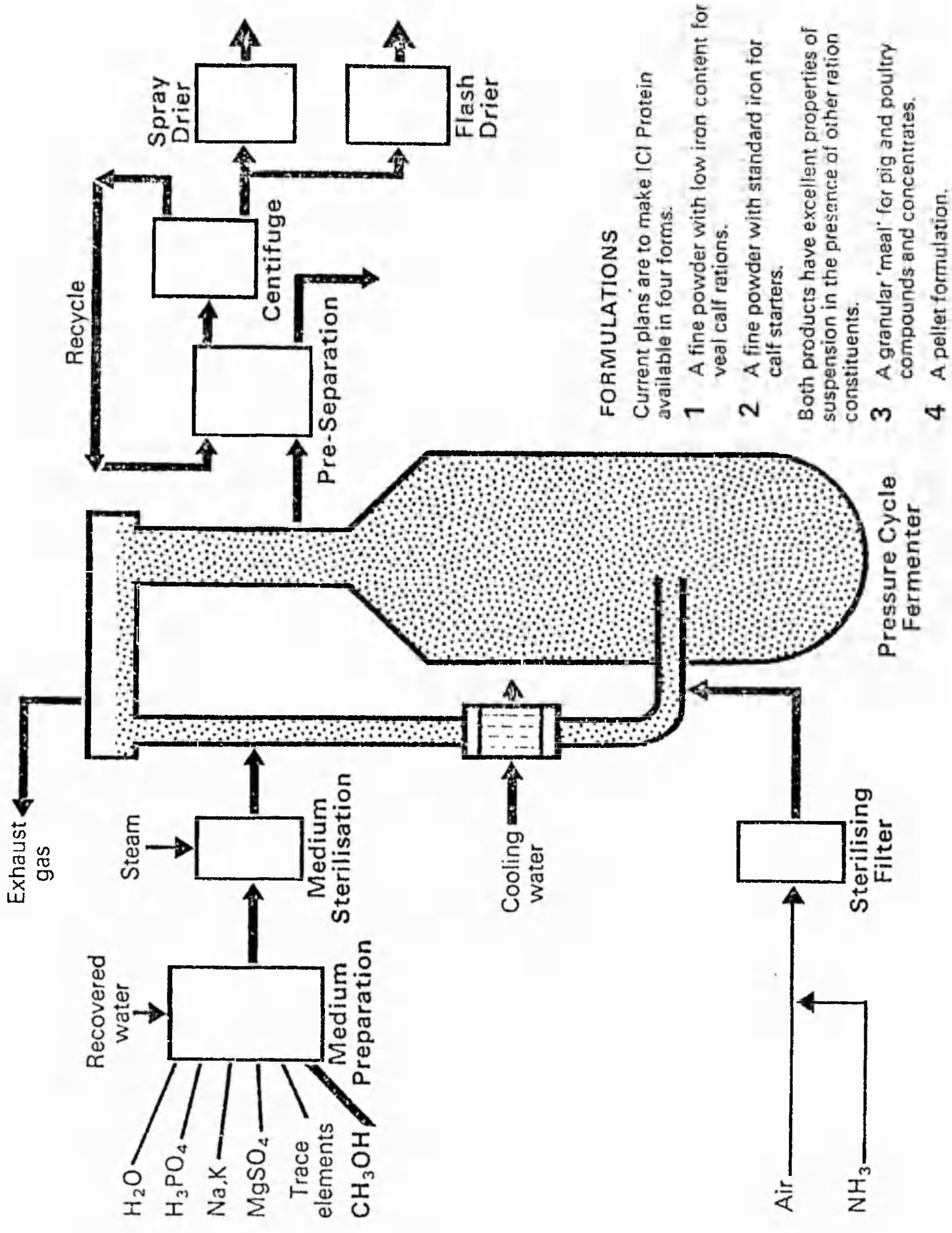

Fig 3.1 Flowsheet of Pruteen Process. (ICI,1974 p10)

Factors affecting choice of substrate were price, availability and control over supply. In table 3.3 the substrate and organism of each company are listed. It is immediately apparent that the business of the company coincides with the type of substrate they choose. For example, ICI had large supplies of natural gas and no petroleum supplies, so this influenced their choice of methanol, produced from natural gas, (the principal substrates are described in table 3.2).

3.5 Considerations in the Choice of Organism

Many hundreds of different types of micro-organism were investigated by ICI, BP and RHM and samples of each were grown in shake-flasks and on agar plates containing nutritive media and methanol. To start with many strains of each organism were present on the plates. After several rounds of being cultured on plates, the cultures of many strains gave way to discrete organisms most adapted to the methanol diet they were being served.

By limiting the amount of methanol available to the micro-organisms in these laboratory tests, the methanol-efficient strains came to dominate the cultures and eventually remained as single strains. This is important for the carbon-conversion efficiency, which is the proportion of carbon in the substrate that is converted into cell mass rather than being respired and lost as carbon dioxide. In this way the carbon conversion efficiency of the ICI organisms was raised from 45% to 60%. Once the optimum growing conditions were determined a pilot plant fermenter could be built to test a handful of organisms out in a continuous growth process.

Table 3.2 The principal substrates

methane -	the simplest hydrocarbon, a gas at room temperature, the main constituent of natural gas, occurs natur ally with oil reserves.
methanol -	the simplest alcohol, a liquid at room temperature. Each molecule containing one hydrogen atom, three hydrogen atoms and a hydroxyl group. The hydroxyl group allows methanol to be soluble in water, which is its big advantage over methane.
n-Alkanes or normal alkanes	These are the simplest hydro-carbon compounds. The n signifies that they are straight chain molecules. The carbon atoms form straight chains of various lengths surrounded by the hydrogen atoms. The importance of the straight chain alkanes is that the microbes which degrade them use an enzyme which acts on the methyl end of the molecule. Carbon-carbon junctions in isomeric molecules cannot be consumed. Crude oil can vary in its normal alkane content and it is from the crude oils rich in alkanes that they are obtained. The alkanes are defined by the number of carbon atoms in the chain: ethane has two, propane and butane three and four respectively. A range can be referred to by the notation C7 - C20, which denotes those alkanes having between seven and twenty carbon atoms in their straight carbon chain. Those used in protein fermentation are the alkanes liquid at room temperatures and some higher chain alkanes which are soluble in these liquid alkanes, typically in the range C10 to C24.
Gas-oil	This is one of the products of the first distillation of crude oil. It is a complex mix of hydrocarbons, some aromatic (benzene based), alkanes and others. It differs from crude oil in that the most volatile fractions and the solid (bituminous) parts have been removed. As a result of this low level of refining it is cheaper than the alkane substrates.
Carbohydrate	These are carbon-hydrogen-oxygen compounds of lower calorific value than the hydrocarbons. Cereal starch can be used directly or hydrolysed to glucose. Sucrose in molasses or other plant wastes can be used. These can be food grade materials even before fermentation takes place, unlike the toxic gas-oil and methanol substrates. When used for fermentation it is because they are a by-product from some other process.

Table 3.3 Substrate, Organism and Company

Substrate	Micro-organism	Company
Methanol	Bacterium	Shell ICI
Methane	Bacterial culture	Shell
n-Alkanes	Yeast	BP Italproteine USSR Liquichimica Rumania
	Bacterium	Chinese Petroleum Corporation, Taiwan
Gas-Oil	Yeast	Elf/Institut Français du Pétrole Indian Institute of Petroleum BP France
Carbohydrate	Fungus	RHM T&L
	Yeast	Swedish Sugar Corporation
Lactose	Yeast	Bel Industrie

The choice of a strain of micro-organism was governed by a much larger number of factors than the choice of substrate. The first choice was between a yeast and a bacterium or fungus. The principle differences between these three types of micro-organism are outlined below. Many of these differences have implications for the kind of plant that could be built, based on the micro-organism.

1 Speed of growth. Bacteria grow most quickly, then yeast, then fungi. The more rapid the growth of the organism the higher the output of a plant with fixed fermenter capacity. So a fast growing organism offers the chance of a higher rate of return on a fixed capital investment.

2 Protein content. Another advantage of bacteria is the higher protein content. Table 3.4 below shows the percentage of crude protein that each type of micro-organism contains. This advantage is offset by the faster growing bacteria also having a higher percentage of ribonucleic acid in their cells. If the protein is to be used for human consumption, this may need to be partially removed. The rest of the cell mass is made up of lipids, (fats) and carbohydrate.

3 Size of organism. Bacteria, due to their small size, presented a harvesting problem. ICI devised a technique to break open the cells and cause the contents to clump together into flocs of coagulated protein. These would be large enough to centrifuge out of the protein-water suspension. This treatment added to processing costs and affected the nature of the proteins. On the other hand yeasts could be centrifuged out of their growth medium in perhaps two steps. Fungi were the easiest of all to harvest because of their large filaments. These could be collected by one simple filtration step.

Organism	% Protein
Bacteria	80%
Yeast	60%
Fungi	45%

Table 3.4 Percentage of Protein in Bacteria, Yeast and Fungi. (ICI, 1974 p8)

Amino acid	Yeast Protein	ICI Protein	Fish Meal	Soya Meal
Isoleucine	2.8	3.1	3.2	2.2
Leucine	4.1	4.9	5.0	3.3
Phenylalanine	2.4	2.5	2.9	2.2
Threonine	2.7	3.3	3.0	1.9
Tryptophan	0.8	0.7	0.9	0.6
Tyrosine	2.0	2.2	2.3	1.6
Valine	3.3	3.9	3.7	2.3
Cystine	0.6	0.5	0.7	0.6
Methionine	1.0	1.8	1.9	0.6
Lysine	4.1	4.5	4.9	2.8

Table 3.5 Amino Acid Profile of Common Animal Feed Protein Sources in Grams of Amino Acid/100g of Product (Water content approximately 10%). (ICI, 1974 p16)

4 Resistance to contamination. Some organisms would be more prone to infection with foreign micro-organisms which would feed off either the extra-cellular products or the dead cells of the principal organism. The latter was the case with ICI's methanol consuming bacterium. This sensitivity to infection may require sterility in the fermentation process and sterility requires a whole new range of engineering standards and products, such as sterile valves and sterile welds and seals. Once the decision to have a sterile process has been taken, it is an influence on fermenter design. The major fermenter types are the stir-tank and the air-lift fermenter, the latter being a type of tower fermenter. Air-lift fermenters, with no moving mechanical parts, are easier to keep sterile than the stir-tank variety.

5 Carbon-conversion efficiency. This has already been described as an important efficiency consideration. Another result of a poor conversion efficiency is that the heat of fermentation will be greater and this must be removed if the optimum growing temperature is to be maintained. This characteristic of the micro-organism affects the choice of capacity for the cooling system.

6 Consumer Acceptability. The final product must win the approval of customers, whether feed suppliers or the eating public. The companies knew that common perceptions of each type of organism would be be used to judge their products. So a food derived from a bacteria might be suspect because bacteria cause disease and decay - that is the popular image of bacteria. Germs! Yeast are already eaten directly in the form of yeast extract by human beings and waste substrate derived slurries by animals. Yeast should be more acceptable if the company were to venture into human food manufacturing. Fungi might be the most desirable

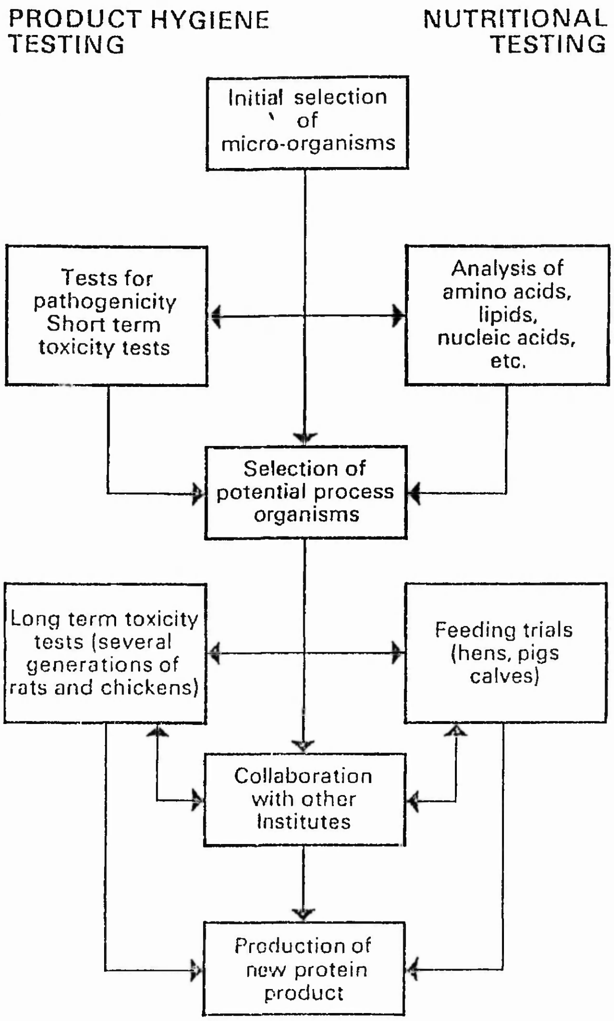

Fig 3.2 Summary Chart of Test Procedures

organism if a human food product was to be contemplated. They are the same family as mushrooms and fungi, and even more so than yeasts are known and accepted in many foods such as cheese.

3.6 Novel Protein Production Technology

Much of what follows in this section is taken from ICI Educational Publications (1974). All the processes can be described in three stages:

(i) Medium Preparation and sterilisation

(ii) Fermentation

(iii) Harvesting

3.61 Medium Preparation

In the ICI Pruteen process, the first stage is the preparation of an aqueous solution of methanol and nutrients. Mineral salts and acids were dissolved inthe solution to supply the organism with nitrogen, phosphorus, sodium, potassium, magnesium and iron.

ICI had chosen to run a sterile fermentation process, so each of the fermenter inputs had to be heat treated to sterility.

3.62 Fermentation

The ICI fermenter was the most technically complex of those used. It was an example of an air-lift fermenter, which use air under pressure to mix the fermenter contents and supply sufficient oxygen to the micro-organisms. The alternative was a stirred tank fermenter of the sort that

BP used. This is sometimes said to be more difficult to keep sterile because a mechanical paddle stirs the fermenter contents and foreign organisms can enter via the moving-part surfaces.

In figure 3.1 the arrows in the fermenter show the direction of circulation of the fluid. The blown in air forms a low density bubble-methanol solution fluid which rises in the outer sheath of the fermenter. The high hydrostatic pressure at the base of the fermenter tower allows oxygen to dissolve rapidly into solution from the many tiny air bubbles. As the bubble-solution mixture rises the pressure falls and waste carbon dioxide comes out of solution and into the tiny bubbles. In the gas disengagement section of the fermenter there is little hydrostatic pressure on the fluid, therefore the solubility of the gases is low. The carbon dioxide and oxygen-depleted air leave the surface of the liquid column leaving a high density, bubble-free liquid. This then descends in the inner vessel of the fermenter, shown as a tube in figure 3.1. In this "downcomer" section there is a heat exchanger which removes the heat of fermentation. At the base of the downcomer the high density liquid is aerated once again and the cycle repeats itself, the methanol solution circulating continually.

3.63 Harvesting

Harvesting the bacteria from solution involved a flocculation step. This step used acid solutions and electric current to make the bacterial bodies clump together into larger flocs. These could then be further separated from the solution by centrifuging several times. This yielded a slurry which was 26% bacterial protein. The last stage allowed the preparation of either a powdered or a granulated form of Pruteen. The powdered form was made by spray-drying and here the slurry was sprayed vertically into a chamber of heated air where the water evaporated to leave a dry powder. Flash-drying is similar but recycles partially dried slurry particles so that they clump together and form granules.

The final product is creamy coloured, odourless, tasteless. For the animal feed market, this is of no consequence, but it is a result of the processing ICI used and their choice of a bacterium as organism. In effect the decision to market the protein as an animal feed is built in to the fabric of the plant. The choice of a bacteria and the method of drying assumes an animal feed market where a lack of texture and the bacterial origin of Pruteen are assumed irrelevant. The human food market is another matter.

3.7 Nutrition and Toxicity Testing

3.71 Nutrition

Figure 3.2 shows the steps taken in the nutritional and toxicological testing of the protein product. As soon as an organism was selected for its promising growth characteristics, its protein product was analysed to determine the amino-acid profile of its protein. This profile is a percentage breakdown of the essential amino-acid content for every 100g of dry single cell protein. Essential amino-acids are the building-blocks of all other proteins. They are called essential because animals cannot synthesise these amino acids for themselves. Instead they must either eat them or eat proteins which can be broken down into these amino acids in the digestive tract. The richer a protein is in these acids, the higher its value to the animal feed manufacturing companies.

Two of the essential amino acids contain sulphur and are the source of sulphur for all protein synthesis. Soya and other vegetable sources of protein tend to lack these two amino acids, lysine and methionine. SCP amino acid profiles show that SCP is relatively rich in lysine and methionine. This increases the value of SCP to the animal feed compounder when working out a nutritionally balanced diet for some animal. It is also another factor that the SCP manufacturing company will consider when choosing a micro-organism, since micro-organisms have different amino acid profiles as well. Table 3.5 shows the amino acid profiles of various crude proteins.

This profile comparison was used by ICI to argue that Pruteen was comparable to fish meal in protein quality rather than soya meal and so could command a fish meal price - perhaps double that of soya meal.

Nutritional trials were carried out on animals. This involved progressive substitution of Pruteen for the soya or fishmeal in their normal diet. Statistical comparisons were made with a control group in terms of daily live weight gain, and the food conversion of the animals. No significant differences in the two types of diet were observed, except for one set of experiments on pigs where the Pruteen diet produced a significantly improved performance in the final growing period.

3.72 Toxicology

Novel food proteins presented something of a problem to the various health authorities. Testing procedures and regulations are established for additives, but not for entirely new foods. The usual procedures for new additives or drugs is to feed experimental animals with doses 100s of times larger than that expected to be administered to human beings. If no toxic effects occur the product is likely to be announced safe. A new food can not be administered to animals in multiple doses of this size, and so poses a testing problem.

ICI tested potential process micro-organisms by injecting them into mice. If a toxic effect was produced the organism was rejected. A second and more costly set of trials were undertaken with the protein product. The product was mixed with other feeds and fed to chicks, rats and pigs. The results were compared with a control group of animals fed only on ordinary feeds. These tests were repeated over three generations of animals which controlled for possible genetic defects and long term deleterious effects. ICI believes the results showed Pruteen to be completely safe and Pruteen has been accepted by the UK government as safe.

This chapter has described the nature of the SCP technology, some of the relevant science and the historical background of project development. Summary lists of the key events in each of the companies to build commercial size plant follow in tables 3.6 to 3.9.

Table 3.6 Main Events in BP Story

Compiled from manager interviews except where indicated.

1957 Payne obtains a 2 year contract for microbial cleaning system for BP France Lavera Refinery

1959 Champagnat, head of BP research is now interested in other microbial technology applications. He and Payne agree on a programme of research. Both gas-oil and n-alkane routes found to be feasible on a laboratory scale.

1960 BP decides to build pilot plants for both processes, one in the UK, one in France. The French are given the choice of process and choose gas-oil.

1963 Lavera pilot plant begins operation. Champagnat and his research team publish the results of 4 years of work in "Nature" and a general upsurge in interest in SCP begins.

1965 Grangemouth pilot plant begins operation

1965-68 The original idea of using the processes to remove n-alkanes from waxy Libyan crude and produce human grade yeast gives way to the idea of an animal feed market.

1971 Grangemouth "semi-industrial" plant begins operation with capacity of 4 000 t/a, based on n-alkanes.

1972 Lavera semi-industrial plant in operation, nominal capacity of 20 000 t/a. Venezuelans offer to buy full scale n-alkane plant if BP can run Sarroch without problems for 6 months.

1973 First oil price rise.

1975 BP now assume oil price rise permanent.

1976 Lavera 20 000 t/a plant closed on economic grounds after 2-3 years of production and sale of product on the French animal feed market. Sarroch plant completed.

1978 Sarroch plant dismantled, BP compiles its 10 volume work containing details of all their technical work. BP have yet to sell this, at £100 000.

Table 3.7 Main Events in ICI Project

1968 A business study on diversification prospects for Agricultural Division suggests protein from methane, the suggestion is to produce pig feed.

1969 Ag Division switch to methanol as a substrate.

1972 1 000 t/a pilot plant in operation. ICI becomes aware of the skimmed milk replacer market for veal calves. Pruteen business area formed.

1973 ICI main board rejects first application from Ag Division for commercial scale plant of 100 000 t/a capacity.

1974-1976 Board members visiting Ag Division to examine proposals for commercial size plant.

1976 Main board approve 70 000 t/a plant, to be built by John Brown Engineering.

1979 Commercial Pruteen plant commissioned.

1980 Pruteen plant runs at up to 80% capacity for short campaigns. Product is sold as veal calf milk replacer. Price of natural gas has risen rapidly in 1974-1979 period, undermining pig and cattle feed market prospects.

1981 Research shifts into human food uses.

1983 Negotiations with Japanese food companies for sale of nucleic acid fraction of Pruteen. Another pilot plant is planned for fractionation of Pruteen.

1984 Japanese withdraw from negotiations, it is not clear why. Pruteen business area merged with some Ag Division research to form Biological Products business. Pruteen plant still stands, unused.

Table 3.8 Main Events in RHM Story

1964 Research begins at instigation of Lord Rank, on starch-fungus fermentation technology.

1965 Animal trials begin on C1 organism.

1966 Product development begins as a third world protein supplement.

1968 RHM switch from batch to continuous fermentation.

1969 Market orientation changes from third world to first world product.

1970 Change to new A3/5 organism, a fusarium. Patenting activity starts. Pilot plant begins production.

1974 Human nutrition trials begin. Scale up studies begin.

1976 Food science input to research team begins.

1978 Submitted to MAFF for approval as a human food.

1980 Preliminary clearance from UK government.

1984 ICI and RHM decide to work together. ICI's pilot Pruteen plant is used for mycoprotein fermentation. Sainsbury's agree to work with RHM on product formulation. "Savoury Pie" product goes on sale at key Sainsbury branches.

1985-1989 Marlow Foods, jointly owned by ICI and RHM, is responsible for the production of mycoprotein. "Quorn" is sold on to food manufacturers for incorporation in an increasingly wide range of precooked dishes.

1989 Number of dishes on market now approximately 40, on sale in numerous supermarket chains. Marlow Foods now considers what investment to make in increased plant capacity eg whether greater than 5 000 tpa.

Table 3.9 Main Events in Liquichimica Story

1971 Pilot plant built

1973 Construction begins on 3 plant complex.

1975 SCP complex completed, Reggio di Calabria.

1977 President of Liquichimica files for bankruptcy, Italian government appoints liquidator.

1978 ENI buys Liquichimica plant, operates original Liquichimica n-alkane refining business as before, three plant complex closed.

CHAPTER 4 - THE MARKETS AND THE ENVIRONMENT DURING SCP DEVELOPMENT

Introduction

This chapter examines the role of market ideas in influencing project development. Different markets were envisaged for the novel food projects and these markets changed over time as conditions were perceived to change by managers. A key concern in the chapter is how market ideas affected the development of technology and how changes in the market ideas led to changes in the direction of development of the technology. The chapter concludes by developing the idea of a reference market.

The initial idea of a market for new proteins relied on the prediction that human population growth in the lesser developed countries would outstrip those countries' ability to feed themselves. The idea of this impending protein "gap", a protein shortage, was part of the thinking of most companies when they began research into SCP technology. There would be an immense potential market for any company that could produce protein from an alternative, non-agricultural source. SCP was only one example of such a source, others were the production of protein from leaf protein and the development of new strains of crops, (see Stanley, 1977).

There were a number of ways in which firms believed they could exploit the protein gap and the first was the animal feed market in Europe, which is based on imports of soya and fish meal which both third world products. There was a possibility that eventually third world governments would retain their soya crops to feed their own, rapidly growing populations and this would lead to a demand for alternative animal feeds in the West, which would be supplied by SCP, (the argument is in Hamer and Harrison, 1980). This was the market basis of the hydrocarbon SCP projects. The waste-utilising SCP projects also sold their product onto the animal feed market, but as a by-product of their principal business. These were all economic propositions before the oil price rises of the 70s, when the long term prospects were of rising soya prices and an increasingly profitable business.

A second way in which the food needs of future populations could result in profitable business was if the governments of the West or in the third world bought protein production technology for use in their own countries. The process might be one which produced human grade food, (RHM), or animal feed to be used locally, (T&L). This assumed that third world governments would be able to acquire and use the technology, or that European governments would be motivated to buy and then install such technology in Third World settings.

This chapter begins by describing how the companies saw the markets in the pre-oil crisis phase of their research. There were four types of market amongst the firms visited, these are described in detail in section 4.1. As the different projects evolved the market concept was seen to have influenced the development of the technology and organisation of each of the projects. Examples of this influence are described in section 4.2.

For most of the projects the greatest changes in market concept arrived with the oil and soya meal price changes in the 1970s. These changes rendered the hydrocarbon processes at best only marginally economic. Section 4 deals with how managers explained the failure of their oil and soya price predictions upon which their marketing assumptions had been based, pre-1973.

The response of the firms to the new market conditions is examined in section 5. RHM was something of an exception in that its process was carbohydrate based and so less affected by energy price rises. However, section 6 examines the response of RHM management to what they saw as an emerging market for their human food product. One response to the loss of the animal feed markets was an attempt to license the technology to other governments. Section 7 examines the management rationale for this attempt and their explanations for why they never succeeded.

Public opinion and consumer pressure groups were important in Italy and Japan in ending those countries' SCP projects. Section 8 summarises the events in these two countries and especially in Italy, (see also appendix 6 for an account of the events in Japan).

4.1 Development of the Initial Market Conceptions

The original market conception that led to the start of research often differed greatly from the sophisticated market understanding that eventually developed. However, four basic market concepts emerged from the interviews and even if the target market changed on a project, it changed to another one of these four basic market ideas. In this section these basic market ideas will be investigated.

1 Market the technology for animal feed production in the 3rd World.

2 Market protein for human consumption in the 3rd world.

3 Market by-product protein as animal feed in 1st world.

4 The 1st world animal feed market.

The first two categories remained closest to the crude idea that increasing demand for food must somehow translate into business. Hundreds of small "village technology" projects were prepared all over the world to help small rural 3rd world communities become self-sufficient in food. Of these a handful succeeded in technical terms and none are known here to be still in use. The T&L projects were some of the few that succeeded technically, but failed to find a market. The next section discusses the extent to which the idea of a market came into the T&L and RHM projects.

The latter sections deal with the 1st world animal feed market. This was thoroughly explored by the multinationals who set out to manufacture SCP as a primary product. Into this same market went the various SCP products from waste-based processes, although with a different set of economics.

4.11 Spotting and Defining Third World Markets

It was remarkably difficult for the managers to talk at great length about market ideas in connection with these projects, which is not surprising considering the retrospective judgement of some of the T&L managers that their research effort lacked an adequate marketing input. Despite this judgement, market assumptions were part of the T&L projects, although they tended to blend in with the technical descriptions of projects. What follows is an attempt to, first, describe the extent to which a general market could be considered to exist. Second, the individual projects are considered because these contain descriptions of particular opportunities. Lastly, there is a summation of managers' reasons for the complete failure of any of these projects to become established.

4.12 A Market Concept for Protein Production in the Third World?

Haydn-Davies, (T&L consultant), justified the attempts to supply protein supplementing technology direct to the 3rd World by arguing that the diet of the people who live in the band 15 degrees either side of the equator is protein short. The plants they eat do not produce either enough protein or the right sort and their food contains too much carbohydrate or too much fat. This is still the case today and in his view the need is still there. He supplemented his argument by saying that the use of fertilisers and the intensification of conventional agriculture were dependent on 1st world technology in the form of imports. This was not a feasible route for increasing protein in third world diets, but eating animals raised on an SCP supplemented diets would be feasible.

During the 1960s, T&L did not believe there would be a "protein gap" but they thought the 1st world would remain in protein surplus and that the problem was increasing the amount of protein used in the poorest tropical countries of the 3rd world. They hoped that their SCP projects would be used to upgrade wastes for animal consumption in regions where there was a local protein shortage. Finlay (T&L) also referred to marketing assumptions when he spoke collectively of the T&L projects. The projects were kept technically simple because, "we thought it was necessary not to have anything too sophisticated because in developing countries you can't have PhDs and white coats running around setting these things up."

T&L and Haydn-Davies believed that selling their technology would depend on political support and a company on its own would be unlikely to buy it. Private capital was never really interested in these projects, because the returns on their use were in terms of reducing pollution and saving foreign currency by substituting for soya meal imports. These were such that only a government might consider the projects worthwhile. T&L developed their SCP technology with the hope that they could convince a government of its usefulness. Three examples of the type of technology that they developed will be examined, the carob project, the citrus waste project and the efforts of Haydn-Davies with Dunlop in Malaysia will be briefly reviewed.

4.121 The Carob Project

In the case of the carob project, the government had to be Mediterranean, since this is where the carob tree grows. Haydn-Davies, a T&L consultant, described Cyprus as a country with a protein problem. Very little grass could be grown, so animals had to be fed imported feeds. The government might want to reduce this import bill through the widespread application of T&L's SCP project. The carob tree grew in abundance and although the beans were collected, the husks were simply thrown away. They could be thought of as a waste material. T&L devised a plant which would allow Aspergillus

Niger to grow on the 50% sucrose contained in the husk, providing a high protein animal feed.

Negotiations began with the Cypriot government headed by Prime Minister Makarios. Haydn-Davies felt that the government were very keen, while T&L were ready to go full scale if the government would pay. Despite the hopeful beginning no progress was ever made. Haydn-Davies explained this as a result of the first of the little wars that ended with the Turkish invasion. Presumably the urgency of this situation meant that secondary issues like SCP were abandoned. However, the war ended in stalemate more than 10 years ago while the economics of the carob project should not have really changed.

Cowen implied that T&L's economic evaluations were upset by the price for the husks changing once T&L actually ordered some, as the producers realised there was a market for what they had previously thought of as a waste product.

Cowen gave another explanation, more damning for T&L. The husks of the carob bean pods were thrown on the ground, true. But pigs would feed on them quite happily. So the carob fermentation was upgrading husks which were already being used as animal feed. The pigs needed some protein supplement to a diet of husks, but there were alternative ways of supplying this, for example, by simply adding urea. There was no need for the intervening and labour intensive step of collecting them, innoculating and fermenting the husks before feeding them to the animals.

4.122 Malaysia

Haydn-Davies twice attempted to establish an SCP project in Malaysia. The first time was for Dunlop who were converting old rubber plantations to the more profitable production of palm oil. The washings from the oil recovery process contained a large amount of oil and in consequence carried a very high BOD. The Malaysian government found Dunlop to be polluting local waterways around their processing plant and required that they treat the effluent.

Haydn-Davies proposed an SCP producing plant attached to the processing plant. The project was abandoned and Dunlop chose the alternative method of digging large pits and dumping the effluent to rot away before it entered the river system. Haydn-Davies believed that what was lacking was the political commitment to independence from importing soya meal in Malaysia.. Should the government have valued this independence from the USA, he felt it could have become largely self-sufficient in animal feeds. And the Dunlop SCP project would have been supported. Instead the Malaysian government set new BOD limits for Dunlop's effluent which made the plant redundant.

The SCP plant was inflexible in that it only cleaned up a fixed percentage of the fats and carbohydrates in the effluent. There would still be some discharge to the environment. It would never clean the waste up as effectively as a method designed to simply degrade the waste with no protein output. So rather than adopt Haydn-Davies' suggestion of a two stage fermentation to remove almost all the effluent, Dunlop opted for the more secure method of dumping the effluent in pits.

4.123 Citrus Waste in Belize

T&L used their SCP technology to upgrade citrus waste from a canning factory in Belize and actually built a pilot plant there. However the reason for siting the plant in Belize was principally political. According to Finlay, T&L did an econometric analysis of their original process based on molasses which showed that the process was only economic when there was a true waste, one which you would be paid to take away. Finlay suggested that this was why they built a pilot plant based on citrus waste, but Cowen felt that citrus waste was not easy to ferment. The plant was isolated and unable to distribute its product effectively. The adjacent citrus canning factory lowered the sum they paid T&L for treating their waste once the pilot plant was built. The economics changed for the worse as a result, but Cowen had never felt the plant was viable, and indeed, after 3 or 4 years T&L allowed it to be closed.

Finlay presented the only optimistic account of the chances for this plant. He described how T&L found communities of Mnemonite farmers in Belize. These farmers traditionally raised chickens and would probably still wish to do so. However, there was no chicken feed in tropical Belize because grain would not grow and imports were too expensive. Finlay felt these farmers could have provided a market for the upgraded citrus waste. However it is clear even from what Finlay says that the market came after the political decision to site the plant in Belize. There was no market input to either the siting of the plant or its construction. Even the choice of substrate, citrus fruit waste, followed on from its position in Belize and was not the optimal choice on technical criteria. On both technical and market grounds, Belize was a poor choice.

4.124 RHM and Mycoprotein

The RHM project ended as a 1st world success story, but began as another attempt to add protein to third world diets.

According to Treeby (RHM), Lord Rank began the project with the philanthropic belief that there was a chance to help the 3rd world by developing a protein rich food from surplus starch from RHM's milling activities. Although Treeby was not present in the early stages of the project, he was confident that,

"while the project was classed as research, consideration of markets did not take place in a significant way. It was only after regulatory approval was obtained and the project was established scientifically that the real marketing began; then, at least, there was the recognition that somewhere along the line you had to sell the product to someone."

In contrast to the T&L examples, which grew out of a grand strategy within R&D, the RHM project began because the chairman intervened and gave the project to R&D. It then continued without hope of real development, because although it was protected by its champions too few managers could see a real market for it. But in the early 1980s such a market was seen to be developing and the project won full commercial backing of the company and received the attention of a marketing team.

4.125 Failure to Sell Waste-based Fermentation Technology to the Third World

Some managers took a very critical stance towards the whole collection of mini-projects for producing 3rd world protein. Referring to the "daftness" of village technology, Peachey (BP) argued that this kind of fermentation could only be done by really high technology, otherwise the protein was not safe for the animals to eat. It was too easily contaminated with foreign micro-organisms during low-technology fermentation.

Garoffalo (T&L) spoke about these projects in general and agreed with Peachey;

> "There have been certainly hundreds of projects of this kind...hardly any of them going now, hardly any got beyond the pilot stages. Two basic reasons: one, they didn't work because you couldn't get a safe and consistent product. Two, the markets were not there. Western scientists assumed humans would eat it or animals would be around to feed it to. Both assumptions were wrong."

The complex feed industry in Europe had no equivalent in the kind of protein deficient tropical countries for which T&L had developed its SCP projects. In these countries the animals feed themselves and there are never enough animals in one place to justify delivery of animal feed, or good enough roads to make that delivery. Waste-based protein projects are therefore uneconomical.

Garoffalo (T&L) felt that in the case of the T&L projects the lack of a market should have been clearly understood from the outset. However, referring to the non-existence of a market he said,

> "It was seen but not enough attention was paid to it. It was assumed that we could encourage people to take up more intensive feeding of their animals. And that is quite a difficult thing to do, to introduce a new product and develop a new market for it at the same time. Very difficult."

Such a task would be almost impossible in the African and Central American countries where these projects were based. In addition Garoffalo thought that there were other more important projects than soya meal substitution for such countries, there were more useful projects to spend their limited resources on.

Haydn-Davies and Cowen both agreed that waste processes in the 1st world depended on the necessity of cleaning up effluent or wastes of some kind. There was a problem of waste disposal, but in the 3rd world, Cowen thought that,

> "no-one gives a damn about pollution, the problem is eating tomorrow... so if you happen to be sticking something in the water that kills all the fish, they really don't care. 3rd world governments only have time to pay lip service to that."

Then there were the problems of having 3rd world populations accept a new source of food. Cowen illustrated the point with the story of how some years ago millions of tonnes of wheat sent to India to alleviate a famine were left to rot in warehouses because, despite starving, the people would not eat a non-familiar food.

It is ironic that all of these projects depended on the idea of a protein gap in world protein supplies which in turn was based on the then current understanding of nutrition science. This has now changed, and the idea of a protein gap has disappeared - it is a food gap. But the protein gap idea as an element of market thinking helped drive the development of these hundreds of village technology projects.

Village technology embodied these assumptions about nutrition and the protein gap. It is an example of how technology is socially structured according to belief and since this belief is no longer current there is no chance of the same set of projects being developed.

4.13 Waste Processes for the 1st World Animal Feed Market

The Pekilo process, Waterloo and Symba Yeast Processes were all 1st world projects that used fungi or yeast to clean carbohydrate-rich effluent and produce some saleable animal feed as a by-product. The economics and reasons for construction differed from the large scale SCP processes of BP , Liquichimica and ICI, but the market was identical - the animal feed market in the first world. (See appendix 1 for a description of SCP from waste sulphite liquor, appendix 2 for SCP from waste lactic serum).

4.14 The Western Animal Feed Market

4.141 The Feed Compounders

In contrast to the tropical countries of the 3rd world, Europe has an organised feed industry where the feed compounders, companies like Dalgety and Spillers make up feeds for different types of animal and distribute it to the farmers. They buy in soya meal and fish meal from the producer nations, the US, Brazil and Argentina. They will vary the proportions of the two meals in the feeds they sell and try to minimise the cost of the final feed while keeping the feed nutritionally suitable for the particular animal for which it is intended.

Soya meal is the base of most of their animal feeds, but soya alone is not nutritionally balanced for animals. It is low in the proportion of sulphur containing essential amino-acids that it contains, lysine and methionine. The animals would have to eat an excess of soya meal to obtain the amino acids they needed for rapid growth. So the compounders add fish meal, more expensive than soya but rich in lysine and methionine, (see chapter 3), to balance the animal feed nutritionally.

The animal feed market is tiered; there is an inverse relationship of price to volume. The smallest markets carry the highest price per tonne, the largest have the cheapest prices per tonne. The higher end of this range starts with feeds for goldfish, then the laboratory animal market, then the calf milk replacer market. The lower end contains the bulk cattle, piglet and broiler feeds. At the top end, the feeds sell for 2 - 3 times the price of soya meal, ranging to close to soya meal price for the lower end of the feed market.

So SCP products would not be total replacements for soya meal. To the feed compounders they would be an alternative source of protein which depending on their lysine and methionine content would have a value somewhere between that of soya and that of fish meal. The importance of this complexity of the feed markets is that the simple equation for the viability of SCP has partly broken down, that is to say that the simple comparison of the price of a tonne of SCP with the price of a tonne of soya meal is no longer valid.

4.142 The Value of SCP to the Compounders

The object of this section is to follow the thinking of the compounders which led them to offer a particular price per tonne for SCP products as a source of their meals. Whatever the costs of production, this would be the maximum price at which the compounders would buy SCP. There were other characteristics of SCP that gave it a greater value to the compounders than simply the amino acid content. When chickens and piglets eat too much fish meal their flesh carries the taint of the fish, so that it can be tasted. As far as the public value their bacon rashers being free of this taint, they will pay more for the bacon and the farmers will pay more for a feed free from fish meal. SCP products gain in value as a fish meal replacement. Saxton (ICI) recalled that Marks and Spencer were one of the companies that were prepared to pay for this quality of SCP. He ascribed this to their involvement in specifying what went into the feeds that were fed to the animals that they sold as meat products.

"One of their producers bought 8 000 tonnes from us in one year. If the economics had been right they would have liked to have moved all their suppliers of turkey and pig meat to using Pruteen instead of fish-meal...it was a very highly regarded product."

Saxton estimated that less cost-conscious companies like Marks and Spencer would have been prepared to pay maybe 2.5 times the price of soya to put 4% Pruteen into their feeds.

Another characteristic of SCP that added to its value viz a viz fish meal was the result of nutritional testing done on the products. Marks (ICI) described how ICI found that Pruteen accelerated the rate at which chickens put on weight. Fish also put on weight more rapidly than with conventional fed mixes. This quality of SCP also added to the value of SCP as a feed.

4.143 The Veal Calf Milk Replacer Market

The consideration of all the advantageous characteristics described in the last section enabled ICI to price Pruteen above the soya price and competitive with the price of fish meal. But with the low soya prices of the early 1980s ICI found that the overall equation still left them losing money on every tonne they made for the chicken and cattle feed markets. Saxton found that they couldn't even cover marginal costs, let alone begin to make a return on the investment. As a result, Pruteen was driven out of these low value, substantially soya based feed markets to the higher value ones. The principal market here was the veal calf milk replacer market. This is worth discussion in detail since both BP and ICI saw it as a premium market still of sufficient size to support SCP production at a large scale.

Smissen (ICI) also thought their plant would have been economically viable (once built), provided it could have sold Pruteen in competition with pre-subsidy prices of skimmed milk powder. Unfortunately for ICI and BP the EEC started subsidising the consumption of skimmed milk as a calf veal milk replacer and eroded the return they could expect in this market. This subsidisation began a few years before ICI's decision to build a full scale plant.

Veal calves have a lifetime of about 20 weeks and during this time they would normally feed on their mother's milk. This being used for human consumption the farmers use a milk replacer feed which is of higher nutritional quality and so higher value than the chicken and cattle feeds. It is also required to be low in iron so that veal remains a white meat.

In the late 1960s the milk replacer industry was using protein isolates obtained from soya, but this changed in the early 1970s as the EEC began to accumulate huge quantities of dried skimmed milk. Dried skimmed milk is made from the surplus of whole fresh milk that the European Community produces. The Community began subsidising alternative uses for skimmed milk to reduce its stockpiles rather than reduce the quotas for fresh milk production in the early 1970s. One of the major uses was to add it to calf feed, since it was, naturally enough, nutritionally ideal for raising calves. The Community even made it mandatory for veal calf farmers to include a proportion of skimmed milk in their feeds.

Pruteen and Toprina were nutritionally similar to skimmed milk powder and could ask the same price per tonne. However, if the price of skimmed milk powder was kept low to encourage its consumption, the SCP products could not ask for a greater price. In the early 70s the SCP skimmed milk replacement market was worth considerably more than the fish meal substitution market. The BP Lavera plant successfully sold its product, almost entirely into the French skimmed milk replacer market for several years. But according to Leivers (BP France), the cost per tonne after the oil price rise was about twice that of EEC skimmed milk powder.

4.144 The State of the Skimmed Milk Replacement Market in the Late 1980s

The skimmed milk replacer market is therefore a very important feed market. Bel Industrie still sell their lactic yeast into the skimmed milk replacer market and Dinsdale (Bel Industrie) referred to the current evolution of this market as advantageous for their yeast product. In 1986-87 the EEC at last began to cut its dairy quotas and so started to tackle the problem of over production of milk and skimmed milk. The result has been a steep rise in the price of powdered milk and so of veal calf feeds. According to Dinsdale, in the last year skimmed milk for animal feed has risen from 6 FF/Kg to 11-12 FF/Kg, a doubling of the price. In his opinion it would be politically impossible to allow veal meat to double in price, but it had already increased by 15% in June of 1988 alone. His expectation was that it would continue to rise and that it would force all skimmed milk users to look to alternatives to veal calf feeds, such as his lactic yeast product.

An article in the Financial Times, (Parkes, 1988) suggests that the veal calf market could soon be transformed. The Biscuit, Cake, Chocolate and Confectionery Alliance has protested to Brussels about the EEC continuing its policy of 60% subsidies on skimmed milk sold for animal feed. This is at a time when the developing shortages of milk products have driven up the price of skimmed milk for use in human foods to around £1 300 per tonne.

The significance of these recent changes is that there may once more be, in 1988, a viable market for SCP in the form of milk replacer products as the EEC changes its policy of subsidising skimmed milk consumption.

It can be seen in this section that initially ICI developed their understanding of the feed market from the feed compounders. This understanding gave them greater precision in the pricing and economics of their product. The identification of tiers of value in the feed market and especially of the calf feed replacer market, gave them the choice of building a plant whose capacity matched the demand of the higher value tiers. There was a two way process of matching market qualities to technical qualities of their process and product and the influence of market ideas on technical choice will now be examined.

<u>4.2 The Extent to Which Market Concept Influenced Evolution of Projects</u>

The technology and organisation of some of the SCP projects were influenced by the developing idea of a market. The projects where the managers most frequently referred to the effect a market idea had on the project were the animal feed projects. The next sections look at some of the examples of how a market idea affected research and technology.

4.21 Idea of Market Influences Choice of Substrate and Organism

4.211 Mycoprotein

RHM intended their protein product to be a food for human consumption and Treeby explained that RHM, being a food company, understood what people are prepared to eat. This understanding influenced their decision to use only food grade materials at all stages of the fermentation.

In relation to the choice of a food grade substrate, he described the company's attitude,

> "we have a prejudice, perhaps, that people don't eat food that you make first of all for animals and they don't eat food that is manufactured from petrochemical residues, or surplus sludges or this that and the other."

The choice of a fungus rather than a bacteria or yeast was also based on assumptions about how people would perceive a bacterial or yeast product. The idea of eating bacteria was seen as unacceptable to most people and although both yeasts and fungi are eaten by people, RHM chose a fungus because it had the possibility of being marketed as a type of mushroom. Filamentous fungi could also be given texture which in Treeby's opinion was similar to the texture of meat. Treeby distinguished the RHM product mycoprotein from SCP, because SCP "is either powders or creams or some degree of wet growth that renders it only suitable for animal consumption."

He also made the point that it was also biologically incorrect to refer to mycoprotein as a single cell protein, since it was formed from filaments of cells connected one to another. In all this reasoning over the choice of a substrate and an organism RHM did no "market research." Their choice of substrate and organism was based on their specialised knowledge of the human food market. RHM's selection of these technical characteristics was governed by their knowledge of human food markets obtained from their experience with other food products.

4.212 Hoechst

Liesser (Hoechst) gave a detailed example of the factors influencing Hoechst's choice of organism which were similar to those influencing ICI, BP and Liquichimica.

After the initial screening of the organisms they had collected, Hoechst prepared a short list of four organisms. These were then compared not only for various technical characteristics such as speed of growth, but also for nucleic acid content and the proportions of the different essential amino acids. These last two characteristics were only important if there was some understanding of the market for animal feeds and the final choice of organism was one which did best against these two "market" technical characteristics as well as other purely technical characteristics, such as speed of growth.

However, Saxton (ICI) felt that ICI was lucky having an organism with such a very good balance of protein to energy to minerals and amino acids. By the time ICI had discovered what the ideal organism qualities were, they had already chosen the organism and begun to build plant adapted to it. This was because the market research was proceeding at the same time as the technical development and some choices such as that of the organism were forced early on in this development, for technical reasons.

4.22 Market Idea Influences Construction of Process Plant and Product

4.221 Size of market Affects Size of Plant

The size of the plant depended on some market size assumptions. The first and obvious one was that the total animal feed market was huge, millions of tonnes in Western Europe alone, so the plant could be as large as was technically efficient if its output was competitive in all of this market.

However, if Pruteen was only going to be competitive in the skimmed milk replacer market, the size of the plant would be limited by the size of this market. There was a debate on this issue at the time the plant was approved. Harwin and Saxton (both ICI) believed that had a smaller plant been built with a high proportion of output going to the skimmed milk replacer market, it would still be in profitable operation today. The capacity of the smaller plant would have been perhaps 30 000 t/a with a constant 15 - 20 000 t/a going to the skimmed milk replacer market, whatever the size of the plant. However, the larger plant was built, (see chapter 7 for reasons).

4.222 Requirements of the Animal Affect Design of Product

The different feed markets required slightly different products. The "granular" form of Pruteen was for the chicken feed market, while the calf milk replacer was a little more complex to prepare for the market. It needed to be low in iron and the fermenter needed to be run within tighter limits. In fact, what amounted to a mini programme of research was mounted to modify Pruteen for this market. An ideal particle size was picked and a wetting agent found to prepare the product for mixing into skimmed milk.[1] Saxton found that the kind of dust they were producing by grinding Pruteen could cause adverse effects in some people, so they began adding cooking oil to prevent the dust becoming airborne. The construction of the post-fermentation processing equipment also depended on choices about the proportions and volume of Pruteen that would be consumed by each market.

4.223 Two Apparent Inadequacies of Product for its Market Solved through the Use of Nutrition Science

Another example of how the process and product were tailored to fit the market requirements was the use of selenium. This is a trace element essential, in different quantities, to the growth of most organisms. At first ICI added the amount necessary to the fermenter for optimal growth of their bacterium but a problem arose because this was insufficient for the animals that ate Pruteen as a replacement for fish

[1] Exactly the same kind of work went into developing "Coffee Mate."

meal in the nutrition tests. What had happened was that fish meal happened to contain the right amount of selenium for animals so the compounders had not had to think about it. Talking to the compounders had not therefore revealed selenium as a critical component of feeds. Animals suffered selenium deficiency if fed on Pruteen instead of the fish meal part of their diet and failed to grow rapidly. The research department quantified the selenium need and added extra selenium to Pruteen to make up for its deficiency.

This problem with the selenium is interesting because before Pruteen was used it was unarticulated by the compounders as a requirement for animal feeds. Saxton suggested that it had originally been trial and error which showed that animals thrived on certain proportions of fish meal in their soya meal, but the same approach with Pruteen in place of fish meal would adversely affect the animals. It was the use of nutritional science and analysis of Pruteen and fish meal that gave an increased precision to ICI's understanding of the market. Here scientific ideas were used to define anticipated market needs.

The market requirements also affected the sourcing of the phosphate rock. ICI learnt to be careful about the source of this rock because some contained high proportions of heavy metals like cobalt, poisonous to animals. It was a matter of determining the levels of heavy metal that could be tolerated by the animals and ensuring no rock was used that contained greater amounts than this maximum. As with selenium, this was a problem that did not occur when fish meal was used as animal feed, because fish meal contains sufficient phosphate and without heavy metal problems. Nutritional evidence on animals' needs became incorporated into the product formulation. This can be seen as a process by which the market needs were in process of being refined and articulated by nutritional science and expressed in nutritional science terms. It was not a matter of collating market needs as expressed by users and delivering them to the process engineers or product formulators. The matching of market needs to product characteristics was more complex than that in this case.

4.23 Market Affects Research

According to Swindall, (ICI), a major part of the ICI research effort, perhaps about a third of all expenditure Swindall, went to toxicology and nutrition. The emphasis on this area was partly due to ICI's sensitivity to the aversion with which the public might receive a bacteria food and this led to what they thought was an unusually thorough toxicology and nutrition research programme. ICI were aware that public opinion had probably been the principal cause of the failure of SCP in Japan and Italy and this heightened their sensitivity to possible accusations of product toxicity. Saxton felt that this perceived need to go further than satisfying purely scientific criteria had a major influence on the way in which the toxicological research was organised. He remarked that,

> "instead of saying, we'd like to do a few things with chicks and pigs and things, we decided what the markets with best value were going to be, we talked to the companies about the trials and evidence they needed. We had the trials done across the world and received evidence from companies doing their own trials. We put together a package of its being a very efficacious product."

Swindall (ICI) adopted the policy of working closely with the Department of Health to develop trust between the two bodies. Swindall helped develop this trust by being unusually open about the results of their toxicology trials. They revealed results with possible negative interpretations - Swindall showed that animals could die when fed a part-Pruteen diet as well as thrive on such diets. He could also show that ICI understood the different responses to the diets and that they could correct any deficiencies by adding the necessary nutrients.

Swindall reported that ICI considered using Pruteen for human food in 1973-1974, when the plant was approved. However ICI, now venturing for the first time into the animal feed market, decided to confine Pruteen to the animal feed market and the policy was that research should also be restricted to animal feed requirements. Human food research was seen as a major diversion of effort, so that once a choice had been made to produce for the larger animal feed market a decision was taken to stop research from diversifying into human food possibilities. In this way the market conception was supposed to restrain the research possibilities. The resulting product was also constrained by its process of manufacture to be an animal feed, not a human food.

4.24 Change in Team Structure Changes Market Conception

When BP began research into SCP Payne (BP consultant) and Champagnat (BP) dominated the project and they believed that their product could solve world hunger. Leivers (BP) joined the project in 1966, when she thought that the company was still thinking in terms of food for human beings. This was a period when BP advertised the "petrol into beefsteaks" idea and published photographs of Champagnat eating Toprina, (Laine and Snell, 1976). By 1968 the idea of the feed market had become dominant. The change had been gradual and occurred as more people with a variety of backgrounds joined what had been a small scale project. Some of them were acquainted with the feed market and they shifted the thinking away from the conception of a human food market. For example, Leivers, as an agronomist, never thought it possible the yeast would be eaten by people. By 1968 the new idea of the market was guiding research towards developing a high protein fish meal replacer in animal feed.

4.25 Technology "Looks for" Market

The T&L research programme generated many projects involving fermentation, for example there was a process developed for the fermentation of high-sugar residue wastes, but once developed no market was found to exist and no-one wanted to buy the technology. They also developed a very simple fermenter which was a hole in the ground lined with concrete, fitted with a stirrer and bubbled with gas. This was abandoned after perhaps 6-7 months of work because Cowen couldn't see how they were to get money out of it.

The approach was to develop a precise technology and then look for an equally precise market niche, which rarely existed. One success was the process for using waste carbohydrate solutions which Cowen thought might match the needs of a new sugar refining process in the T&L Technical Services department. T&L Technical Services was approached by Bassetts, the confectionery firm, about a sugar effluent problem at this same time. So Technical Services used Bassetts as a test bed to develop the research department's technology into a full scale working plant. Bassett's paid for it, but T&L never succeeded in selling it anywhere else. Luck would seem to have played a part in finding this almost unique market for one of the research departments ideas.

4.26 Research Department's Idea of the Market

Occasionally managers widened their comments about the market to generalisations about how far the research department could use market ideas. Cowen (T&L) thought some kind of market idea was always present in the research department and said,

> "...you never completely get rid of the idea of a commercial end product from the research. However divorced the scientist is from the market, he still thinks that one day this may be something amazing, its that crude, but there's still an element...that's industrial research after all."

Treeby (RHM) was rather more caustic when describing the market ideas of the research department. He began by trying to debunk the myth of any marketing input to successful inventions.

> "When they are telling you the stories of the great inventions they will tell you, well, of course we thought through the marketing issues, and as a result we decided how we were going

> to do it. A load of lies, most of them found something and in a process of moving forward, come to understand the issues."

In response to the suggestion that the scientist in R&D would have some kind of image of what they were doing as being a useful product, Treeby scoffed,

> "Not at all. The R&D department would not have understood what a market was if it came up and bit them."

These comments suggest that there was little marketing input to the project in the research phase, yet, as described earlier, the project was begun by Lord Rank with the world protein shortage in mind. So there was an idea of a potential market in the original conception of the project. R&D believed they understood the market sufficiently, but Treeby commented on the sample products that R&D came up with, that they were interesting, but dreadful from a marketing point of view since they were not capable of being sold to anyone. When Treeby talks of market input he refers to the process of relating market characteristics to product development, the process by which technical choices are guided by knowledge of market characteristics.

4.3 Forecasting the Protein Market

The economic viability of the hydrocarbon projects depended on the relative prices of the hydrocarbon substrate and soya meal. SCP would only be economic if it undercut the price of animal feed, linked to the soya price and the major cost of the hydrocarbon processes was the substrate, at around 50% of production costs. The great dependence on two price factors meant that company forecasts for their price evolution were critical to the decisions to construct plant.

4.31 Expectations for the Evolution of Hydrocarbon Prices

While gross movements in the price of crude oil were reflected in the price of alkane substrates, so changes in the price of crude oil are a guide to the economic viability of these processes. The case of methanol was rather different.

There were fewer management comments about the oil price rises of 1973 and 1979 than about the evolution of the market for soya meal as an animal feed. They accepted that the 1973 oil price hike had been totally unpredictable. The rise had been counter to all the predictions of economists and the price trends of the last 20 years. Northgate (BP) pointed out that in real terms, oil had been stable and even become cheaper throughout the 1960s. The 1973 price rise was,

> "totally unpredictable, totally out of the blue. They blew the world economy and SCP was one of the casualties. No question of that."

Marks (ICI) agreed that economists were predicting price rises for crude oil in the late 60s, early 70s, but not on the scale or with the suddenness of the actual jump, which was to $35 a barrel in 1973. Marks explained that many predictions were based on the experience of a 6-7 year cycle in oil prices and the expectation that this would continue in the 1970s. The failure to predict the rise amounted to a failure to predict the political success of OPEC in forcing the rise.

No manager at any time suggested that the economics of SCP estimated pre-1973 could have been improved with regard to the crude oil price predictions. The case of methanol is similar, but a little more complex.

At the time that ICI were deciding to build a large scale plant, in 1973-74, the price of methanol was very low. This was because it was manufactured from North Sea Gas which was available in large quantities without an equivalently large market with much gas being flared off as oil fields came into production. So North Sea Gas was cheap.

ICI had developed its unique low pressure catalytic process for converting Natural Gas into methanol in the 60s. The late 60s to early 70s had seen a steep fall in the price of methanol as this method of production had become the standard. The early 70s was a period before North Sea Gas was used as a fuel, so its value was not linked to the price of crude, which represented the price of energy. The result of this decoupling was that the 1973 oil price rise did not severely affect the economics of methanol based SCP processes such as ICI's. Once the UK switched over to using natural gas instead of town gas as a fuel, this was no longer the case. The major use for natural gas became that of a fuel. In the later 1970s the price began to rise in real terms and in the 1979 oil price jump, the price of methanol doubled due to its dependence on the price of natural gas, and natural gas' link to the price of energy. Harwin (ICI) believed this jump was the one which made Pruteen uneconomic to produce.

According to Marks, ICI had thought the margin of profit in the early 1970s to be so large that any "reasonable" methanol price rise would not affect them. They did not predict so large a rise and whether they could have done so depends on whether it would have been possible to predict the opening up of entirely new markets for natural gas,which at first seemed to be almost a waste material. There was also a trend to lower methanol prices immediately preceding the ICI decision to invest in Pruteen.

4.32 Evolution of the Price of Soya Meal

SCP was to compete as an animal feed and the price of animal feed was linked to soya meal prices. Even the niche markets which allowed a high value added per tonne of SCP product, were linked to the base soya price. If soya was cheap enough a compounder could forgo some of the higher value feed inputs and simply use more soya.

The next three sections look at managers' reconstructions of how they saw the protein or soya price evolving during the 60s and 70s, the different interpretations of the "blip" in prices in the period 1973 to 1975 and the hindsight reasoning which they use to explain the failure to predict the price changes.

4.321 The Protein Gap

Akinin (Shell) thought that a shortage of animal feed protein began to make itself felt by the early 1960s. He talked of a general worry about the adequacy of protein supplies in general, the level of resources that the earth could support. This was partly fuelled by the Club of Rome report which received a great deal of attention at a time when there was a fashion for world futures studies, in the 60s and 70s, (see Cole, 1978 for comments on this report and others) most of which forecast dire food, energy and materials shortages within 10 to 20 years.

Swindall and Saxton explained that ICI thought that there would be more people who would want to eat meat as living standards rose in the third world. At the same time,

> "there were finite supplies of existing feeds...scares in the early 70s over fish meal supplies, shoals disappearing for odd years, soya seen as being limited by a finite amount of land surface, fairly specialised in its needs, unlikely to be able to respond to the demand for animal feed."

This idea of a protein gap also entered Shell's reasoning on SCP and Akinin described how Shell,

> "can be criticised for wasting a natural resource (like methane). The thought of being able to use that methane to generate something like protein...you could be seen to be doing something positive to improve the supply of protein in the world...it was all attractive, it was all positive."

4.322 The Viability of SCP Changes According to the Interpretation of the Significance of the Tripling of the Price of Soya Meal, 1973 - 1975

At this time the price of fish rose due to low catches off the Peruvian coast, while the US soya harvest was also poor for one or two years. These events, concurrent with the oil price increase of 1973, led to a trebling in the price of soya meal.

The drop in the price of crude undermined the economics of SCP, the rise in the price of soya improved them. For ICI the rise in the soya price was crucial because it came when they were deciding whether or not to invest in a full scale SCP plant. Marks expressed the Agricultural Department view,

> "There was no reason whatsoever to suppose that protein prices were going to fall. The margin that you could get on this process at the time was very high. And as far as you could look forward it was going to stay high."

ICI based their estimates of the Pruteen project's economics on this high price - 73-74 was the period when the building of the plant was approved. At the same time the price of methanol did not rise sharply with crude, so the project looked especially attractive at a time when the alkane based projects were in doubt. The soya price fell back to lower than its pre-1973 level over the 3-4 years after 1973. It has remained at this low level until the present and this drop ruined the economics of the Pruteen process completely. Saxton made the bleak comment that,

> "Protein prices have continued now for 5 or 6 years at what is something like a 50 year low in real terms. We got that wrong."

The ICI view was that it could be seen as the start of the long forecast protein shortage. Treeby (RHM) and the T&L management all expressed the view that the soya price rise could have been seen to have been a temporary "blip" after which it would return to its normal level. Treeby commented that RHM had been buying soya for 50 years and everyone in that industry expected the price to fall back again. Discontinuities in price were possible, but,

> "if you are going to postulate a plateau change in something which has been level for 40 years you have really got to advance a better reason than, it just happens to be up there just now. That seemed to us to be what they (ICI) had done...our people were saying there is nothing in the agricultural system that is driving it to stay up there."

Perhaps most interesting is the view of ICI's Plant Protection Division at Fernhurst, who monitor world trends in cereal prices. Geoff Scott in the Pesticide Marketing function described the evolution of the soya market.

> "in the late 60s and 70s there was a period when demand was increasing slightly faster than supply. This led to a steady tightening of the supply-demand balance. A gentle rise in prices in real terms. Then when the oil crisis came there was an outbreak of paranoia and the prices of all commodities rose many times higher than could have been predicted. In turn, this over reaction gradually evaporated and the price drifted back again. But this had stimulated increased production in

Brazil and the US...A period of over-production began, a period for the late 70s and early 80s of weak prices."

For Scott, the Club of Rome report and all the protein shortage forecasts of the 60s and early 70s were based on an extrapolation of his first period of gently increasing demand over supply. He felt that although the extreme jump in prices in 1973 was not predictable, once this had occurred the increases in soya production and the consequent drop in price were predictable. This is the opposite view to that of those in ICI's agricultural division, and appears to confirm agricultural division's lack of experience in an unfamiliar market and an internal failure of communication.

4.323 Retrospective Rationalisations of the Failure of Soya to increase in Price Permanently

The Agricultural Division managers had a variety of explanations for why they failed to predict the return of soya prices to their post-War norm. Swindall suggested that it was partly ICI's invention of new crop sprays and the introduction of the no-till farming technique to Brazil that helped increase production in the late 70s, early 80s. Fernhurst discounted this explanation as no more than marginal.

Saxton had a more stark view,

> "Basically I think what we didn't believe was that the world would allow so many millions to go hungry and to starve. We got that wrong."

Saxton and many others, Payne (BP), Hamer (Shell) and Bettley (John Brown), all pointed to the subsidised production and export of soya by the United States as a reason for its low price. Bettley is representative of these managers when he says,

> "...the farmers in the USA were lobbying to ensure that production of soya was kept up high with subsidies to farmers. And that suited the American Government very well because they, for political reasons, are happy for a number of countries to be dependent on them for protein supplies."

However, while subsidisation of an unspecified amount goes on, none of these reasons is needed to explain the progress of the soya price in this period. The supply-demand explanation of Scott (ICI Fernhurst) is sufficient and it would appear that the ICI managers were looking for post-hoc rationalisations of their old perspective.

4.4 The Loss of the Original Market Stimulates a Search for New Markets

By the late 1970s BP knew that the plant they had built would never be economic if its product was sold entirely into the animal feed market, their reaction was eventually to abandon the project. ICI was in the same position in the early 1980s and their initial reaction was to hunt for alternative markets for Pruteen. This is something BP had already done during a phase of senior management sponsored diversification in the early 1970s.

4.41 A Move to the Human Food Market

By 1980 ICI were looking for alternative markets to the poultry feed market which was to have taken most of their production. The calf veal market remained viable as did the piglet feed market, but this still left more than half the plant capacity unused. Bettley describes how between 1981-85 the plant was operated in "campaigns" at its full capacity of around 7 tonnes per hour. The produce was stored then ground for the skimmed milk replacer market. Production was kept low to avoid flooding this market and lowering the price obtained per tonne of Pruteen. Bettley thought that ICI could just meet its costs of production, despite running this giant plant at less than half its capacity. For 2- 3 years after 1982 ICI experimented with fractionating Pruteen[2] and considering it as a collection of chemicals. There were two main fractions, the nucleic acids and a proteinaceous mass. Saxton described this period as exciting because for a time it looked as if they had a high value added market in the Japanese and Korean nucleic acid market. The economics of the Japanese project were thought to be very advantageous by Saxton, partly because of the yen's appreciation against sterling. The discussions were encouraging to ICI because it appeared that the Japanese had a real problem. Their old sources of nucleotide flavourings had been SCP grown on pulp mill wastes and many of these mills were being closed or superceded by new technology and the food flavouring producers were worried about their supplies. Saxton described the marketing of ICI's nucleic acids,

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[2]See chapter 8 for detail

> "We produced nucleic acid, classic sort of marketing thing, taking samples to the Japanese, four or five times, getting a feel for what they thought of it and then they gradually refined it, could we do this to it, then that and that...we met virtually all their requirements. At the last minute they took cold feet."

A reason Saxton gave for the Japanese abandoning negotiations with ICI was their fear of a repeat of their 1972 experience, when public protest had led to the Japanese SCP projects being banned by their government (see appendix 6), especially since this time they would be openly adding an SCP derivative to human food.

The failure to secure this market for the nucleic acid fraction of Pruteen ended the chances of profitability for the fractionating project. However, some years of work had been put into developing the market for the proteinaceous fraction which would be left after nucleic acid extraction. This material could in theory be changed in various ways to give the physico-chemical characteristics required by different foods. For a short period it was the job of the research department to investigate how to modify it to give it texture and other desirable human food qualities.

Saxton said that at this point ICI were thinking of a small integrated plant producing some animal feed, human food and nucleic acids. But it emerged that Pruteen was very limited as a basis for making human food, Saxton describing Pruteen as having few functional pluses, with even a yeast having more uses than this bacterial protein. Its only realistic use was as a soup additive, a meat extender, a sausage filler, all low value-added uses and none of these was viable without the sale of the nucleic acid fraction. It was Saxton who initiated the paper that led to the end of the fractionation project, for reasons of poor market pull in the human food area, the unreliability of the Japanese as long term customers and the poor macroeconomic climate.

4.42 Loss of Animal Feed Market Leads to Development of a Diverse High Value Added Food Market for Lactic Yeast

Bel Industrie's lactic yeast Protibel was originally cheap enough for the animal feed market, in the 1960s. This market was abandoned after the 1973-74 oil price rise which affected Protibel by raising the cost of energy. The aeration, drying and separation of all SCP products was very energy intensive and according to Dinsdale the rise in energy costs roughly tripled the costs of production, despite the substrate being a waste product.

Bel Industrie found the calf milk replacer market in the same way as ICI and BP and they modified their yeast in a similar manner to ICI to suit this market, calling their product Sassiyen. They began marketing Sassiyen in 78-79 and continued to develop the human food market. Bel Industrie made a decision to cultivate several independent markets, to the point of refusing large orders for their yeast product because they would have had to give up the smaller markets (large orders being 3 000 t/a). Bel Industrie built one factory for Sassiyen and one for human food. Dinsdale thinks one of the best markets is that for dairy free products, a market which has only developed in the 1980s and one of the best of these is the market for dairy free chocolate. Yeast tablets for child diet supplements are another very high value market, although Dinsdale thought this was a limited market with few future opportunities, especially as the waste yeasts from the breweries competed in this market. Other speciality markets were the goldfish feed market, especially in Germany and Dinsdale thought the goldfish market to be of great future value although developing slowly because Bel Industrie had to gain acceptance of yeast used as a fish feed. Other markets were as a vitamin preparation for dog coats, a binding agent in charcuterie and as a feed in Japanese aquaculture.

This behaviour of Bel Industrie in response to the oil price rise is in marked contrast to the SCP producers' response, but then Bel Industrie had a substrate they had to pay to dispose of. However, they could have continued to market their yeast solely as an animal feed and accepted that yeast production was a by-product to their mainstream dairy business. Instead, they invested management effort in developing the high value added human food niche markets, with some success. The key technical characteristic of the Bel Industrie process which aided this exploitation of these markets was the food grade quality of the lactic serum substrate.

4.5 Perception of a Market Trend leads to Product Development

4.51 Mycoprotein

In the early 1980s RHM saw that there was a developing trend for healthy eating in the food market and decided that this could be the basis for marketing mycoprotein. Treeby thought that RHM saw this marketing opportunity for mycoprotein about a year before it became fashionable to advocate a low fat, high fibre diet. RHM were actively seeking ways of marketing the product and had already decided to market mycoprotein products seriously, and then came reports by various food and health committees which began to raise the public's consciousness of diet and health connections. To Treeby, this gave the added rationale for buying mycoprotein products that was previously absent. Until the developing healthy eating trend appeared, it was never clear why consumers shouldn't eat the chicken or beef for which mycoprotein was a substitute.

Once RHM decided that there was a market opportunity for mycoprotien they carried out active market research. Treeby spoke of the commercial team in charge of the product having to decide what attitude they were going to have towards the product.

> "We had said we had to be evangelical about this product. If we don't believe in the product enough, if we keep trying to insinuate this product onto the UK market we are going to fail. We will deserve to fail."

Before launching the Savoury Pie in Sainsbury's in 1983 RHM had started to do attitudinal research, consumer research and had begun to talk to other companies about joint development, for example Unilever in 1983. This led them to distance themselves from soya and SCP. They would not even join the clubs and societies that people who made soya joined. And there were the healthy properties of the product.

Once they had decided their attitude and image of the product, they began to promote it,

> "...first among the decision makers, people like the BMA, the universities, the guys the journalists go to for information... like Tony d'Angelo because he's editor of the "Grocer". We spent time talking to those people, getting them on board, so we had a cascade theory starting to emerge, we had people saying mycoprotein is worthwhile, yes, its very good for you."

Treeby pointed out that there was a difference between the peripheral purchases in people's lives and the "centre of the plate" purchases,

> "...not putting chicken or beef in the middle of your plate, that's a whole different cultural change. You are going to stop doing that only for some very profound reasons, something as enormously powerful as 'if you go on eating this stuff, its going to kill you,' and that's almost the message the NACNE, JACNE[3] people were saying."

Now mycoprotein's nutritional characteristics could have a market value, whereas before the early 1980s, they had none. Mycoprotein contained no fat, had more protein per unit weight than chicken and contained fibre where chicken and beef do not.

4.52 The Nature of the Novel Food Market

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[3]Food advisory groups

RHM put together a full commercial team with marketing, product development and a significant investment. At last there was to be a serious attempt to market mycoprotein, but RHM had clear ideas about the dangers involved in marketing a new human food.

4.521 "Novelty" as a Food Characteristic

Both Treeby (RHM) and Thomas (ICI) thought mycoprotein to be completely novel in its origin. Treeby thought the last time anyone had done what he was trying to do with mycoprotein was "Sir Walter Raleigh with the potato." Thomas thought margarine was the last completely novel food accepted by the public over 60 years ago. Treeby was quite clear, novelty in food was not "great news,"

> "...they will buy technology in a watch. But if you turn up with a food and say "great news, I've got this totally novel steak, what do you think?" in about 4 nanoseconds you'll be out on your ear. Nobody wants this kind of thing...centre of the plate, they look for the most unprocessed traditional product they can find."

Peachey described the practical result of this fear of novelty. She gave the example of rhubarb and the potato as foods that would not pass toxicological tests if introduced today. Thomas gave the example of ice cream to show that whatever the manufacturers did in terms of shapes, colours and tastes, they kept the ingredients to traditional names.

Many managers referred to the same "disaster anecdotes" in relation to marketing novel foods. One was BP's advertising in the 1960s (see earlier), and the other was the soya meat substitute fiasco in the 1970s. In the case of the latter, many food companies had been preparing to launch a variety of soya based meat analogues when Cadbury-Schweppes launched its product ahead of the others. Thomas thought that this product had been inferior and had spoiled the market for other companies. None of the soya products were successful and the conclusion drawn by the food industry had been to avoid novel food sources and to remain conservative.

4.522 RHM's Understanding of the Public Perception of Healthy Foods

RHM had detailed knowledge of the market for food, which they saw they could use to sell mycoprotein. Treeby related this understanding of the market to the characteristics that mycoprotein either had, or could be given. As far as additives were concerned, the less the better.He was scornful of how people avoided certain names of additives like sodium caseinate or sodium chloride, but sought out the common name equivalents, milk powder and salt. This was the level at which the public made decisions. There was also a particular public conception of fat, fibre, sugar and salt which RHM had to follow.

> Fat. "Everyone recognises, for reasons they don't fully understand, that fat isn't healthy. It causes you to fall over with your legs in the air sooner than you should do."

> Protein. "Sort of good for you, like fish, cheese and eggs and things."

Fibre. "'Well, it seems to, well, make you sort of better.' They haven't made the connection to cancer of the bowel or of the lower intestine. But they have heard Kellogg's telling them that, particularly bran fibre, is good for them, and you know...its a good idea."

Salt and Sugar. "not fully articulated yet, but certainly people are saying, if its got less salt it must be good for me."

There was a trend for the public to become more aware of the nutritional breakdown of food and to become more precise in its attitude to each ingredient and this trend was more pronounced in the UK than in the rest of Europe. Treeby's example of "the rest of Europe" was France, where fibre was not a health issue at all and fat was just becoming one. The trend meant a developing market for mycoprotein if it could be sold as a low fat, high protein, low salt food rather than as a novel food. Another word to which the consumer attached a value was "wholesome." Treeby said that RHM spent months working out whether "wholesome" was the right word to put on the packet of the Savoury Pie.

The pie was launched in 1985 and RHM began formal market research to find out how the pie was perceived by the consumer. Treeby believed there was a hierarchy of reasons for buying the pie. In answer to the question "why do you buy it?" the first response was "it tastes nice". The second response was value for money. As regards pricing Treeby thought it was important not to price too low, even when it was possible. It was important to get over the idea of value for the money spent, without allowing the price to suggest it could be compared to low value meat products...or something that wasn't meat at all. An unexpected piece of marketing survey feedback was the advantage of a product that contained no gristle. RHM had not thought this important, if they had thought about it at all, but, Treeby again,

> "it's amazing the number of old people and parents who say, when you ask why they buy this product, because when my kids find these funny bits of biological plumbing inside these products, that's the end of it."

Treeby saw the pie as a substantial success because it was an innovative product selling in an extremely conservative market where firms were reluctant to innovate but very fast to follow other people's successes. However, he thought sales of 10 - 20 times the present value were needed to prove the pie was the kind of success he wanted. Treeby did not want mycoprotein thought of as a "meat substitute", that was how soya had been thought of and that had failed, but,

> "There is still a tremendous amount of market pull, with meat creating the market idea..."

The analogy of meat allows RHM to see a great potential market for mycoprotein. Treeby sees his job as getting mycoprotein into the burger, steaklet and recipe dish markets, to produce a product wherever there is a meat product.

However, some managers were sceptical about the prospects for mycoprotein. Duckworth, head of research at one of Unilever's laboratories just laughed at the suggestion that mycoprotein had a future. Thomas, who came from Unilever to ICI to work on the project agreed that there was no consensus on its prospects. Thomas commented that you could see it as a fungus, with connotations of rottenness, decay, poison, or as a "member of the mushroom family." The crucial issue is whether someone will start to "market" this opposing image of mycoprotein. Thomas said that RHM and ICI were prepared for this, they had thought through a counter advertising strategy already.

4.523 ICI's Understanding of the Public's Perception of Pruteen as a Human Food

Managers from all companies believed that the chances of successfully marketing a novel human food were less with a yeast than with a fungus and less still with a bacteria.

A fungus could be marketed as "a member of the mushroom family", as RHM describes mycoprotein on its Savoury Pie boxes. Swindall thought a yeast process could be described as "natural" because its food uses were already established, and "natural" was a word you wanted in your product description. Yeast processes had an advantage over Pruteen when it came to the human food market for this reason.

ICI had found that the proteinaceous fraction of Pruteen acted in foods functionally like skimmed milk and casein. But when they turned to the Government's Trading Standards Board, they were told it would have to be described as "bacterial protein" on the list of food ingredients. This became another reason for abandoning the efforts to make a human food from Pruteen. ICI did not have to do market research to believe that any product containing "bacterial protein" rather than "skimmed milk", would be at a huge disadvantage.

4.53 Fashioning a Company Image through Selling Toprina

While RHM tried to present the Savoury Pie as a product that would be perceived as healthy in the terms in which the consumer understood "healthy," BP tried to use the positive way in which they thought the public would see a novel protein producer to reinforce the public's positive image of BP. This is Northgate's (BP) view,

> "BP were very clearly blowing the trumpet about bridging the protein gap, solving world hunger by making food from petrol. In fact they had picture of people at petrol pumps decanting soup from the pumps...backfired badly in the end. Very badly."

Leivers (BP France) described how BP moved away from the idea of feeding people to that of feeding animals, but the media continued to think of the project as an attempt to produce the "petroleum beefsteak". This became the standard way in which the Italian newspapers referred to SCP projects and it was never possible to convince the Italian public pressure groups that Toprina was not intended for human consumption. The initial advertising became a liability and helped break down trust between BP and the Italian public and government. It was also referred to by Zamgrandi (Liquichimica) as something which was hugely damaging to Liquichimica's SCP project because of the way it affected public opinion.

Yet BP were acting in a similar manner to RHM. They knew there was public perception of a protein gap, they assumed any method of producing new protein would be appreciated by the public, they wanted to have their name linked to that appreciation. But they did not account for public reaction to the association they were making between crude oil and food.

4.6 Attempts to License SCP Technology to Developing Country Governments

4.61 The Decision to License

When SCP for animal feed was seen to be uneconomic in Western Europe, companies turned to the idea that less developed countries might buy the a license to build their own SCP plants. Bettley thought that ICI moved from the idea of building plants worldwide to licensing as a way of getting back some of the money spent on the plant in Billingham. This involved ICI and John Brown Engineering putting together proposals for around 25 companies. These proposals cost ICI hundreds of thousands of pounds each, up to £0.5m per proposal.

During the late 1970s and early 1980s almost every hydrocarbon based SCP company sought to license their technology to the same set of countries and up to the present day no company has succeeded in licensing any plant.

4.62 Why Less Developed Countries Should be Interested in Purchasing SCP Technology

By 1974 BP knew they would not be building a series of SCP plants in Western Europe and after this date Leivers (BP) thought they continued to construct their plant because they wanted two full scale plants to demonstrate that the technology worked to prospective licensees.

> "We wanted to go on because for some countries economics doesn't mean anything; some socialist countries."

BP, ICI and Liquichimica were thinking of the Soviet Union, which was persisting with an uneconomic alkane SCP programme which had technical problems.

There were political reasons for the Soviet Union and less developed countries to be interested in SCP. Bettley (John Brown) thought that these countries were interested in,

> "reducing the import of soya protein so that they become to a greater extent independent of the soya producers. The decision to build such plants became political. In every case where we have been involved in detailed negotiations the political element has been very marked."[4]

These countries tended to be oil rich with a deficit in foodstuffs and a growing market for meat products. They would typically be selling oil to gain the foreign currency needed to buy essential feedstuffs. Such countries are Mexico, Venezuela, Indonesia, Kuwait, Saudi Arabia, Libya, Algeria. The economics of the process would be

[4]Most of these countries had rapidly growing markets for meat and therefore a growing dependence on grain imports to provide animal feed.

similar to that in Western Europe since at any time crude oil could be exported and soya imported.

There was at one time an excellent incentive to build methanol plant in the gas rich countries. Kuwait and Saudi Arabia are too far from the markets for natural gas for its price to reflect its value as a fuel in those markets. It is, once again, almost a waste material in these countries. Methanol production made sense because it is another commodity with a value on the international market and unlike liquidised natural gas, it would not evaporate on the journey to its industrial markets. Methanol has a different price structure from crude oil and so the economics and incentives to license methanol SCP technology differ from those of the oil based SCP processes.

4.63 Managers' Views of What Went Wrong With the Licensing Market

Swindall (ICI) explained the failure of any country to take up SCP licenses in terms of disaster anecdotes.

> "We were talking to the Mexicans, then they had an earthquake. We then talked to Russia, the deputy PM who believed in this and was pushing it forward dropped down dead at one of the Trade Fairs, 1982-83. There was a change of government in Indonesia when we were just about to clinch the deal. We went back to Mexico and then their whole finance collapsed. Virtually everywhere we went, something happened which was really irrelevant but stopped the project."

If ICI was unlucky there were other reasons for this failure. Haydn-Davies and Bettley described the less developed countries as very cautious and slow in negotiation. Bettley said many had had bad experiences with licensing Western technology before because,

"they have been rooked left right and centre by the West."

Lewis (Shell) was critical of the Arab countries' ability to negotiate. They had no technological expertise and didn't know what questions to ask at the negotiating table. They were thereby forced to trust the company trying to sell its technology for a profit, something they were naturally reluctant to do. He thought that only Kuwait was able to make a serious independent assessment of the technology. This they did through the Kuwait Institute for Scientific Research, which compared the Shell, ICI and BP processes. However, he thought the political will to buy was missing. Lewis described Kuwait as a very rich country that did not need to take risks with an untried technology. They also faced the problem that they could only consume around 30 000 t/a SCP themselves, the rest would be exported to Saudi Arabia. Since the plant would be built for import substitution purposes if at all, they would be subsidising Saudi Arabian consumption of animal feed as they were only being offered licenses for 100 000 t/a plants.

Lewis felt that the Arab countries never got over their suspicion of why SCP was stopped in Italy and Japan. They felt that if SCP wasn't good enough for Italians to eat it certainly was not good enough for Arabs and this was especially important since they were unable to judge the technology for themselves, and were therefore looking for independent evidence of the value of SCP plant. Lewis thought it unlikely that they ever understood what really happened in Italy and Japan, it was enough that something unspecified had gone wrong and money had been lost.

It is true that in the last few years the Arab countries have returned to look at SCP once more. Payne (BP France consultant) has been asked to prepare reports, for Algeria, Saudi Arabia and Kuwait in the middle 1980s, because of the fall in the oil price.[5]

4.7 The Political Debate Over Safety Forces the Abandonment of SCP in Italy and Japan

4.71 SCP in Japan

Many Japanese companies had begun to develop SCP technology in the 1960s, but after the Japanese Ministry of Health and Welfare gave them "administrative advice" to close down their protein projects Kanegafuchu and Dainippon announced their abandonment in 1973. The reason for the government's "advice," was the successful public campaign waged by two consumer groups who had alleged that the SCP products were contaminated with carcinogenic material. Lewis and Payne thought that Japanese public opinion was very hostile to industry in general at this time because of the Minimata mercury poisoning disaster. (See appendix 6 for detail of events in Japan).

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[5]Payne believed the American ambassador had warned Saudi Arabia off from developing SCP and that this explained their failure to buy an SCP license.

The significance of the events in Japan was that they were to be almost repeated in Italy with the BP and Liquichimica plants. The events in Japan affected the events in Italy since until this time Japan was the only other country where there had been an attempt to build and operate full scale SCP plants.

4.72 SCP in Italy

BP completed its Sarroch plant in 1976 and Liquichimica was ready to begin production in 1975, but neither plant was ever licensed to produce SCP by the Italian Ministry of Health. The companies kept their plants staffed and ready to produce until 1978 when Liquichimica went bankrupt and BP gave up waiting for the Ministry's production license and dismantled their plant. This section deals with the nature of the Italian regulatory and scientific system and a scientific debate strongly influenced by interest groups and Italian public opinion of SCP.

4.721 Experiences of Italy as a Country in which to Operate

Many anecdotes were told whose point was that Italy was a difficult country to do business in, at least by British standards. Some of these anecdotes had a bearing on SCP, and suggested that it was the nature of Italy as a country that led to the problems with licensing the SCP plants. Lewis said that when Shell was evaluating sites for its methane SCP pilot plant it considered the Superior Institute of Health in Rome,

> "...and yes, if we had been prepared to set up trust funds for most peoples' grandmother's aunts sort of thing, it would have

worked. We actually became so nauseated, the backhanders that were wanted to make use of anything, that we said, no way."

His opinion of the BP view that the "soya lobby" had worked against both BP and SCP was that if it was going to happen anywhere, it would happen in Italy. Payne gave a similar story about the Superior Institute of Health, saying that the head of the institute offered BP an exchange; build us a new nutrition and toxicological testing laboratory and we will give you permission to produce SCP.[6]

Lewis's view of Italian scientists was that they were always dabbling in politics.

> "Most Italian scientists live above their means and are dependent on consultancy which comes in various forms, like making public statements about issues. There has never been any difficulty in buying Italian scientists...a different basis of ethics, because they are badly paid."

It was Northgate's (BP) view that this is just what the opponents of the BP and Liquichimica plant in Italy had done. They had paid the biggest name in Italian microbiology to side against SCP and raise toxicological objections against the product. He couldn't prove this, but in Italy it was more than likely, given the nature of Italian scientists.

[6]But there was no confirmation of this allegation from any other source

> "There are some honest scientists in Italy. Some. I can say that, I'm half Italian."

4.722 The Soya Lobby in Italy

A number of BP managers thought that the press campaign against SCP had some kind of organisation backing it besides the pressure groups formed by the public. BP never publicly blamed the Italian soya importers, but some managers did think the soya importers were funding the public pressure groups and making submissions to the Ministry of Health that SCP was a danger to health.[7] Northgate (BP) had the most radical belief in an organised soya lobby.

> "Soya was extensively grown in northern Italy...centred on Bologna. Bologna happens to be communist controlled. There was no way you were going to allow a fascist-imperialist joint venture in Sardinia put soya farmers out of work in communist Bologna...that lobby, the soya bean lobby, which was very strong, very powerful, very clever, got hold of this toxicological link, paid one of the biggest microbiological voices in Italy at the time to back their side, because BP

[7]Payne reported a conversation with Zamgrandi where Zamgrandi said that he had seen documentary evidence leaked from the Ministry of Health which revealed that soya importers were attempting to influence the Ministry. However, Zamgrandi was reluctant to admit as much in his interview.

Payne was also convinced that the Americans had been exerting pressure. He claimed to have talked to the director of Italproteine, who had told him that during a conversation he had had with the American ambassador, he was told that "there is a risk that it (the Italproteine plant), will not be appreciated by my Government". Payne felt that it was not coincidental that the press campaign against the plants grew after this event.

were too slow in getting him to back their side. He backed them and shouted loudest."

Zamgrandi (Liquichimica) objected to the idea of a powerful organised soya importer's lobby. He presumed the soya importers secretly funded the anti-SCP consumer groups, who were organising meetings up and down the country, paying scientific speakers and leafleting, all with no declared source of income. He felt that speculations about the existence and degree of activity of a secret lobby were only attempts to avoid having to explain the real hostility of Italian public opinion towards the SCP plants.

"It was a problem of public opinion...It was quite easy to say it was the soya lobby. The problem was that public opinion was not prepared to accept this kind of product in Europe...when it appears to come from an unnatural source."

Peachey referred to the idea that a soya lobby interfered with the Ministry of Health as,

"...total speculation, just as it's total speculation that the mafia stopped the Liquichimica plant. No-one is ever going to prove it. But when so many factions appear to be anti the BP plant, you decide, it just wasn't going to be allowed to work."

Leivers (BP) went further and provided a counter explanation for why there was so much talk of a "soya lobby". She also believed that it was public opinion that stopped BP and Liquichimica, the negative attitude of which she explained by a number of events. One of these was the banning of SCP in Japan in 1973. Even if the reasons for this were not understood, in fact especially if this was not appreciated as a complex series of events, what happened in Japan strongly influenced the Italian press and Italian public opinion against SCP.

A second factor was that BP's original advertising of their SCP activities was well known and taken to imply that they were working on human food from petrol sources. All managers saw this as a colossal error in hindsight, one whose effect was to weaken the credibility of BP and Liquichimica denials that they were working on human food SCP products.[8]

These events were given added importance by the secretive policy of both BP and Liquichimica during the 1975-1978 period. Leivers admitted that BP's policy was to talk only to the necessary officials in the Ministry of Health. She herself was unable to make any comment to journalists who managed to locate her. There were not even any official company press releases on Toprina or the plant in Sarroch. In the absence of such information releases the public debate on SCP safety was heavily against SCP.

4.723 The Ministry of Health

The Italian Industry Ministry could only issue licenses to produce SCP once the Ministry of Health had declared the two SCP products to be safe. A special committee of the Ministry of Health called the

[8]In fact Zamgrandi admitted that Liquichimica was working on such products, but were attempting to keep the work secret because they were aware of how hostile public opinion would be.

Superior Institute of Health (Consiglio Superiore di Sanita, or CSS) was given the task of commissioning toxicity research on samples of Toprina and Liquipron and reporting back to the Ministry. Zamgrandi believed the decision to approve the products effectively rested with this institute and that the Health Ministry would accept its recommendations.

This institute never found the SCP products to contain any harmful residues, but it never made a recommendation that SCP was safe to the Health Ministry. What it did do was to return to BP and Liquichimica repeatedly over a 2-3 year period to ask for further tests and changes to their plant. Throughout this period the plants were complete and only awaiting permission to start production.

Zamgrandi believed the delay was deliberate,

> "Because the decision would have been unpopular. Never any evidence of toxicity. Nothing. But they kept asking for more tests...You see the problem with toxic waste (Karina B). I am sure public opinion pushes the politicians to treat the problem unobjectively. The type of experiment requested was the sort to take time, to allow a decrease of the anxiety of the people."

Zamgrandi had talked with many officials in the health institute and did not believe that any one was really against the product. The decision to delay was political and he implied that the Health Ministry might have influenced the outcome of the CSS deliberations, "if the Ministry say, give us conclusions to allow us to avoid giving approval...CSS is managed by one representative and he is continually in touch with the ministry.[9]"

Zamgrandi thought that perhaps 35 members of the CSS were in favour of SCP and only 3 or 4 against. However, without a unanimous recommendation the Health Ministry would not approve SCP. If they had done so, the 3 or 4 members against SCP would have started to oppose the decision, perhaps in public which would have embarrassed the Ministry at this time.

According to Zamgrandi, Liquichimica lost 2 years waiting for a mistake by the public testing laboratories to be rectified. The Istituto Superiore di Sanita, ISS, found that the Liquichimica strain of yeast was pathogenic. Liquichimica thought the ISS had contaminated the Liquichimica strain with a pathogenic strain, Candida Albercans, in the government laboratory. The ISS was eventually proven to have been mistaken by various independent experts who repeated the tests on Liquichimica's yeast strain. The ISS also thought at one stage that Liquichimica were using Candida Tropicalis, which was untrue. To clear up these confusions took 2 years and since Liquichimica had been driven close to bankruptcy the President of the company decided to sue the ISS for production lost between 1975-1977.

Peachey's account of what happened to BP is similar to that of Zamgrandi's.

[9]Il Sole (1975) refers to the history of "le bioproteine" as akin to a detective story in its complications and its secrecy.

"They produced objections, we countered them with fact, they produced more, we went to MIT, they had rent-a-mob, the local mayor at Sarroch, wanting to be reelected, I will save you , the local population. I think the last one, they asked for totally unreasonable effluent levels, by any industrial criteria. We kept on building, all sorts of things, but they kept on coming back."

The problems over the toxicology of the product did not occur in other countries. BP had been selling SCP from Lavera for 3-4 years in France and ICI obtained UK government approval for Pruteen and no other European governments or testing laboratory found SCP to be unsafe.

4.724 The Scientific Debate over SCP Toxicity in Italy

Swindall of ICI gave the most detailed account of the toxicological issues that concerned the licensing of SCP production in Italy. Accusations of toxicity in SCP compounds were made by some Italian microbiologists based on a scientific reasoning that the companies doubted were ingenuous. The result of the split amongst the experts was that the public and the non-expert officials in the Ministry of Health did not know who to believe and so avoided making any decisions.

The first problem with the BP and Liquichimica process was that the alkanes were derived from crude oil which was known to contain carcinogenic aromatic hydrocarbon compounds. These were present in the refined n-alkanes used as a substrate but only in quantities below those permitted in ordinary foods in Italy. It was alleged that the aromatic compounds might accumulate in the back fat of pigs raised on SCP, because it had been shown that traces of n-alkanes did accumulate in the pigs' back fat. The companies could show that this pig meat was safe through toxicity tests they had undertaken before the plants were built. They had anticipated problems with aromatic hydrocarbons and had designed their tests to show that they were not in fact a problem.

An example of a toxicity problem which was not anticipated was the human metabolism of yeast cell fatty acids, which Swindall thought had proven to have been one of the most important problems for BP.

> "This was used as a whipping post for BP. BP were stopped by arguments over the odd fatty acid chains. Personally, I have no problems over this metabolism."

The fatty acids produced by yeast metabolism have an odd number of carbon atoms in their carbon atom chains and these were shown to be present in the meat of animals raised on diets containing SCP. It was known that mammals produce and metabolise even chain and odd length fatty acid molecules and that the waste products from these two classes of fatty acid were acetic and propionic acids respectively. These two acids were similar chemically and according to Swindall there was no a priori reason for thinking that propionic acid could have toxic effects on human metabolism. However, since the companies had not expected fatty acid metabolism to become a political issue they had no research to prove that odd chain length acids were in fact harmless. By the time work had been done on fatty acids, both BP and Liquichimica had pulled out of SCP.

Another problem was the environmental discharge of live organisms from the drying and harvesting processes into the atmosphere. Swindall made the point that ICI's organism was so fragile that despite being emitted from the plant, unless it landed in a peat bog where anaerobic metabolism could take place all the organisms would die. This was not necessarily the case with the yeasts of BP and Liquichimica.[10]

The BP organism was Candida Lippolitica, the Liquichimica organism was Candida Maltosa. The first problem was that people confused these two organisms with Candida Albercans, or thrush, which was certainly toxic and had the short hand name of simple "Candida". There were then strains of each species of yeast which also differed in their metabolism and so in their possible toxic effects. Swindall thought C Lippolitica strains were non-toxic, but some strains of C Maltosa were toxic, although not Liquichimica's strain. Swindall thought that this confused the Ministry of Health officials especially as the Liquichimica process was based on the Kanegafuchi process which had been banned in Japan. He also thought that if this had caused them to have doubts about Liquichimica'a strain so that they could not license it, they would certainly not license BP.

> "The trouble was that the scientists and bureaucrats in the Italian government were ignorant, not trained in this area, so that to say strain 1 is pathogenic and strain 23 is not did not convince them completely...especially when the debate amongst the experts was split. So there was a combination of political

[10] BP had had emission problems at the Lavera plant for a time, but had eventually solved them.

influence and no specific training to distinguish between strains of a genus..."

Payne also thought the soya lobby was at work generating confusing research.

"There were some experiments in America, sponsored by the soya people. They took rats, irradiated them nearly to death, injected them with immuno-suppressant drugs, then injected several million living yeast cells into the blood stream of these, these miserable beasts. After killing and dissecting them they found there was some persistence of living yeast cells, therefore the yeast was potentially pathogenic. Absolute, complete nonsense."

4.8 Conclusions on the Market for Innovation

4.81 The Market and Technology Interaction

This chapter has examined the managers' perception of the markets for the novel food and feed innovations from early in the innovation development process to the time when some products began trading. It can be seen that there was a continual interaction between market ideas and the developing technology of the project, even in those firms where the managers did not interact greatly with a market, such as those in T&L, (see 4.121 and 4.123). In the latter firm it was the managers' experience and imagination that supplied the idea of an end use.

But in looking for a means of structuring the new process, managers were breaking down an existing market into its attributes, for example, ICI used teh soya market and its qualities; an amino acid profile, a measure of bacterial contamination, tests for a mineral balance etc. They then used combinations of these attributes to define the market of the innovatory product, (see 4.14 and 4.322). These selected "existing market" characteristics were used to structure the development of the new technology. This is the same language as Metcalf uses, see 1.2, and here the detial of this structuring process has been illustrated in practice.

This process of abstracting qualities from existing markets and using them to structure new technology explains why the innovatory product is at once new, yet made up of existing market ideas. This process can be described as the use c^f a "reference market."

4.82 Reference Markets for Innovation

A reference market is the market that the innovating firm intends its new product wholly or partly to replace. Another way of putting this is that the reference market is a metaphor for the innovatory product and they have qualities in common. It will be used by the innovating firm to guide development of the innovatory product.

Where does the innovatory firm obtain the idea of the reference market? At one extreme the firm would not do any market research, but like T&L, (4.12) with the third world protein product, would rely more on experience or received wisdom to guide development of a product. At the other extreme ICI talked to the feed compounders, (4.142), and came to have as good an understanding of their requirements as they had themselves, despite having no previous experience of the feed industry. In either case the idea of the reference market can be broken down into a number of product "qualities" that are thought to satisfy consumer "needs". These qualities can be used to guide development of the innovatory product. Innovation will proceed if the innovatory product is thought likely to exceed the worth of existing products which satisfy the reference market.

To use the feed market as an example, the compounders who deal in this "real" market cannot be relied on to have an exact knowledge of the qualities of feeds they trade in. The compounders themselves only have a model of what qualities match the "needs" of the farmers they trade with. For example, a "good feed" is one that gives rapid weight gain, lean tissue gain etc. This is related by their model to amino acid profile, mineral and vitamin content of feeds. The models they have developed allow them to discriminate between the commonly encountered differences between feeds. However, these models would limit their ability to judge Pruteen if Pruteen had qualities other than those they routinely encountered. The reference market is not fully adequate as a means of guiding the development of the innovatory product, it too is a model, designed for a particular purpose.

Without entering the market, how does a firm identify and then judge the qualities of the innovatory product that differ from those previously encountered in the reference market? There is a danger that the reference market consumers will interpret the results of these differences in an unfavourable way because they judge it by their usual standards. An example is the selenium deficiency of Pruteen, which led to poor growth in experimental animals, which could have been interpreted as a biological deficiency in Pruteen, (see 4.23). This was avoided by ICI using nutrition science as a common base of knowledge between compounders and ICI, to convince the compounders that there was an acceptable alternative interpretation of these results, ie Pruteen was simply deficient in selenium.

The idea that a market is only ever a model allows innovation failure or success to be understood less as a matter of whether there was enough "marketing input" or "market research" and more as a matter of whether the relevant qualities were selected and used to guide product development. Some kind of an idea of a market was rarely absent from any of the attempts at novel food innovation, but these "models" differed in quality and sophistication.

It is also easier to understand why, however much effort is put into market research, there is always going to be a chance of market failure for innovatory products. It is going to be difficult for these market search techniques to improve on the consuming group's ideas of its needs, (that is the reference market), but these are inherently limited. They are limited by the products already consumed.

It will be more difficult to link the more radical products with a reference market. They will face the more difficult problem of picking out "needs" and "qualities" from entire industries or for consumers in general. The reference market, once chosen does give a guide to which qualities should be considered for relevance to the innovatory product, but how should one make the initial match between firm technology base and a reference market? It is likely to be the most common qualities of the innovatory product and the products that already satisfy the reference market. Pruteen can be used as an example, both it and soya meal are bulk, protein commodities. The gross similarity is enough to establish the soya and fish meal market as a guide to the qualities that Pruteen should have to be at least a "good" product. With this established, market search would be directed to investigation of the animal feed market requirements.

This chapter shows that the choice of the reference market may be guided by implicit assumptions which later prove to have been misleading. For example, BP in Italy, (4.7), concentrated on the reference market defined through the feed compounders needs, which did not take into account that they were using a crude oil related substrate. They did not anticipate that meat consumers would repudiate a product with such a characteristic, because this did not concern the compounders. In contrast the end user was the prime concern of RHM who were using the "meat market" as their reference market for Quorn, (see 4.51), but selling Quorn on to intermediate manufacturing firms.

4.83 Summary

Much of the material in this chapter has described how technical choices have been influenced by market considerations. As the project develops both the technical and market understanding grow together. The SCP projects can be seen as processes of matching technical possibility to market opportunity, but not in any rational linear fashion. The chapter which naturally complements chapter 4 is chapter 8, which focuses on the firm's technical decisions and shows how these are bound up with market ideas.

It is interesting to examine the kind of market uncertainty we are dealing with in the reference market model. It is not the uncertainty of the unknown or the unknowable, rather it is the uncertainty of how to select among a finite but large pool of guiding principles that have diverse value to the innovatory product. The guiding principles all relate to human needs or wishes and are themselves only a small selection of the "possible" methods of developing a product. It is not possible for a small group of people in a firm to consider all these alternatives "objectively", or to consider all the alternatives. There is not enough time in a life time, hence the reference market as a guiding concept.

CHAPTER 5 COOPERATION AND COMPETITION BETWEEN COMPANIES

Introduction

The last chapter examined the relationships between the ideas of the environment external to the firm which were mainly market influences and the development of the project inside the firm. This chapter continues to look at another feature of the environment external to the firm, the inter firm relationships and how managers perceived them to affect the projects. Managers referred to inter firm relationships in terms of firm cooperation more often than in terms of firm competition.

Since few SCP products ever established themselves in their potential markets, competition or collaboration was based on the only current firm activity, which was the development of the technology.

Collaboration tended to occur when the demands of a project in terms of finance or skills exceeded the parent company's resource. The first sections will study the examples of cooperation drawn from RHM's project and the later sections examine technical competition and how scientists coped with the needs of commercial secrecy.

5.1 Commercial Cooperation on SCP

5.11 RHM - Cooperation with Du Pont, BTG, (British Technology Group), ICI and Sainsbury's

CHAPTER 5 COOPERATION AND COMPETITION BETWEEN COMPANIES

Introduction

The last chapter examined the relationships between the ideas of the environment external to the firm which were mainly market influences and the development of the project inside the firm. This chapter continues to look at another feature of the environment external to the firm, the inter firm relationships and how managers perceived them to affect the projects. Managers referred to inter firm relationships in terms of firm cooperation more often than in terms of firm competition.

Since few SCP products ever established themselves in their potential markets, competition or collaboration was based on the only current firm activity, which was the development of the technology.

Collaboration tended to occur when the demands of a project in terms of finance or skills exceeded the parent company's resource. The first sections will study the examples of cooperation drawn from RHM's project and the later sections examine technical competition and how scientists coped with the needs of commercial secrecy.

5.1 Commercial Cooperation on SCP

5.11 RHM - Cooperation with Du Pont, BTG, (British Technology Group), ICI and Sainsbury's

RHM sought to collaborate on the mycoprotein project for financial reasons as Treeby (RHM) remarked,

> "At that time we were not a rich company and we didn't have the money to carry this one through on our own account."

RHM searched for a suitable company and came up with Du Pont. Du Pont subsequently supplied money and some engineering input to the project for 3 to 4 years, until a period of retrenchment in Du Pont when the joint project with RHM was cut. Then the British Technology Group was approached and agreed to support the project financially, during a period when RHM profits were under pressure and it would normally have been impossible to justify this high risk project. Finally the current relationship with ICI was established. ICI had first been approached in the late 1970s and Treeby described their attitude,

> "...they said, you have a very nice little project here. We are working on lots of problems that you are working on. We have to tell you that a) we don't know how you did it for the money because it cost us 40 times as much, b) we need another protein project like a hole in the head. We have enough problems with our own, thank you very much."

Until ICI lost its commitment to Pruteen they were not ready for a collaborative project. In the early 1980s RHM and ICI managers were meeting to share views about obtaining regulatory clearance and found that they had many complementary interests. Meetings followed the first contacts to explore the chances of cooperation and the two companies agreed to work together. Both Smissen

(ICI) and Treeby described the rationale for cooperation in similar terms, with Treeby commenting that,

> "the ICI relationship is a combination of sharing risk, costs, skills....about bringing together a whole complex package of, I think, complementary skills and interests rather than competitive skills and interests."

ICI was international, but RHM was not, although both had a history in fermentation. ICI had the ability to design and build large plant, RHM had the ability to develop complex food systems, a number of market entrees in Europe and food marketing expertise. The collaboration took the form of a jointly owned company called Marlow Foods which is responsible for developing and marketing mycoprotein. Research on mycoprotein is split between ICI's Biological Products Division at Billingham and RHM's High Wycombe food laboratories. Mycoprotein is actually grown in the former ICI Pruteen pilot plant at Billingham.

RHM had also shared the costs of product development with Unilever who had been experimenting with mycoprotein since the mid 1970s by treating it as a raw material, putting it in pies and testing consumer reaction before giving feedback to RHM.

Marlow Foods has worked especially closely with Sainsbury's to market the first mycoprotein products. Sainsbury's could offer Marlow Foods access to 16% of the UK shelf space for meat. They owned their own meat pie company and could offer RHM knowledge of the meat products' market and manufacturing expertise that RHM did not possess.

5.12 Hoechst and ICI

Various long standing agreements on technology exchange were used to exchange technical information on SCP. An instance of this was between ICI and Hoechst, who had had a general technology exchange agreement since the early 1970s. As part of their work to develop human food from SCP, Hoechst had patented the "Schlingmann" process for removing nucleic acids from microbial protein. Hoechst thought this was a unique piece of downstream processing technology, which they could offer to ICI in exchange for bio-mass from ICI's Pruteen fermenter. Liesser (Hoechst) thought that cooperation also made sense because both companies had processes based on methanol and both used similar organisms. However, this did not happen. Liesser believed there were problems of communication between higher levels of management in the two companies and that this delayed negotiations, but they broke down completely when ICI found that UK food safety regulations made success more likely if the product was processed in the UK rather than in Germany. Subsequently Hoechst approached T&L and RHM but cooperation never progressed further than a few informal discussions.

5.13 BP and Collaboration

BP formed a joint company in Italy called Italprotein with their partners, ANIC, an Italian chemical engineering company and part of the Italian state hydrocarbon group, ENI. ANIC was nominally in charge of building the Sardinian plant and Northgate thought BP needed ANIC's ability to engineer in Italy and it should have been useful that ANIC was state backed. However, Northgate also thought that no other Italian companies, such as Montecatini, were really interested in cooperation on SCP and to some extent BP had no choice in their partner.

Peachey had seen the Japanese chemical companies as the only true competitors to the Toprina process. BP was interested in a technology exchange agreement with one of them so as to limit the competition or at least to keep abreast of Japanese developments in fermentation technology. This was perceived to be the Japanese strength, while BP could offer the Japanese its R&D facilities. BP began discussions with Kiro Hako and according to Northgate BP licensed its SCP technology to Kiro Hako for a sum that paid for the initial and pilot plant stages of SCP research, (see appendix 6).

5.14 IFP (Institut Francais du Petrole), CFR (TOTAL) and ELF

A group of French companies cooperated to share the costs of researching in SCP. The French Petroleum Institute maintained a programme of research on SCP from the late 1960s until the late 1970s. This started when in 1966 they began work with the Indian Petroleum Institute on a small scale fermenter. In 1968 ELF joined this research and with CFR, (Total), formed an association to share the costs of this research.

The aim of ELF and CFR in this venture was to keep abreast of developments in SCP technology at low cost. If Toprina succeeded they wanted to be able to follow BP into the SCP market quickly. ELF contributed research personnel and money while CFR only paid a share of the costs and followed the work through seconding one engineer.

This project had 25 researchers in the early 1970s. The three partners also created an economic interest group[1] called the Groupe en France de Proteines which continued until 1976, when CFR and Total abandoned the project.

This was an example of national technical cooperation between French private companies to enable them to enter the SCP market and compete with BP should they judge it to be expedient.

5.15 Shell Protects its Relationship with Giste Brocades

According to Lewis (Shell) Shell's cooperative agreement with the Dutch fermentation firm Gistes Brocades led the board to believe there was a conflict of interest in developing their own fermentation based projects. He believed that had SCP been economic Shell would never have developed SCP, because it would then have threatened their relationship with Giste Brocades. (See chapter 7 for detail).

5.2 Cooperation with the Authorities and Other Firms on Regulation for SCP

BP and ICI were anxious that the new regulatory guidelines that had to be drawn up for SCP would be as favourable as possible to their SCP products and as unhelpful as possible to potential new entrant companies. According to Swindall BP and ICI worked together in

[1]This was a GIE, Groupe d'Interet Economique, a specific form of corporate structure established in French (and since 1987, EEC) company law, eg Airbus Industrie is another.

approaching the food safety authorities in the UK, the EEC and UNPAG.[2] The aim was to agree the kind of regulatory framework that would best suit the two companies' SCP projects and then to present the same arguments to the authorities when they began drawing up a framework.

Swindall (ICI) described BP's role in obtaining guidelines from UNPAG as enormous. This organisation was concerned with ways in which the UN could overcome world famine and was set up in the 1960s in response to the protein gap. It was important to BP that it picked SCP as one of the solutions to this protein gap and Swindall said this eventually happened,

> "...BP saw an opportunity to get the UN thinking about SCP...and from about this date, 1973, there were several conferences, I think one a year, until 1978."

Swindall described the ICI and BP purpose in cooperating with each other in negotiations with the authorities.

> "Individual projects had to be tested rather than have generical tests for SCP. The EEC directive on SCP reflects UNPAG thinking in this way too...our approach to testing was conditioned by our need to deter late entrants. Because if each product belonging to each firm had to be individually tested it would cost £2-3m at 1976 prices, for each company. This in fact became a very marked disincentive to the late new entrants because by 1976 specific, not generic guidelines had

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[2]United Nations Protein Advisory Group

been accepted by UNPAG."

Swindall thought BP had a special reason for wanting individual product, and not generic testing procedures from the EEC. Liquichimica'a SCP was produced by Kanegafuchi technology which Swindall believed was backed by an inadequate amount of animal testing - unlike Toprina, which had been thoroughly tested. BP were arguing for specific testing procedures with the Italian health authorities, while Liquichimica were arguing that their process was a yeast grown on alkanes exactly like BP's and so if approval was given to BP, it should also be given to Liquichimica. At the time of the debate it would have been of great value to BP to have had the EEC directive on SCP testing procedures. By 1984 it was of course useless to them as well as to ICI. Swindall also believed that it was because the Italian authorities could not approve the BP process while refusing to license an Italian company's process that they stalled for so long in approving either process. So here we have one more rationale for the Italian debacle.

In the case of the EEC regulations, ICI were only becoming interested in influencing the regulations when BP had already decided to close their Sardinian plant. ICI had to persuade BP to work with them, even though there was no longer a gain for BP. However, there was little cost to BP in talking with ICI. Swindall commented that after 8 years of debate the EEC had finally approved SCP testing procedures similar to those desired by ICI, but too late to be of any use to either company. However Dansk Bioprotein are benefiting from this legacy. They are able to design their process to meet fixed and agreed product safety standards.

Swindall recalled that in one at least of the early meetings BP did not realise how committed ICI were to SCP and tried to warn ICI off a technology which "belonged" to BP. Once they realised that ICI was serious about building a large scale plant, they accepted them and they worked together on regulatory issues.

The principal reason for collaboration was not a need for resources, as with RHM, but that some danger was common to the group of companies competing to produce SCP. The interesting feature of the collaboration was that it occurred at the same time as the companies saw themselves as competing to produce SCP and to this we now turn.

5.3 Technological Competition

5.31 Technological and Market Share Competition

The SCP companies were all attempting to obtain a share of the animal feed market and so soya was the competitor product. In the case of mycoprotein meat is the competitor product. The innovative products are competing through their technical advantages as a result of their radically different production technology. In no interview did managers show that they were consciously considering competitive moves against the soya or the meat industry. They would compete by producing a superior product at a cheaper price and in achieving this the actions of their "competitors" were irrelevant, since they had no access to the SCP companies technology.

Harwin (ICI) had the view that with a total market for soya meal of near 13 million t/a, any output from SCP plant would simply be negligible compared to the size of the total soya market. SCP companies were not a threat to soya consumption and they were not really competing with each other for market share. Akinin (Shell) accepted this view and believed that as a result, the cooperation between company research teams was greater than was usual for a commercial project. However, Harwin did see the SCP companies' relationships as technically competitive and commented,

> "Competition? Yes, we were very aware of what they [other companies], were doing, mainly for what they were claiming for their SCP products...colour, texture and so on. Yes, minor characteristics."

These minor differences resulted from the different production processes. In order to best meet perceived market criteria for a good product, each company was interested in other projects' technical characteristics but secretive about any of its own which could aid another project, (see below), but the SCP company competition was not really for market share.

5.32 Competitors are Perceived in Terms of their Level of Technological Achievement

Companies that were only in the research phase of SCP could not really be called competitors to a company building a plant. For a company like BP the judgement that a company was a competitor depended on how similar their process was to BP's and how close in time they were along the development path. So in the early 1970s Peachey thought the Japanese were the real competitors to BP because they were intending to use the alkane route to SCP at about the same time as BP. Since they were perceived to have fermentation technology skills that BP lacked, the Japanese were even a threat and BP's talks with the Japanese were intended to tie them up to some sort of a deal, for example an exchange of fermentation skills for R&D skills. With the end of the Japanese companies plans for SCP, Peachey saw BP as having a clear field and ICI were not a competitor because they started development so long after BP. She said,

> "They were coming along, snapping at our heels, but I don't remember seeing them as a challenge, no. If we had had no problems we would have been producing in 76-77 and we'd have been perfectly able to tolerate ICI going into the same market as well...they were not a rival but a younger brother to be patted on the head."

Peachey thought of the ICI process as second wave technology which would be on the market when the BP process was at its peak, giving BP time to develop a third wave of SCP technology, this time ahead of ICI.

Swindall thought that control over technology was the major way in which ICI attempted to block new entrants to SCP,

> "By a) good patenting and b) control of the raw material. ICI has licensed or built 70%, 80% of all the methanol plant in the world... we could control methanol production by the

> catalysts essential to produce it from methane, if not by the license for the plant. All methanol plant uses ICI licensed catalysts."

When asked why the French companies failed to build commercial plant Swindall thought the ownership of patents a great disincentive to following the ICI methanol based technology;

> "They were late coming in and when they did they found BP and Liquichimica were well established...and second, ICI was going down another path and presumably had the patent position tidied up without any gaps."

Many managers referred to the example BP set as a pioneer in SCP. Other oil companies saw that BP believed SCP could be profitable and were drawn into research on the technology for this reason, like the French consortium. BP's oil company competitors were unwilling to allow a traditional rival, BP, to develop a major new technology based on hydrocarbons to which they had no access. According to Selfridge, this was the principal reason for the IFP, ELF and TOTAL involvement in SCP. It was also one of the reasons why Shell and Esso examined the technology.

BP was acting as the innovation leader, the rest of the industry as the potential followers. Freeman (1982) refers to the advantages and disadvantages of being a leader or a follower in innovation. In this case the followers gained from a cautious approach and BP lost heavily through being the innovation leader.

5.4 Scientific Research and Competition

There was a conflict between scientists' wish to publish papers for the academic community and the need for commercial secrecy. Cowen referred to the attitude among the more academic people in T&L,

"...who, generally speaking, don't like industrial research because they feel they will do all this work and someone will lock it away in a filing cabinet and they will never be allowed to use it."

Treeby (RHM) described the company attitude,

> "...there is a natural inclination not to share information which has taken 5 or 6 years to assemble, especially regarding the organism. We were obviously much more relaxed when we had established a lead by way of a body of data...and had patented the organism and the process that surrounded its growth."

Companies would compromise and allow their scientists to publish in order to attract the people they wanted, but the publications would be scrutinised for commercial disclosures. The scientists would also have a code of personal behaviour with regard to commercial secrecy when at conferences and when talking with former colleagues. Thomas (ICI) described how this code was acquired and applied at a conference,

> "...you're left to your own judgement how much to tell them [other scientists]...nobody ever teaches you, you find out from experience what is and isn't sensitive...and some will

think that is, and some that it isn't...get someone buying a few extra pints on the night of a conference and there is no knowing how much some people will tell you. Occasionally...well, not occasionally, you've got to be careful you don't go wide of the mark and by discussing the problem you don't actually give away the process or something like that."

Marks (ICI) and Akinin (Shell) thought it was easy for a scientist to decide what was commercially sensitive. Basic science knowledge was exchanged freely, for example how organisms grow in general, the energy flows at different stages in the biochemical pathways because these were of interest to all the scientists. On the other hand, talk about how to grow organisms at high process efficiency was commercially sensitive because this was the characteristic by which companies were selecting one organism over another, and it related to the need to attain economies of scale, a commercial necessity.

Besides these informal control mechanisms there were the formal ones, and at ICI this meant that a prospective paper had to be signed by four different groups of people. Marks said that the research manager, the research director, the business area manager and possibly even a Board member's signature were all required before a paper could be presented at a conference. Even talks, with no written proceedings, would be checked by business managers. Thomas found that he learned what was permissible through these formal checks then applied the same checks in informal discussions with colleagues, and he commented that,

> "Sometimes its ludicrous, and they nit pick like hell...but the business is what pays the money for the research, so we can't upset the business."

Northgate (BP) agreed with Marks that you learnt nothing of commercial significance from scientific papers.

> "They are as bland as you care to make them. No company worth its salt publishes anything."

Commercially important information did leak out and using logic and intelligent guesswork much could be deduced of a company's commercial targets. Leaks were described by Northgate,

> "Over the table in an unguarded moment, people say things they shoudn't say, And people move from one company to another, that's how it happens. Companies don't publish, the most secret things they don't even patent. The last thing you do."

In the case of SCP Haydn-Davies described what he thought would be a hierarchy of commercially sensitive topics.

> "The most important thing was always the organism. Number one. Absolutely. You don't actually give it a name, or you keep the name secret. If you look down the microscope...well, a yeast is a yeast. So it's the cultures and where they keep them. The second would be the medium, not the single medium but its make-up."

The companies would admit that the medium was methanol etc, but the precise concentrations of minerals required to maximise growth would be kept secret.

> "The third thing would be the type of process, there is quite a bit of know-how there, growth rates, balance of amino-acids, (% mass that is protein). The fourth thing would be separation, that is a very key area indeed. In the Pruteen process a lot of technology was developed to separate the organism. The final thing is what you do to it once you've separated it, downstream, that is a key area too."

This list varied depending on the company and it also changed through time. RHM referred to their organisms by numbers, C1 and A3/5, but BP named their yeast as a strain of Candida Tropicalis. Haydn-Davies thought that RHM eventually named their organism because it became clear that unless a competitor had the exact strain, they could not reproduce the same results. As time passed companies gained a more precise understanding of what it was necessary to know in order to reproduce their technical results and this resulted in some changes in what was considered "commercially sensitive", as did the unavoidable leaks of information from the projects. In the early days of research on SCP the names of the organisms were kept secret for as long as possible. Haydn-Davies (T&L consultant) recalled the leaking of RHM's first organism.

> "...RHM kept their bug secret for a very long time, everyone knew it was a filamentous fungi and we had a very good idea what it was . I remember it leaking out , it was a Fusarium

you know, and then everyone wanted to know what sort of Fusarium, and when they discovered that the first organism was a Seletectum strain they all went rushing round looking for Seletectum strains. But they didn't get the right one. And then lo and behold, RHM chose a different strain anyway."

Northgate (BP) believed that certain areas became less secretive as time passed because people realised that the skills of fermentation were extremely difficult to acquire, even with the name of an organism and its nutrition requirements,

"Monoseptic continuous fermentation is the sort of process where you can give someone the name and pedigree of the yeast, a sample, but if you have not got all the 10 - 15 years of culture experience, medium optimisation, its hardly worth the effort. So you can publish lots of facts and figures, they don't help you to ferment. Fermentation is an art and a skill, you don't pick that up by reading about it."

On the other hand certain key events had resulted in a general increase in secretiveness among the same scientific community. Marks (ICI) described the effect of the discovery of monoclonal antibodies, which now represented a "cautionary tale" among microbiologists.

"In those days (1970s) academics were extremely free with their ideas in the UK, and we've seen some of the consequences of that too. Milstein and monoclonal antibodies...it was at a time when academics would go along to a scientific conference and talk about their work and not appreciate the commercial relevance of it...that has changed."

There was one way in which scientists cooperated to help SCP as a whole. They recognised that it would help legitimise SCP as a safe and respectable industrial product if they referred to each other's work whenever they delivered a paper at a conference and so Spicer and Solomons from RHM would mention Pruteen at food industry conferences to which ICI scientists would not normally go, and vice versa at chemical industry conferences.

5.4 Conclusions

5.41 Reasons for Cooperation

Cooperation occurred on the basis of an exchange between the collaborating companies of specialised skills, assets, finance or a legal stake in a joint venture. Cooperation could be informal and involve the exchange and clarification of views rather than skills. This occurred when companies recognised a joint interest viz a viz the regulatory authorities or public opinion.

5.42 Nature of Competition

There was no direct competition for market share between the SCP companies, but there was technological competition and technical rivalry. The soya industry was the real target market, but competition in this market depended on developing the complex technology of an SCP process. In developing this technology companies could be aided by information gained from the other novel food projects, but not the soya industry. The competitive structure of the soya industry, to which SCP posed the greatest competitive threat, barely featured in managers discussions because it offered no lessons for SCP technology. So although the novel food companies were not competing in a cut throat market share fashion, they still resisted helping other novel food companies through being secretive. Competition is not simply technological or market in this innovative technology. It varies in intensity and quality according to the managers' conception.

The companies used technology or scientific work to which they alone had access, to prevent competition from emerging. This they did by lobbying for particular types of regulatory framework, restricting access to particular technologies such as the methanol catalysts and of course, patenting.

It is an obvious feature of the novel food fermentations that competition and collaboration occurred between the companies simultaneously. The section on technical secrecy (5.4) showed that there was an evolution in what was regarded as commercially sensitive as the product developed and once patents were issued and the understanding of the process had progressed. This shows how the boundaries for cooperation and competition were drawn and how they shifted in time. These boundaries were set by the past experience of managers in their industry. The market for SCP never became established, but managers used their past experience of competition in established markets to conceptualise the dangers from competition in SCP and applied them during the development period. This conceptualisation of the competition was modified as the project developed.

CHAPTER 6 - FIRM AND INDUSTRY CULTURE[3] INFLUENCE THE PROJECT

Introduction

This chapter considers the characteristics of the firm which managers felt had affected the evolution of the SCP projects. These include physical resources available to a firm, its organisational structure, the approach of people from a particular skill background and the "style" or approach of a company. It is the style of the firm as observed by middle ranking managers that dominates this chapter, while the different structural features of firms are more important when the perception of the role of senior management is considered in chapter 7.

Many of the novel food fermentation innovations were radical in terms of existing technology and required a new combination of working relationships between scientists and engineers from traditionally separate backgrounds. The multi-skill teams and the planning of the construction of novel fermentation based plant led to new management experience. The issues in this chapter are those picked out by management that were distinctive in an SCP project, not those necessarily important in their "standard" business projects.

6.1 Material Base of the Firm Affects Substrate Choice.

[3]The word culture was first used by managers and then used by the interviewer. During the analysis of transcripts it was found that there was material where the word "culture" was absent, but the idea was present.

6.11 Shell and the Choice of Methane

In the 1960s Shell was seeking new uses for the natural gas to which it had access off the East Anglian coast. The availability of large supplies of gas was a principal reason for choosing methane consuming bacteria for its SCP process. Two subsidiary reasons which supported this choice were the lack of prospective alternative uses for natural gas and Shell's special knowledge of the paraffin market.

Hamer (Shell) recalled that the obvious use for natural gas was as a fuel to replace town gas, but there was no confidence in the management ability of the UK gas industry to change from town gas,

> "Town gas went out through the 40s and 50s, they were losing their share of the market daily. So they were in a dreadful state. The gas industry was a disaster...the marketing of gas and the business was an absolute disaster. So companies like Shell really felt they had to find some other way of selling their gas. No confidence in Gas."

Natural gas was being flared in enormous quantities and it was doubtful whether the technology existed for laying pipeline to the distant offshore fields.

The other reason for Shell choosing natural gas over paraffins was its lack of secure access to paraffins and its possession of an industry based on paraffins for the production of biodegradable detergents. Their internal forecasts for the development of the paraffin market predicted rising prices in the medium term, and so Shell saw no future in paraffin based SCP processes at a time when BP was becoming fully committed to them.

6.12 BP and the Choice of n-Alkanes as Substrate

In the 1950s and 1960s BP had access to Libyan crude oil which has a very high n-alkane content. However the alkanes must be removed before the crude is fractionated otherwise the heavy n-alkanes would freeze at low temperatures and prevent diesel engines working in winter. The initial attraction of SCP for BP was that the yeast preferentially consumed the n-alkanes in the Libyan crude and so they could solve the n-alkane extraction problem at the same time as a useful by-product was produced, yeast for animal or human food. Only later did production of yeast become an end in itself.

Unlike Shell, BP had no developed industry based on n-alkanes so they were actively looking for new outlets for these chemicals. Another difference was Shell's possession of the world operating rights to a urea dewaxing process for extracting n-alkanes from crude oil. This was not available to BP so they had another incentive for finding their own method of separating crude oil from the n-alkanes.

6.13 ICI Chooses Methanol as a Substrate

Marks (ICI) described ICI's "methanol culture" in the early 1970s.

> "If you were coming up with innovative processes then there was a culture that said if you couldn't make it from methanol then it was not something for ICI...and there is a very famous story about this...there was a discussion with Hart saying,

> well, we've been beavering away on a new process that we haven't told anyone about, we've got this microbiological process for turning lead into gold. And Hart's response to that was, well, that's all very interesting, but can't you do it with methanol? And that was the sort of culture you had."

According to Marks, this "methanol culture" was based on commercial reasoning and the choice of methanol for SCP was because it was the most suitable substrate for SCP. This "culture" was used to select viable methanol based projects over other substrate based projects, whether or not these were viable.

ICI had negotiated a huge contract for natural gas from British Gas in the early 1970s for a very low price per therm. Peachey (BP) and others believed this privileged price contract was the reason why ICI chose methanol for SCP. Marks denied that this was the case because ICI had undertaken to pay for the conversion of the UK from town gas to natural gas as part of this contract. So the apparently advantageous contract was not so cheap as it appeared, but it was true that ICI had an incentive to develop new uses for natural gas and methanol.

6.14 Other Cases

The pattern in which the company chose a substrate over which it had commercial control is repeated in most of the other projects. T&L's first SCP project involved the fermentation of molasses, their by-product from sugar production. Liquichimica chose n-alkanes as a substrate because the refining of these paraffins was their main business.[4] Hoechst were the exception because they chose to buy in methanol, although since they chose to develop a human food they were not so sensitive to supply or cost of the substrate. However, Swindall (ICI) suggested that Hoechst's choice of the human food market actually derived from their lack of control over methanol supplies. This reinforces the idea that companies were not willing to embark on an SCP process without control over the substrate supply.

6.15 Skills as a Resource

When ICI and BP eventually ran down their SCP projects they both had the problem of what to do with the skilled people they had employed. BP had seen microbiological skills as necessary to service SCP development. When SCP failed, they dispensed with them because fermentation, according to Northgate, was seen as outside their main business.

ICI took a different view and Thomas (ICI) explained that,

> "There was an awful lot of expertise built up in the development of Pruteen, in terms of fermentation, biochemistry, physiology etc. I think the view was taken, we've built up all this experience let's not lose it. So out of Pruteen came Bioproducts. Let's use our expertise to develop a new business area."

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[4]Liquichimica considered the heavier paraffin fractions to be effectively a waste product which had no market value. Certain strains of yeast would preferentially consume the waste, heavy alkane fraction and so SCP was attractive.

Bioproducts is the business group which contains not only the joint venture on mycoprotein, but also research into enzymes and biopolymers. It began in 1985 as a relatively small department. A wholesale transfer of Pruteen personnel into Biological Products did not take place.

6.2 A Chemical Engineer Culture

ICI's chemical business required the employment of many chemical engineers and chemical engineering was the dominant background of ICI managers. Swindall believed that ICI had a progressive record in creating interdisciplinary teams to research and develop particular projects. However, the predominance of chemical engineers was noted by managers from inside and outside ICI as something which was not wholly beneficial on the Pruteen project. Thomas referred to what might be called a chemical engineering culture,

> "...here the chemical engineer was king, because ICI always used to recruit the bright young chemical engineers from Cambridge and it used to be a self-evolving system...now, in Biological Products there are still quite a few chemical engineers about but their status and their influence are waning slightly."

The chemical engineering background of Pruteen managers and researchers affected their business decisions and Cowen (T&L) gave one example of an ICI friend who,

> "was always saying, you have no idea the grief I get from a particular divisional director, because he doesn't see why I'm

messing about with bacteria when what he knows about is pumping ammonia around reactors and catalysts. You are doing something which the body of the organisation doesn't understand. It's viewed with suspicion."

There were also more subtle ways in which the prevailing skill background manifested itself. Thomas (ICI) compared the engineers' attitude to the Pruteen process, with a food scientist's.

"An engineer's criteria are throughput and yield etc. The fact that he might have altered his process to improve the yield, which knackers the quality or whatever, in a sense doesn't really matter to them. This is being a bit callous about it all, but engineers, if you knock the quality down by 10% and improve the throughput by 10%, they say, well, lets sell it for 10% cheaper or something. Then you say, you just can't do that, its either good or it's not good. There is no sliding scale. People either like the food, or they don't."

Akinin (Shell) believed the engineering background of senior management at Shell created difficulties for biologically based technology like SCP. Greenshields levels of management would apply rules of thumb based on their engineering experience to judge biotechnology.

"If you are a chemical engineer and you are given the bones of a process, you will probably accept that if you work hard enough you might be able to improve the yield by 2 fold or maybe 5 fold, but that is probably the limit due to the nature of the chemistry. But in biological sciences that is not the case. You know perfectly well that once you have the biological reaction going, you are certainly going to increase the yield 10 fold, with a bit of work 100 fold and 1000 fold is down the tracks...its very difficult if you are doing biological R&D to convince someone who is not a biologist that this is actually true...So they tell you, come back when you've improved it, but to do it requires quite a high level of resource...very difficult to put that message through to the kind of culture we had in Shell at that time."

Hamer has written a paper on chemical engineering and biotechnology which discusses the problems of developing microbiological processes,

"...two important orientations exist, ie the approach based on biochemical engineering and the approach based on microbial physiology." (Hamer, 1985 p346)

Hamer goes on to say that the biochemical engineering approach has largely failed over the last 25 years, despite it being the favoured approach of educational institutions.

Thomas, ICI's only food scientist, gave his idea of how a food scientist would run a novel food project. This was to start with a product that people would eat, and then to work back into the process design. The attempt to modify the Pruteen process to make a food human beings might eat, was not something a food scientist culture would have attempted to do. Thomas's personal experience of working in ICI had been initially frustrating, "I must admit, I found this bloody annoying at the start, why should I have to convince a chemical engineer that what I knew about food science was correct?"

The process of establishing his credibility took him almost a year. Thomas epitomised the kind of attitude he met during this year, especially amongst more senior chemical engineers,

"no-one's being aggressive or anything like that, but the view is, almost that the food scientist is someone who stands in the corner and stirs the pan with a wooden spoon. An awful lot of people thought, "a food scientist, you must be good at cooking then?""

6.3 Differences Between Research Styles

6.31 Shell

There were other managers who commented on their company's, or their colleagues' tendency not to think beyond the confines of their disciplines. Bett (Shell),

"You tend to draw battle lines, some people are very divided on it, especially SCP...the chemists have an enormous prejudice against biotechnology."

Certain ways of developing SCP technology were closed to companies like Shell simply because of their style and their size. Lewis said,

"...a company like Shell, they couldn't think in terms of human food, it was difficult enough to think in terms of chemicals. Shell are in chemicals, the concepts that define the chemicals business, selling things in Kg, its just too small for their operation."

6.32 Differences in the ICI and RHM Research Styles

Thomas (ICI) and Treeby (RHM) compared how RHM and ICI approached research. Thomas felt that much of the friction between the two companies' styles was at the researcher level,

> "the meeting of cultures has occurred at my level...everything at senior level has been OK, so in terms of companies like mammoths colliding, its not on, because its been the troops who have been fighting it out, the generals have been having cocktails together."

Thomas contrasted ICI and RHM research,

> "most of the ICI people would probably say fully understanding things is the way to go before you can really build the business, whereas some of the elements in RHM say we understand as much as we need to...if it works it works."

Thomas considered this to be an understanding versus an empirical or pragmatic style. He thought the cost of the empirical style was that it would not be understood why a process did not work when it had problems. Possible simple changes to the process that could correct the problem would be missed with this "empirical" approach. When the two companies came together in the mycoprotein project, they moved the process research to Biological Products at Billingham and the recipe formulation stayed with RHM. One could say that each company controlled that part of the mycoprotein project that suited its style. Thomas commented on the project at the time it was inherited from RHM,

> "a lot of the things we inherited in the process were purely empirical...people of my background started coming in and asking, why do you do this, and why that? Nobody could answer, so my role in the first year was to challenge dogma or myth or whatever, accepted wisdom...find what was right and what wasn't."

The reason Thomas gave for the different research styles was financial. Mycoprotein research had been much shorter of funding compared to Pruteen because of the relative sizes of the companies. A shortage of funds meant there was less time and money to spend on the "understanding" of the various mycoprotein processes. Thomas described how the present research on mycoprotein was still subject to interruptions of the ideal kind of work on background, science based understanding of the mycoprotein product. When problems in production occurred at the Marlow foods factory Thomas and other researchers would abandon their long term work to "firefight." Thomas contrasted this with Unilever, where the level of understanding of factory processes was high within the factories themselves and problems could be dealt with without recourse to Unilever research facilities.

In comparing RHM to ICI Treeby (RHM) agreed with Thomas that ICI were probably more used to applying rigorous fundamental science to their problems. But in comparing RHM to the rest of the food industry, RHM stood out as unusual because they applied a rigorous science approach to some of the relationships that underpinned food, unlike the rest of the food industry which was a low technology industry.

6.4 Differences in Firm Culture Affect the Projects

Treeby and Thomas were both aware of a difference in attitude to the mycoprotein project which reflected more general differences between ICI and RHM. The principal difference stemmed from RHM being a food company and Treeby thought,

> "ICI's posture is somewhat more aggressive than ours. They are more aggressive worldwide...they are prepared to test by pushing what the boundaries are. RHM has more of a partnership style as they are very, very, very sensitive about anything that might damage their reputation for food."

Thomas made similar comments about the two companies. ICI had a lot less to lose on any one project than RHM because RHM depended on its good company image to continue to sell its products. The public was more likely to link one product disaster to the rest of the company's food products than was the case with ICI. ICI stood only to lose money on mycoprotein and that was a small amount in comparison to the firm's total business.

6.5 Big is Beautiful

Cowen (T&L), Treeby, Thomas and Marks all referred to the size of ICI to explain its behaviour or potential behaviour with respect to SCP. Large size meant a greater financial resource and that explained the rigour of ICI's research. Cowen described the Pruteen project as not very successful largely because of ICI's predilection for "big" projects.

> "...they couldn't look at the sort of small market we could look at. Almost as if the size itself imposed the requirement that, hell, we're not interested in anything that is less than 100 000 tonnes per annum, because that is what we know. There is a house style, and in ICI it is part imposed by size...the kind of research we did in T&L would never have started in ICI."

Thomas made the same point as Cowen about ICI, but Marks felt this "big" culture was more, "if it is big it is better" than an addiction to bigness. He thought that this feature of ICI had waned in recent years but that it had been the correct approach to SCP, since SCP plant had to be big to reap the economies of scale necessary for its viability.

Treeby cited a case when Du Pont's predilection for big projects almost changed the direction of the mycoprotein project.

> "You have to say the vision was lost a little bit around about the time of the Du Pont relationship, a combination of growing oil prices and seeing the complexity of the task ahead, people started to turn to some kind of dried form of the

product, a burger extender, particularly in the 3rd world. Du Pont were very keen on this because their idea of a world scale business was, how can we make it as cheaply as possible, how can we sell it as widely as possible? What is the easiest form to go and sell the product in?"

Du Pont and RHM were sufficiently convinced that this was a better approach that they began a joint project with the Iranian government to build a plant to provide a biscuit protein supplement for school children.[5]

6.6 Cultural Characteristics of the Oil Industry

6.61 BP Withdraws From Fermentation Technology

Northgate (BP) explained BP's withdrawal from SCP as something one might expect given that BP was an oil company. They were quite happy to abandon the fermentation technology they had built up because this was only a means to a commercial end for them. He thought that ICI for example would tend to think of the technology as an asset in itself.

> "...they were quite happy to leave it as a one off development to see how it went. It was clearly stated that they were not in the business of developing a new fermentation industry."

6.62 Liquichimica Scales up too Quickly

[5] The Iranian revolution intervened and ended the project.

Zamgrandi (Liquichimica) believed Liquichimica made a mistake in scaling up their process from the pilot plant stage to a full scale plant without an intermediate stage. This mistake was due to what he referred to as Liquichimica's "petrochemical culture". Liquichimica wanted to build a large plant as soon as possible and was used to being able to make these kind of jumps in plant scale in the oil industry. The medium sized plant would have allowed them to understand the fermentation process better before scaling up fully.

6.63 BP Brings Oil Industry Culture to Italy

Northgate referred to BP coming to Italy with "an oil refining culture" and antagonising the Italian authorities. BP were,

> "...used to dominating, "if you don't like us you won't get your oil from us", type of big brother attitude."

Leivers described BP's behaviour in a similar manner to Northgate, but saw it as due to a difference of national character. Leivers was French, but the only Italian speaker in BP's London headquarters involved in the Health Authority negotiations. Talking of these negotiations Leivers said,

> "...the way the English behaved with the Italian administration was a disaster, a complete disaster. They considered the Italians as under developed. They didn't consider small things like translating documents into Italian, because Italian was not an important language...it (SCP), worked in France,

because the English were there as tourists, that was perfect, but in Italy the English wanted to behave like English."

In her 3 years working for BP Proteins in London Leivers translated in face to face meetings between BP managers and Italians. Leivers was scathing of the lack of knowledge of Italian among BP managers and the disadvantage to which this put them in meetings. The Italians discussed the English in front of their faces and,

"I was embarrassed, sometimes, to translate what they really said."

When the Consiglio Superiore di Sanita[6] in Rome wanted new equipment from BP in exchange for the safety clearance of Toprina, BP refused and the request was seen as demand for a bribe. Leivers, however, felt that it was reasonable to help these research centres improve the quality of their equipment in this way. Instead, BP offended the research centres by criticising the quality of their analyses. Leivers made the point that BP never understood how the Italian civil service functioned. According to Leivers the head of the veterinary service was a very powerful man with the ability to halt the Sardinian plant, a power which he exercised. However, BP persevered in ignoring him and in believing that it was the civil servants in the Italian Ministries that had the power. Leivers said,

"The decisions were taken mostly in London and Milan. The head of the veterinary service was in Rome. Once he asked

[6]The CSS was an advisory committee to the Italian Ministry of Health

someone to come and talk, and they said, very sorry, we have no time."

She described how BP even tried to use the UK ambassador to pressure the Italian health ministries into approving Toprina. Leivers thought this further antagonised the Italians and the attempt was,

"Really stupid. It was a disaster."

BP ignored the advice of their Italian partners, ANIC. According to Leivers, ANIC staff were not involved in BP decision making.

"The Italians were aware of the problems and told the British what to do, but BP didn't care."

Leivers was the only BP manager to talk to the Communist mayor at Sarroch. Northgate saw the mayor as someone out to make political capital from public feeling against the plant. Leivers thought his views were legitimate, or that at least they should have been taken into account by BP.

"When you decide to build a plant in a country you have to consider the view of the country, you can't change those views, you have to adapt. Or go somewhere else."

Neither BP nor Liquichimica made press releases about SCP. Leivers was contacted by Italian journalists wanting to know the BP view on Toprina's safety, but it was BP policy not to allow such contact.

Leivers summed up the Italian feeling towards BP,

> "The main thing was to be able to say to a multinational company, don't treat us like a colony. The money involved was important, but not so important as showing, we have the right to say what can be done in our own country."

Zamgrandi (Liquichimica) differed from Leivers in that he did not think it was a question of oil refining culture, or even national characteristics, but of individuals and particular mistakes on the side of BP.

> "It is a question of some people, some are more fair, some are more aggressive. **** was quite a nice man, a scientist, not used to dealing with the Italian authorities. He was involved in some meetings and he had some very bad aggressive reactions. It was a BP mistake to send **** there. Never bring a pure technician to the ISS where he will have to deal with politics...not a question of English and Italian cultures."

6.7 Conclusions

The word culture was used by managers to refer to the perceived values and rules of firms or groups which explained these groups' patterns of behaviour. Defined in this way one thinks of a possible complete set of "rules and values" which could be listed and understood by a term such as "chemical engineering culture". In practice, managers only gave one or two such cultural values at one time, and always in relation to a specific event or collection of events that occurred in the SCP projects. "Culture", as used by SCP managers, was dependent for its meaning, more than most concepts, on the context in which it was used.

Culture appears to be a concept used to explain events and behaviour especially confused or complex. It is an optional causal explanation. When there is a series of events, like BP's experiences in Italy, managers seek patterns. They may infer the secretive but active intervention of a soya lobby, or a typical pattern of oil company behaviour in BP, or the characteristic English behaviour of the company as causal explanations.

The table below is an attempt to draw all the values belonging to a particular culture into one place.

Culture	Values	Relevant to SCP?
Chem Engineering	Big projects if possible	Not as necessary as assumed, depends on choice of market
	Yield, throughput are most important design parameters	Quality of product comes first, then design plant to max. yield etc
	Rigour, understanding as research style	yes, for maintenance food quality during production
Oil Industry	Big if Possible Some insensitivity, high-handedness with Italian institutions	Depends on market choice Italian institutions need a sensitive approach
English Culture		
	Assume Italians and their institutions are similar to English	Italians and their institutions need an Italian approach

Perhaps another characteristic of the use of "culture" is the perception that people do not necessarily have "reasons" for the values they hold and apply to projects. These values are shown through characteristic patterns of behaviour, a way of doing research, an approach to project development, a negotiating strategy in a foreign country.

The term culture is useful because it identifies the common rules and values a group uses to guide its behaviour. The descriptions given suggest that these values are defined only by reference to other groups and other sets of values. So the characterisation of chemical engineers is only possible by reference to those, for example, of the food scientist or microbiologist. These are not stable and unchanging characteristics and are only identified with respect to another set of values and aims.

It was a feature of the comments in this chapter that they referred to culture or style when the "approach" failed to fit with another approach or a new set of activities. It is when a firm with a set culture has to approach a novel market or technology, or when two distinct firm approaches have to blend because of the requirements of, say, a new technology like SCP, that the cultures themselves become distinguished. A number of areas of interaction involving the firms can be identified from managers' comments, each of which gives rise to comments on culture, as follows.

Culture Type	Origins of type in contrasts between the following groups/approaches
Skill background	Chemical engineers Food scientists Microbiologists
Research styles	Understanding Empirical
Management styles	Food industry Chemical industry Oil industry
National culture	British firm Italian regulatory authorities

The managers' comments suggest that it is when managers move from firm to firm or when firms combine activities that the idea of culture is most often used to explain differences between the companies.

CHAPTER 7 MANAGERS' PERCEPTIONS OF THE ROLE OF SENIOR MANAGEMENT AND STRUCTURE OF THE FIRM

Introduction

Chapter 6 described how a firm culture was perceived as an influence on project choices. The idea of culture was used because these firm characteristics were not primarily linked to formal structures within the firm and culture was used to characterise the firm as a whole by people inside and outside the firm. This chapter looks at the more formal organisation of the firm and how the projects were perceived to be influenced by the senior management and the board. Crucial to this chapter are the relationship of the R&D department to higher management, formal procedures for project selection and appraisal and beliefs about the commercial awareness of R&D.

Most of the comments made in this area recounted a sequence of events of higher management involvement in the project and so would lose their value if analysis broke them up. So this chapter is naturally organised around the firms and the narrative of what happened in each one.

In general senior management was important when a project began to demand finance that was an important fraction of a company's total resource. The decisions to build the full scale plants of BP, Liquichimica and ICI required the involvement of the most senior levels of the companies. However most of this chapter contains material concerned with ICI and T&L, since a few managers in these companies were particularly forthcoming about events at board level, while this was not the case with BP interviewees.

7.1 T&L - A Strategy of Diversification through the R&D Department

The SCP projects investigated by T&L were a consequence of a restructuring of the company and a linked decision to increase the resources available to the R&D department. The series of events that led to the expansion of the R&D activity were unrelated to any specific project such as SCP. However the new, divisionalised structure of the company helped Finlay[1], head of R&D, to persuade the T&L board to accept his idea to use the R&D department to spearhead T&L's diversification away from sugar. Before these changes Finlay described research in T&L as restricted to improving the sugar refining process.

In the mid 1960s the T&L board seized an opportunity to buy a molasses trading company on very good terms. The company had similar turnover to T&L and Cowen thought that it became obvious to the board that assimilating this company into the existing structure of T&L was problematic. The board asked the consulting firm McKinsey to review their structure. McKinsey duly suggested that the T&L adopt a divisionalised structure, which led to a major shift of responsibility from the board to what was called EXCO, the Executive Management Committee. This was made up of the heads of the new divisions and included the head of research. The committee met as

[1]In this description of events in T&L Finlay is clearly a key character and his role as a product champion is taken up again in chapter 9.

often as it felt was necessary to operate the day to day business of the company. This was something that the board had supposedly been in charge of under the previous structure, but according to Cowen,

> "There was no-one on the main board...and until EXCO was created and Chuck (Finlay) was put there, no-one at any senior level who really understood what research was doing...and the main board met something like once a month, except in August, so basically they couldn't run a paper bag factory. EXCO met, if necessary, on a daily basis, they met on a functional requirement basis."

The change to a divisionalised structure was complete by 1970 - 1971 and for Cowen the effect on research of the creation of EXCO and the membership of the head of Research was that,

> "it meant more money...we had a pipeline to the top, we didn't have to convince anybody except Finlay. When I wanted to build the [SCP] pilot plant I was talking about a lot of money, because we had never done this before. If I could persuade Finlay, he would make the case to EXCO."

Cowen was sure that without this reorganisation a pilot plant for SCP would never have been built because the board would have been responsible for taking the decision to proceed. Cowen felt that at no time was the board capable of approving such investments or of judging research activity.

> "Because the board had not got a clue what was really going on. One of your questions was directed towards that..."how far did senior management's ignorance of technological matters affect its decision making?" Totally. Totally. The successful research orientated companies usually have an ex-research man on the board."

The T&L board did not have this kind of R&D expertise available to them. Directors had responsibility for particular divisions of the company and tended to represent "their" division's views to the board. Cowen described board practices which further reduced its ability to intervene knowledgeably in research matters.

> "Because it was a family company the main board was essentially Tates and Lyles and what we used to call the "hangers on", who had married into the family...In those days there was not a thought that this director ought to be responsible for R&D because, damn it all, he knows more about it. It was not a functional appointment, it was more or less, you've had it for 3 years Col, now its my turn, sort of thing. Because R&D is a toy that lots of directors of large companies like to play with, particularly when its successful."

Within a year of the creation of EXCO in the early 1970s, the board decided to use R&D to spearhead diversification away from sugar. At this time the director for R&D was Tony Hugill and Cowen described the decision as, "a consensus, I don't know who championed it. I think Finlay himself put the idea into Tony Hugill's head, again through his technique of talking into the wee small hours. Tony Hugill had talked to other members of the board and they had thought, generally speaking, this is a good idea. I suspect the decision came from below rather than from above."

Finlay was now able to reorganise the R&D function away from the sugar refinery servicing function it had once had. Together with Fraser Cowen as head of fermentation and the other sub-heads of research he worked out the new directions for research, based on the raw materials of the business; sugar, molasses, bagasse. Cowen described the results.

"What you finish up with if you think it through, is a matrix, we used to do this...in management meetings. They plot what you are good at, your functions, by your research needs. So you say, what happens if we apply our skills in fermentation and biochemistry to the need, some other use for sugar?...out of that comes an SCP programme. But you also have to look at bagasse and molasses. And again, as regards this skill, you end up with SCP, to produce alcohol and liquid waste disposal...You have a research scheme, not original, but very effectively used by Finlay. He said, I want four basic departments for the basic skills, these are biochemistry, organic chemistry, fermentation, and physical and inorganic chemistry."

The decision to rely on R&D for the diversification away from the traditional sugar-as-sweetener business only occurred because

Finlay was such a strong champion for the idea. Cowen described how Finlay persuaded Hugill who convinced the board that this was the right course to take. However there was a background of worry over the future of the business if it continued to depend on direct sugar sales. The board were bound to be unusually open to suggestions that would appear to solve their problem. However, the detail of what the R&D department's expanded activities would be was left entirely to Finlay and those he chose to include in the process of creating a research strategy.

7.12 T&L's Decision to Build and Site an SCP Pilot Plant

Cowen was recruited by Finlay to run the new fermentation activity of the R&D department. As described in chapter 9 Finlay was already supporting an SCP project in Greece and Cowen was given to understand that this project had to continue. However, Cowen was able to change the project to suit his own interests. He had the management problem that his scientific staff in England resented the enhanced status of the two technicians who were working on the project in Greece. Although they were only qualified as technicians they were effectively running the Greek project, something that would not be allowed in England. Cowen solved this problem by expanding the SCP project so that the Greek activity became only a part of the whole. the project became one to test a variety of different substrates for fermentation suitability. The Greek project became a sub-project which was testing the suitability of carob husks as a substrate. In this way the solution of a management problem helped create the SCP activity, although Cowen was interested in SCP in its own right.

In the mid 1970s there appeared to be a chance that the Cyprus government was interested in acquiring the carob fermentation technology. Cowen persuaded Finlay that a pilot plant was necessary to continue research,

> "Scientifically, we needed a pilot plant somewhere under 3rd world conditions...so often when you are running the project it is a personal thing. I thought, I had done a spell in Thailand, seconded to the UN development programme for a while. I said, I like Thailand, we should consider putting a pilot plant there. But at board level it was made known to us that if we were going to do this it would have to be in Belize."

Cowen talked of how the economy of Belize is dominated by the Belize Sugar Corporation, itself effectively controlled and managed by T&L. Such companies,

> "...were viewed with deep suspicion by liberating governments who knew they had to have them, because if no sugar was exported they would have no income. So companies like T&L come up with what I call the political project. The Belize plant was one of them."

Cowen thought Belize was a particularly poor choice for a plant.

> "I said, for God's sake, why Belize? I put up all the standard arguments. To start with, there is no agricultural waste. Don't worry about that, the plant has to be in Belize, the Government

has requested it, and we have decided that that is where it is going to be. So the usual fanfare of trumpets and the PM of Belize came and we all stood around looking suitably enthusiastic. I was left with the problem, what do we do? Because really there is nothing there. Which is why we worked on citrus waste, because there is a citrus canning industry and it uses sugar, and there is citrus waste, which is fed to animals directly...and they seem to like it....the last thing one would choose, citrus waste, very special characteristics. Highly acid. A so and so of a time getting the thing to work."

The plant had never been an economic proposition and so,

"After 2 or 3 years, when the company judged that the time was ripe, they quietly shut the thing down and stole away...that's a fairly normal story for a company like T&L."

The plant did work despite the technical problems, but the Cyprus government never purchased the technology.

7.13 T&L Board's Control of Research

The research department embarked on an exceptionally free ranging programme of research by the standards of other industrial R&D departments. Provided that the fermentation department could think of a technically feasible project connected to sugar, molasses or bagasse, it had a good chance of being investigated. The matrix by which the various projects were grouped was a guide for the application of technical skills to the raw materials of the company.

There was no formal marketing input ie no marketing department involvement, no independent judgement of projects market potential. It was left to Finlay and the scientists who had created their projects to judge their commercial potential.

Finlay described how the board would enquire into his reasoning on SCP and how he would reply.

> "Our decisions...I think this is important...that the decision to go into SCP never came from the board, it came from the bottom upwards. We indicated to the board...they'd say, why are you doing this, and we'd say well, because we think it was successful in this and may lead to that and that...that often happens, decisions don't come down from the board to research, in those years it came up the other way."

The board did not seem to apply its own criteria to particular projects like SCP. They were dependent on Finlay and Hugill for project information and showed no sign of disagreeing with Finlay or Hugill's judgements.

In 76-77 a new division was set up to manage the development of the projects which had commercial potential. This was called New Ventures and Cowen was promoted to manage the division. Someone had to take over the fermentation sub-department and Cowen chose Garoffalo, who had joined T&L from Glaxo. Cowen described Garoffalo, perhaps not surprisingly as having a pharmaceutical background and his research interests lay in that area. This did not include SCP and once in charge of fermentation Garoffalo began the process of closing the SCP projects. In Garoffalo's opinion,

> "...it (SCP) was not something I could put forward to the board for assessment...just didn't make sense. For T&L, proceeding with the project was an R&D decision and the closure of the project was an R&D decision...perhaps one might question why there wasn't closer questioning from the board given the amount of money that was spent on it...but it's probably a good thing in the R&D world that you can hide and get things done...if you believe in something you can proceed with it without it appearing to be a major item."

His view of SCP was that,

> "it was a typical example of the dangers of research push, it was very easy, early biotechnology. Good public image, popular, the board of directors would understand that sort of thing in very simple terms; muck-into-protein, feed-the-starving-millions."

The board was really irrelevant to decisions made about the SCP projects. The projects were created, maintained and eventually shed by individuals in the R&D department who differed in their views of the value of these SCP projects. There was therefore no remaining SCP project by the time T&L went through its 1979-1980 financial crisis, precipitated by a drop in the world sugar price. T&L came sufficiently close to bankruptcy that the non-executive directors called the banks in to examine the company's activities. Drastic action was necessary just to save the company. New Ventures was closed and the research department activity curtailed; employees were reduced from over 180 to 100, (Cowen). Research had returned to a service function, with the exception of the experimental synthetic sweetener named Talin, which is only now close to commercial development, (1989). If Garoffalo had not closed the SCP projects he believed they would have been closed in any case during this period of financial upheaval.

7.14 Commercial Scrutiny in the R&D Department

Cowen referred to the change that occurred when Finlay had become a member of EXCO as one that at once increased the resources available to R&D but which consequently brought an increased commercial scrutiny of projects.
However, Garoffalo described SCP as a typical example of "technology push" without hope of commercial development. By implication he was disagreeing with Cowen's and Finlay' assessment of the project since they did not close it down. Garoffalo compared the department under Finlay and the new department of which he became head and commented that the old department appeared far less commercially orientated than the new, despite Cowen's perception that it had become more subject to commercial criteria when it was restructured the first time. Garoffalo's view of the 1970-1979 period was supported by Cowen in retrospect.

The R&D department under Finlay published a series of booklets called "New Ventures" which detailed the department's activities. Cowen pointed out that the function of the "New Ventures" booklets was to show that the board were getting value for money; that research was "cost-effective". The booklet had the effect of convincing the board that R&D was cost effective, whether they were or not. Cowen argued that R&D was seen as cost effective,

> "...in its broadest sense. They were spending £x a year into a kitty called R&D, the research organisation had to respond by showing that that money had been spent wisely. Because those who controlled expenditure were unable to judge technical matters the sorts of things that the R&D people did appeared to be cost-effective. That is why the "New Ventures" booklet thing arose, this was Chuck's response to them saying, "we're giving you £2m/year, what are you doing with it?"...It served a real purpose of communication but a secondary one of being a very good PR job...Cost effectiveness means people believe that the money they are spending is spent to good effect."

Although the board's approval for the large scale funding of research was necessary, the structure and membership of the board allowed Finlay and the R&D department to develop its own strategy for diversification. In hindsight this was insufficiently market orientated for the company's needs.

7.2 The Shell SCP Project and Senior Management

Research at Shell's Sittingbourne site had to be supported by one of the Shell Divisions or by Corporate Research. The SCP project was supported by first the Natural Gas division, then Corporate Research, then Chemicals Division. Each year the division responsible for funding would review the project and decide whether to continue its support. The Natural Gas division was interested in SCP as a possible use for its large reserves of natural gas. When Natural Gas lost interest because other uses for natural gas had appeared, Corporate Research took it over for its strategic interest in biotechnology. Then Chemicals acquired it because, according to Bett (Shell),

> "it was trying to diversify at the time, look for new activities...the operating divisions act independently in that way. Chemicals, after a learning lag, costed the process, which neither Natural Gas or Corporate Research had bothered with."

In 1975-1976 the project was closed after the report prepared by Chemicals decided that SCP was unlikely to be economic unless a partner could be found to bear further development costs. Out of all the hydrocarbon SCP projects, Hamer (Shell) thought that,

> "In retrospect, Shell probably made the best decision, from a commercial point of view."

The relations between the R&D personnel who ran the project and the operating divsions' management who funded it were described by Bett,

> "Links between R&D and management here are very weak...they have been. We have moved to justifying R&D more, priority rating of projects so that in times of little capacity, we can save the most useful projects. The organisation of responsibility had a diluting effect on hard commercial analysis. The costing (of SCP) was delayed."

Bett went on to describe this relationship in general terms,

> "We have the 'New Scientist' syndrome...Fishlock might write something in the FT and we get these articles sent down from on high...with comments scribbled in like, 'Why aren't you working on this area?' Some messages on PHB came down recently...in fact, the easiest way to get approval is to have something published in the New Scientist. We have to sell our research, looking at it from year to year. They look for profit in the short term. In Research, we have a duty to provide options for the longer term. You must have faith and believe in it yourself, and yes, do what we believe in and sell it to the divisions."

Bett and Brewed did not believe research was seen as more than a peripheral activity in Shell, Bett,

> "Senior management don't know a thing about what's going on in Research...if we were all sacked tomorrow it would make no difference to the profits of Shell."

The research department picked its own projects and researched areas of general interest to the research scientists. When SCP was closed the people who had been involved looked for other projects that they thought might be useful to Shell and that were concerned with their fermentation and microbiological skills. Bett described this period, "After 1975, there was a period of trying different projects, a good 5 years before we settled down. The next sort of buzz thing in biotechnology was the oxidation of propane, petrochemicals and biopolymers. Now, we have a better understanding of the role of biotechnology in Shell. We choose what we think will be of value to the company...no manager has the information to decide amongst the biotechnology projects...nearly all the biotechnology research is bottom up research. We are pretty independent of company strategy."

Hamer believed senior management strategy could have affected the SCP project, albeit in what he saw as a negative manner.

"...basically, all development, almost by law of the company, has to be carried out at Amsterdam. So research that is carried out at Amsterdam sees development at Amsterdam, research anywhere else never sees the light of day, they will never put it in the development phase, because the Amsterdam labs believe all process research should be at Amsterdam. (SCP) was always going into development, but they always found excuses to slow it down, it was always more important to do something else. They never gave it high enough priority in the management."

The Amsterdam laboratories did not enter biological research,

"because they said it would be competing with Royal Dutch Fermentation industries, Giste-Brocades. Alright, Shell and Giste-Brocades have a number of tie ups now. But, "We cannot compete against our friends in Giste-Brocades." I've heard them say that, at senior management level. They used to have a microbiological department in Amsterdam, who did nothing. But again, because it would be competing with Giste-Brocades, it was closed down, about 1970-71."

Hamer explained the low priority given to research by Shell management,

> "Shell doesn't make money out of research. It makes money out of holes in the ground, that's its business. And it's made money that way for so many years, that research, OK, pay a subscription, keep a few scientists off the streets...ICI are a research based company, that's the difference."

For Shell, research insured against change in their main business,

> "It is preparing for change. What happens if the equation goes that in chemicals there is all the added value and all oil production is nationalised? What do you do? That is why they diversify into gas and metals."

Marks had been a Sittingbourne researcher on the SCP project before his move to ICI. He was also critical of Shell research.

> "You have to recognise that the R&D facility down at Sittingbourne was really a drop in the ocean for Shell. It was just a tax benefit. Really, whether the thing went on (SCP) at Shell or not was neither here nor there, unless they were going to commit to build a big plant. As far as I know they

were nowhere near making a decision to do that. I think its a sad reflection on the research at Shell that the research in biotechnology has been going on for a very, very long time, 20 odd years now to my knowledge -not one single product has come out of it."

Marks acknowledged that Sittingbourne was run in a different way.

"...there was a hell of a lot of academic freedom in the Sittingbourne research labs. ICI were totally different and BP totally different too. There was a major thrust on projects and you were allowed very little academic freedom. That I think was right, and that is why Shell never got anywhere with anything in the biological sciences."

The SCP project in Shell did not come near to being developed into the full scale plant stage. However, Hamer deduced an informal senior management strategy from various events in the company, for example the idea that development of projects took place in Amsterdam "almost by law of the company." Another example is Hamer's idea that Shell fermentation projects would be suppressed in favour of cooperation with Giste Brocades. Hamer's view was that , even if the SCP project had been seen as commercially viable, these company "rules" would have made it unlikely that development would occur at Sittingbourne. The block to the development of projects beyond the pilot plant stage due to an "informal strategy" of the company left the research centre at Sittingbourne to generate its own small-scale projects.

The relationship between R&D and senior levels of Shell management was seen to be minimal and the board as remote. Everybody interviewed who had worked at Sittingbourne felt that Sittingbourne was fairly irrelevant to the company.

7.3 Hoechst and a Government "Technology Strategy."

Liesser attributed the idea of the Hoechst project to Prave, who saw the rate at which BP was advancing in SCP and began a yeast project himself. Prave worked in the pharmaceutical division and this is where the initial research on paraffins and yeast was done. By 1971 Prave was looking for a company to help scale up to the pilot plant stage. He chose Uhde, a plant construction company owned by Hoechst. Support was given by a government agency, the BMFT or Bundes Ministeren Forsch und Technologie. A state owned mineral oil company called Gildenburg had also approached the BMFT for support of their own SCP project and so the BMFT suggested a link between the two projects to Prave. This was agreed by Prave and the BMFT began to fund the joint Gildenburg, Hoechst and Uhde project in 1974. Liesser told how,

> "...support was around 50 - 60% of costs. Because they said it could be a nationally important project, we lack experience that English companies already have, maybe the Japanese have, but no German companies. At that time, because of the protein gap, only 20% animal feed produced in Germany, you should look for the national security so that in case of a shortage, as in 74, there would be the opportunity to produce German synthetic

> protein. Very important, this, that it was seen as of strategic importance."

Liesser thought it was decisive for the Hoechst board that Uhde joined the project. This convinced them that it was worth Hoechst supporting the project as well.

Liesser thought the end of the BP project in Sardinia influenced Hoechst.

> "This was in favour of our switching from paraffins to methanol. We used their experience to show that paraffins were uneconomic."

In 1977 the BMFT announced that it would cut its funding and it was up to Hoechst to continue if it wished. Hoechst would not increase funding to make up the government's contribution and so the work declined to the value of Hoechst's contribution.

The project was moved to the general research division in 78-79 because it had become so involved with animal nutrition and was not seen as linked to pharmaceutical research, its originating department. The project gradually came to be seen as one that would never sell. It was the director of the general research division who closed the project. This was done after consultation with the project managers and scientists, but also with the ICI board of directors for their Pruteen experience.

The project can be seen as one in which the government was the most important controlling partner. The government agreed to funding provided Hoechst-Uhde and Gildenburg worked cooperatively. The government paid the entire cost of the pilot plant and attached its own technical criteria to its construction. The project was supported for national strategic reasons and without the government it would not have taken place, despite the fact that Prave had the original idea. Jasanoff (1985) considers that the BMFT funding of the Hoechst SCP project was one of the largest public-private undertakings in German biotechnology. Although Jasanoff also describes the programme as technically successful, she considers it to be of questionable value from the BMFT's standpoint of wishing to place Germany in the forefront of biotecnological competition.

7.4 RHM and Senior Management Decisions

The mycoprotein project was conceived by Lord Rank and Arnold Spicer, the RHM director of research to provide a protein rich food to third world countries. As described in chapter 9, the project was the brainchild of Lord Rank. After his death the project passed through a period when Sir Peter Reynolds, Jack Edelman and A Spinks as executive sponsors of the project, protected it during its early stages of development when it could easily have been closed for short term reasons.

The project was run in collaboration with Du Pont for many years, but when Du Pont left the project in the 70s the project managers had to rethink its future - if it was to be paid for by RHM it would have to face board scrutiny. The economics of a low cost, alternative source of protein for the third world meant that board support was still unlikely. Treeby described the effect of Du Pont's withdrawal on the project mangers.

> "In fact, funnily enough, it didn't feel like it at the time, Du Pont leaving was one of the more positive spurs to the project. It forced dramatic reappraisal of the project. It caused the science and commercial base to think again about where they were going. To see if there were any discontinuities in, eg price-volume relationships, in the technology that might, might not be available."

The research did change direction as a result of this period of rethinking.

> "It was about that time that fresh, frozen higher added value forms of the product, more suited to Western rather than global markets (were considered) and if you like, the perceived value of what the project was worth dramatically improved. (Because)...suddenly RHM had to think, solo, about what it was going to do next. The shock that we had no money...since that was a very strong part of the previous reasoning...if we continue, how do we make money? If we are going to make money we must sell it for rather more than we think we can sell it for at the moment. How do you do that? Well, you don't sell a powder, you sell a wet, moist form of the protein to Western Europe, not to the 3rd world, ...suddenly there was just a sharpening up of the rationale in the period, 72-73-74."

The new rationale for the project was one that Treeby and others used to convince the board that the project was worth supporting. However, they only approached the board once they believed it had a good chance of being supported. Advance knowledge of how the board made commercial decisions was essential in helping them to achieve a new vision of the project. The project that the board had placed before it was one that had already met the most important criteria by which they were about to judge it. However the board were not willing to spend the £4-£5m required to build their own pilot plant and the project had become more expensive than had been estimated in 1972-1974 when the new marketing vision was adopted. Once the base technology for the new form of the product had been developed there was a need for a pilot plant, and according to Treeby,

> "we didn't have the money and we couldn't find a partner on terms that were suitable to us...Had they understood the full financial significance of what they were doing, I think they (project management) would have found that decision (to support the project), much more difficult to make, much more difficult to carry their colleagues on the board."

Then in the early 1980s RHM found ICI with a spare pilot fermentation plant on their hands. According to Thomas,

> "...rumour has it that their technical director met our technical director at a conference in Switzerland, or whatever, and they got together."

ICI and RHM formed Marlow Foods to coordinate the marketing of the food products containing mycoprotein. The research activity was split according to the perceived strengths of the two companies, process research taking place at Biological Products, Billingham and texturising research staying at High Wycombe.

Although the project was initiated at the highest level the board were not willing to fund development unless they could see how it would bring a commercial return to RHM. Until this time the project had to rely on outside funding and internal high level protection (see chapter 9). Ironically, it was the shock of the withdrawal of outside financial support that triggered the rethinking process which led to a rationale for the project which did promise to bring a commercial return to RHM, and so the board's approval for development funds.

7.5 Liquichimica Management and Government Incentives

Liquichimica was the subsidiary of the giant Italian company Liquigas. Liquichimica specialised in refining normal paraffins out of crude oil, fractionating the paraffins and selling them on to end users. The idea of using SCP to add value to the least useful heavy paraffin fraction, arose within Liquichimica. Liquigas management were kept informed of Liquichimica's progress by Ursini, the President of Liquichimica, but took no active part in the project.

Zamgrandi described the company's strategy,

> "They tried to be downstream integrated, in the sense of, normal paraffins, normal olefine, linear k-benzene, petro-protein.

> The weak point was that they were not linked to the company supplying gas-oil. They had to buy gas-oil to purify and sell...When introduced into ENI the problem was overcome."

Liquichimica bought Kanegafuchi SCP technology licenses before the Japanese government banned licensing. It was convenient to use Japanese technology.

> "We were supplying paraffins mainly to the Japanese area at that time. Through Mitsui. So we were familiar with the big Japanese companies like Subito etc. We also bought the synthetic fatty acid technology from Nippon-Soda. There was a particular intensity of relationship at that time."

Liquichimica originally intended to build their SCP plant adjacent to their existing paraffin refining plant in Messina, Sicily.

> "Then the government asked Dr Ursini to invest in some southern Italian area. But to build the plant on the mainland required auxiliary services, steam production, energy, water etc. This was not a feasible investment with just one plant. So we looked for other projects over which to distribute the fixed costs...so (we thought of) the citric acid and fatty acid projects, the citric acid plant was only built because we were determined to make an investment. The port facilities, everything had to be built from scratch."

The integrated plant was to be built near Reggio di Calabria, 20 km across the Straits of Messina and 20km from the paraffin plant. The construction of the integrated plant was heavily subsidised, but Zamgrandi thought that Liquichimica was exposed to an investment of between 150-200 billion lira, by 1973.

> "They paid us, that's why we did as they wanted. The citric acid and fatty acid plants were feasible with government funding...Ursini was a financial man, born here. He accepted this role we were to play with the state, to affect the social conditions of the south of Italy."

Zamgrandi felt that for Ursini,

> "...probably his mistake was to approach this high risk project too rapidly. I think there is a co-responsibility between the government and the technician people, the technicians with a petrochemical mentality, not an industrial microbiological mentality, gave Ursini dimensions of a plant that were too big."

When asked why Liquichimica management didn't close the plant after the 1973 oil price rise, Zamgrandi said that the plant was almost complete and the money had been almost completely spent.

> "So they decided to complete (construction) and start a very wide ranging project of research on toxicology in order to be ready to demonstrate that this product was also safe for human food. I was supervisor of this project..."

The company wanted to escape competition with soya and Zamgrandi felt that it was the rumour of this intention to move into human food that sparked the anti-SCP consumer movement in Italy. The rumours were well founded, which is perhaps why Liquichimica (and BP) refused to discuss them with the media.

Liquichimica attempted to deal with the problem of the unlicensed SCP plant,

> "Liquichimica had planned to have the plants completed, 75; SCP, 77; citric acid, 78; fatty acids. When the approval date was seen as unforecastable, they changed the dates. To finish citric acid immediately and start manufacturing it. The problem was the utilities...(which) were engineered to cover 3 working plants. It was uneconomic to run just the citric acid plant with the fixed cost of the utilities. We ran it for 1 year producing some 20 000 tonnes of sodium citrate."

Liquichimica became bankrupt in 1978 and a committee was formed by the creditor banks in order to appoint a commissioner to decide whether the company could be saved in some form. By 1979 this commissioner had formed the opinion that approval would never be given to the product, Liquipron. The result was that the government decided to apportion the Liquichimica plant to ENI. The paraffin refining process in Sicily operates as before, the integrated plant remains unused in Montebello di Calabria.

The senior management of the firm in the person of Dr Ursini allowed the SCP project to become the basis of the government's (Cassa di

Mezzogiorno) social and political objectives. Ursini's personal commitment as a southern Italian was perceived as a factor which helped bring about the government involvement. The board of Liquigas does not really feature in this story.

7.61 ICI Agricultural Division and the Main Board

Before the idea of Pruteen arrived some managers saw Agricultural Division being used as a cash cow by the main ICI board. Harwin thought that,

> "For years they milked Agricultural Division and the result is a total bloody mess. I think the last plant to be built was over 10 years ago. Things were allowed to go on as they were because of the money it made. £100m profit a year. They got precious little back from the centre...nothing."

Saxton made comments similar to Harwin,

> "Yes, in those days fertilisers were churning out about a third of (total ICI) profits...the amount of money being generated...why not spend a little of it here?"

So the background of perceived "investment neglect" partly explains the adoption and solid support of the Pruteen project by the Agricultural division board.

The Agricultural Division board was responsible for the design parameters of the Pruteen plant. The decision to fix these parameters was referred to by Saxton.

> "In those days Agricultural Division was very much a science and engineering company. Marketing did not play a very big part. The vast majority of the employees and the senior managers and the directors had an engineering or research background. Basically I think they got mesmerised a bit by the benefits of scale. For myself, in hindsight, I would have been right, I would have gone for a 25 000 tpa plant where you could have been confident that you could sell the output. The engineers convinced themselves, and they had the power, that to get the unit costs down, you needed an excess of 50 000 tpa."

Harwin described the divisional board as without sales people or even many scientists. Those that were there,

> "bitterly resented the control of the chemical engineers. There were not enough voices to create a debate."

Harwin felt that in 74-75 when the design parameters of the Pruteen plant were set,

> "a decision could have been taken to stop the development of a 50 000 tpa plant. Instead the debate was over building a 100 000 tpa or a 50 000 tpa plant."

A 100 000 tpa plant was obviously more expensive than the smaller plant envisaged at this time. But Saxton recalled,

> "Even with the extra capital costs there were a whole lot of arguments around; many items are standard, it isn't that much more, we were in a development area and there was 52% free depreciation and 20% development area grant. The amount of cash it cost you was only something like 28% of the cost. All these arguments went along with a big plant. I went along with it at the time. I didn't have the power to do otherwise, but in hindsight it would have been a smaller plant. The argument against the smaller plant was that if you are going to build a world scale business in a market of 10s of thousands of millions of tonnes of Pruteen, you don't build tiddlers; if ICI were going to be in, it should be done properly."

The argument for the smaller plant was that this was of a capacity, 25 000 tpa, which suited the size of the calf veal milk replacer market. In this market Pruteen would effectively replace skimmed milk powder, with which Pruteen was, at first, competitive (see chapter 4). However, skimmed milk powder even then was being subsidised by the EEC for use as animal feed. In Agricultural Division most managers believed that this was a temporary phenomenon. According to Swindall.

> "At the time our colleagues were writing the capital expenditure proposals for the Pruteen plant the skimmed milk mountains were only just starting to evolve. These are now

permanent features of the economy of Europe. We assumed that the mountain was a temporary feature, it would disappear and we would be able to obtain a premium over and above fish meal because of the price of skimmed milk powder."

Swindall believed ICI's lack of experience of how the EEC behaves allowed the board this belief that skimmed milk prices would be well above those for Pruteen. Liesser recalled debating these issues with ICI managers.

"And we said, there is no way of seeing the (EEC) give up influencing the skimmed milk price. A difference of opinion! We never thought to compete with skimmed milk powder. With the agropolitics in the EEC..."

Treeby has already been quoted (4.4) as disagreeing with the ICI (Agricultural Division) assessment of the soya market at the time of the ICI main board's decision to approve the Pruteen plant construction. He went on to give his own explanation of how the agricultural division board was motivated when they proposed expenditure on the Pruteen project.

"...if you speak to Hart, who was front running this thing, his view is quite simple. They wanted reasons to develop this technology because they believed in it. They believed it was the basis for the future. And if it hadn't been Pruteen it would have been...they would only have had to find something else. So I think there was a preconditioning that said, look, the last thing we want to find out is that this is not a very good thing to be doing at the minute. Because it makes life a bit tedious when we think about the technology we will need in the 21st century. Just find the reason that says the thing is sensible and get on with it."

This idea that the Pruteen technology was worth supporting for its own sake was supported by Marks, who described how he and others in Agricultural Division saw the technology,

"...they'd recognised fairly early on - I think this is very important -that ICI's process was around a very novel piece of technology, around a novel fermenter design which was called the pressure cycle fermenter, which ICI patented. They'd had that design for a number of years in the early 1970s. It was an extremely important piece of technology...what ICI recognised was that in the longer term, biotechnology and fermentation processes; were going to be needed on a very large scale. So there were two processes driving it really. One was the technology, the fermentation technology they had developed, and the other was the process itself."

The capacity and other design features chosen by the Agricultural Division board had to turned into a detailed design document and submitted to the main ICI board for approval. Agricultural Division worked with John Brown Engineering to prepare the plant design. Bettley of John Brown described how the division's proposal was eventually approved by the main board.

"...it took some time before the board said yes. ICI came here (John Brown, Portsmouth) and we set up 200 people in a team to do this very complicated design engineering, and 6 months later the board said no. That was in 1974. So the whole team was disbanded, so every one went home. 6 months later ICI said, well look, send up just 6 of your people, who were process engineers and have another go, devise a revamped design. It was during that time that the size of the plant came down and certain other things with regard to efficiencies came down...from 100 000 tpa to 65 000 tpa, which is what that plant is capable of doing...we made it cheaper in one way or another. And they said no again...well, a year after that, 2 years after we first started, the board gave the go ahead. (That was) 1976...3 years later we commissioned the plant. Now that was pretty fast track for new technology and such a large plant."

The reason for the delays was explained by Swindall,

"You are dealing with a decision by the main board at Millbank, making comparisons between projects from other divisions. It is he who gives the most convincing stories at the time, combined with the strategic view of the Chairman that decides what happens. A project may be told, come back in 12 months time...if you still think you want it, then maybe. There are a whole lot of reasons why the actual decision taken can vary on a timescale which could be completely independent of what an outside assessor might think is the actual investment case. You need to go back and look at the company reports, starting in 1971-72, look at the capital investment projects the main board has supported and also the profitability, which comes from different sectors of the company. Put the two together and then make your own judgement."

Saxton told how the main board directors informed themselves of the background to the proposed Pruteen plant.

"Virtually all the executive main board directors came up on their own and spent a day, (at Agricultural Division), during which they received a presentation from us. They had opportunities to probe as much as they liked...there was plenty of opportunity at that stage for the directors to get to know what they were letting themselves in for."

Saxton told how the main ICI board functioned in the 1970s.

"It was still that main board directors had responsibility for one or two divisions, or areas of business. And Alan Robertson was really our link between the division and the main board. A lot of the discussion was really with him. If he approved it, then...in fact my directors, Hart, then Rob Margetts, were able to by-pass the board (of agricultural division) and go straight to Alan Robertson."

Saxton described one of the results of the system, superficially similar to T&L's, where each board member was responsible for a particular division.

"You see, people like him tended to be product champions. Once the likes of him thought, we'll run it for another year, and we'll try and achieve this, once he was convinced that was what we were going to do, he could peddle that...there was no dissent, (on the main board)...Now the way ICI's organised, its much more dependent on a business manager reporting to a small sub-group of the main board, with no-one too committed to it...I think it is healthier now, reviewed with some frequency, so if they are not doing as they should, they can be changed."

Alan Robertson continued to be the main link between the main board and the Pruteen project in the first few years after the completion of the plant.

"During the first 2-3 years when we believed we could build big plants or license...Alan was supportive, but I guess he didn't expose too much what we were doing to the board. It would have got maybe a couple of half hours a year, kind of thing."

During the first years after completion of the Pruteen plant Agricultural Division managers appeared to remain optimistic about the project's future. Harwin commented that,

"In 1981-82 they were planning "Pruteen 2"...250 000 tpa!"

The Agricultural Division board were still looking to future economies of scale. Saxton explained that it was recognised that the plant that had been built could be improved upon second time around,

> "Technically I think it was possible to go from 1.9 tonnes of methanol per tonne of SCP to 1.3 tonnes. Technically, it was possible to use less refined methanol. There was not just the cost of methanol but of drying etc. The benefits of scale...we certainly went through a phase when we believed that with 300 000 tpa plant we could produce good businesses provided we were careful about the market we went to and where we sited them...but all that was still based on high soya."

These mega-plants were never built. According to Pickles,

> "The decision not to build a second large reactor was one that took itself; it became self-evident that it would not be viable."

This decision not to try and build a second generation of Pruteen plant appears to coincide with another decision. When asked at what point human food research began, Swindall replied,

> "At no particular time. It just became obvious, yes, a gradual evolution...at no time did we say, right stop researching animal nutritional properties of Pruteen, start human food research."

This was in contrast to 1973-74 when the human food market was considered and rejected as a matter of policy. It was decided that it would be a diversion of resources from what should be the priority, the animal feed market.

This section is about the decision to fund the large scale Pruteen plant. The structure of ICI allowed that once Agricultural Division came to believe that the larger plant was necessary and viable, it was almost certain that it would succeed in obtaining the funding from the main board. This was so despite comments that some of the reasons for Agricultural Division's adoption of the project could be construed as in the division's interest. Agricultural Division was represented on the board by one director upon whom the board relied for information.[2] It appears to have been the case that if this director approved of the project, the board was likely to follow. It appears that the Agricultural Division reasoning was not going to be closely examined by the board.

7.62 Reorganisation and the End of Pruteen

The realisation that the Pruteen project was not going to rapidly expand and that the animal feed market was not going to materialise appears to have come over a period of 2-3 years. There was no single point at which Pruteen came to be seen as a commercial failure in Agricultural Division. Saxton commented on the main board's view of Pruteen in the 1982-83 period.

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[2] An arrangement reminiscent of T&L.

"I don't think they knew what to do with it...Alan Robertson, in the latter days, was ill."

Hart took early retirement from his post as general manger of the Pruteen Business Area some time in the early 1980s. Saxton was party to the discussions that followed on what to do with the Pruteen plant and the people working with it. He thought that Rob Margetts did most of the thinking on how to deal with the Pruteen project.

"Rob Margetts was brought in as general manager of Pruteen, but then within about a year and a half he was made a director, but he also got research. He had two groups of people, Pruteen and research. Research were more or less divided into catalysts, support of ammonia, methanol and biological."

Rob Margetts looked at the future of Pruteen along with these other responsibilities. This review came after Saxton had written a report which concluded that Pruteen had no commercial future.

"We started from Rob being an optimist. When we realised we were not going to make it in the animal feed market, his reaction was, Christ, we can't throw away all these skills. The least we can do is to see if anything can be done with the plant...Although it didn't succeed we still had a lot of knowledge of how to develop and evaluate products and to get in and understand markets. We should not throw that away."

Saxton described how Rob Margetts saw the existing structure in Agricultural Division.

"...we had big research, big engineering departments, quite quickly we realised they were working on the wrong things. When I got involved there were 31 projects. Some of them there was little being done on. But you could sit down and list 31 projects in what was the biological part of the research department. What we needed was a structure that would get that much more market orientated. That would begin to reduce that 31 down into 6 or 8 strategic areas, and get some criteria around which you could judge those."

The process of thinking out what to do was confined to a small, informal group.

"Basically he was using the few other people he trusted to help think how we could make this thing more effective. What was apparent was that in this day and age you could not have a free standing research activity that set its own targets...the commercial input they had was a couple of blokes from planning and coordination, who looked at the market and assessed the market...but there was no real executive authority, that resided with the research manager and they had to fight for his money each year. But a lot was being spent on things which never had a hope in hell of seeing the light of day."

Asked why, if the planning people defined the market, there was expenditure on such non-commercial projects, Saxton replied that, "they didn't (define the market). It was a cosy club. They were all my good friends...and still good friends...who sat around review meetings once every two months and reviewed all the group projects. But there was not enough steel or hardness about it...there was no-one saying, where is this taking us? If we spend £200 000 in the next year, where are we likely to be and what are the options? That may seem odd for a company like ICI, but it is typical of British industry. I think we did a fair part to sharpen that whole thing up."

Margetts had the problem of how to implement his ideas for making the Pruteen business area and agricultural research more market orientated.

"Now there was great resentment against actually imposing this kind of thing. But we won them round. What you've got to do is for people themselves to see that this isn't actually going to make anything. If you can get some criteria for whether a project has any chance of succeeding, you get people to close down their own projects. But in a way that does not demoralise them, so that they will still look for new things."

One of the events Margetts and Saxton arranged to help persuade managers of the need to change was that,

"we arranged a 5 day session with Manchester Business School, around the Pruteen project...on the process of innovation. And we got through to a lot of managers on my level or a bit below, what the mechanism of innovation is about. You have to have a hell of a lot of ideas, you have to allow people free thinking, but then you had to get rid of most of (the ideas). And you had to spend a little money on a lot of things. You had to keep doing tests, technical or marketing, without spending too much money, to actually see if this is something that could grow (or) that fits with your strategy. And you've got to look at maybe 100 to get 2 or 3 that are worth putting £0.25m into. And you shouldn't be too hard at that early stage. But people have got to realise that when you spend real money you must be hard. With £200 000 and 8-10 people working full time, you have to believe something worthwhile is going to come out of it at the end...at least the macro sums must be looking OK. When you move to spending £2-3m, you must be even harder. People...hate their pet projects being dropped. But you've got to persuade them that they should drop them."

The Pruteen Business Area, which had been formed in 1974, finally became part of one of the new business areas, Biological Products. The Pruteen plant still exists and continues to run in campaigns, producing Pruteen at well below its design capacity for the calf veal milk replacer market. This probably covers costs, but certainly does not give a return on the capital invested.

In chapter 4 Payne was quoted as having the belief that the recent (1986) fall in the oil price once again over turned the economics of SCP. Independently of Payne, Swindall recalled that in about 1986, when Swindall left ICI,

> "there was a concept last year or the year before that the problems associated with the economic production of our plant were being removed because of the fall in the price of hydrocarbon fuels. The strategic position remained the same however. Yes, it would be economic to operate the Pruteen plant in 1985, 1986, 1987, but ultimately the prices were going to go back to what they were. So we would spend a lot of management time wooing back the customers that we had originally had, they start to buy our products and then in 5 years time we walk away from them. Its not exactly the way to win friends."

There is an immediate possibility of making money from expanding the existing plant's production to full capacity. Agricultural Division have decided against this by taking a long term view of the likely development of methanol prices. This time they believe the drop in prices is a short run hiccup in a long term trend of rising prices. Agricultural Division took a number of decisions "against the grain" when they decided that Pruteen had a future in the 1970s. They chose to believe the soya price would stay high, apparently against the expectations of both the feed industry and ICI crop specialists (see chapter 4). They preferred to believe that the EEC would not continue to subsidise skimmed milk prices when Hoechst believed the EEC would continue. The project was approved by the board, but from the way the board operated at that time it appears unlikely that it did more than to take Agricultural Division's projections on trust. That is not to say that Agricultural Division mispresented figures to the main board. They undoubtedly believed the project to have been worthwhile. But their reasons for thinking it worthwhile may not have coincided with the main board's and the main board would have discovered this if they had investigated the reasoning behind Pruteen as they would the reasoning of a similar project submitted to them today.

A similar conclusion can be drawn here on the use of marketing input as was drawn from the T&L case. A planning and marketing function existed in Agricultural Division research to advise on the commercial nature of research projects, yet the aim of the post-Pruteen restructuring carried out by Margetts was to introduce stricter commercial control into research. It could be suggested that despite the existence of a discipline provided by thorough project selection and evaluation procedures there is no absolute standard for when research is sufficiently market orientated.

7.7 BP

The BP managers interviewed had little direct contact with the BP main board. When asked for the board's motivation for particular decisions they would refer to the understanding of the board's intentions current amongst their colleagues at the time. This leaves a more remote account of the board's thought and function than was the case with ICI.

Most research and development in BP is done in major stand alone sites, such as the Sunbury Research Centre. The businesses award contracts to these major sites for particular problems. There is also research funded by BP International, which is more strategy related and directly under the control of the board. So the funding of research is similar to that of Royal Dutch Shell, but in the case of BP it was the corporate body, BP International, that funded Toprina from the early stages of the project in the 1960s until the creation of BP Proteins. Toprina, unlike Pruteen, was a project that the BP main board actively supported and pushed along the path to commercialisation.

This is underlined by the absence of a Toprina champion[3] at a level in the company lower than the board. Bernard Laine became the most important Toprina manager. He began as project leader at Lavera and finished in 1978 as general manager of BP Proteins. Yet he was never referred to as other than a competent manager doing his job and was not seen as a "Toprina Champion" by interviewees. He survived the demise of BP Proteins to become general manager of BP Chemicals, his current position in SFBP, (Societe Francaise de BP).

7.71 The BP Main Board and Toprina

Payne remarked that some time in the 1960s the BP board took an interest in Toprina and appeared to identify with the project. Outsiders such as Lewis commented on why this was should be so,

> "It (Toprina) was a flagship for their getting into something other than oil. The top management identified with it. No question, it had identity at the top of the company. Marvellous publicity for them. This was all before their big discoveries on the north slope of Alaska."

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[3]See chapter 9 for comments on the different roles of "champions" in the companies

The BP board wanted to identify the name of BP with Toprina. As has been remarked upon in chapter 4, they saw BP as making money from a project that would help feed the protein hungry world. Peachey also remarked that Toprina was the first step in a long term strategy to diversify away from dependence on oil and Toprina came before BP Chemicals or any of the other major BP diversifications.

7.72 The Lavera Plant

Champagnat and Payne at the Lavera refinery[4] had developed two routes to producing SCP, one based on alkanes and one on gas-oil. Payne and Champagnat were responsible for the decision to develop the two processes in parallel, Payne believing that SCP was to become so important that two routes would be needed. The board must have accepted their thinking because it approved the construction of both the Lavera plant and the Sarroch plant to provide working examples of both types of technology. This is something no other SCP company did.

The Lavera plant was based on the gas-oil process chosen by Payne for French development. According to Payne the capital cost was two thirds born by the EEC and one third by the French Ministry of Agriculture. BP also succeeded in licensing this process to the Japanese company Kiro Hako. However, the plant suffered from bottlenecks in production and Payne thought these persuaded the main board to make Lavera a semi-autonomous profit centre in the early 1970s. Lavera was unable to

[4]The Lavera petrochemical complex is near Martigues in southern France.

even cover its costs with the 1973 oil price rise and was closed in 1976.

7.73 The Board Choose Italy for the Toprina Plant

All BP interviewees were surprised by the BP board's choice of Italy as a site for the Toprina plant. Peachey saw the choice as,

> "Amazing. The funny thing is that BP Oil had just withdrawn from the Italian petroleum market, when BP International went into this joint venture with ENI. The reasons (for the Toprina investment) were that BP didn't feel able to (pay for) a full scale plant, because they were committed to megabucks investment in the North Sea, just about to open up Forties. There were plans to have one built just done the road, at Grangemouth. In retrospect, a much better idea. But they decided to go to Italy for the joint venture and extremely attractive development grants."

Northgate outlined some of the attractions of Italy and Sarroch.

> "...the biggest single Italian refinery in Italy, Sarroch refinery, was owned by ANIC, which was part of the ENI group. Now it's ENI Chemicals. The feedstock to the Sarroch refienry was Libyan crude, very, very rich in paraffins. Sardinia was closer to Africa than to Italy, with deep water port facilities. So from a geography and existing trade point of view, Sarroch was a very good source of paraffins. Next door to Sarroch refinery was Sarroch Chimica. It was the obvious

> place to refine the crude paraffins (from the crude oil in the refinery), take them over the fence to Sarroch Chimica, build a paraffins refining plant at Chimica to give you pure paraffins, then over the fence to Italproteine."

So both logistical reasons and finance were strongly in favour of building the two plants at Sarroch. Leivers thought that the board fixed on Italy because,

> "...Italy was a big market for feed. It was in the common market, which Spain was not. Things could have been different if Spain had been...but once a product is made in one country of the common market, it can go to all the others."

7.74 BP Build the Sarroch Plant

Leivers compared BP's huge returns on capital and profits before the oil crisis of 1973 with the present day to explain the building of the plant.

> "...and again, we had the money to build it. If it had been now, it wouldn't have been done...once you start something and you have the money to go on, why not?"

No one gave figures for the extent of the Italian subsidies of the two (alkane refinery and SCP) plants, but Leivers stressed that they were large indeed, greater than 50% of the total capital cost.

> "On paper it looked good. On paper. The Italian government was able to pay for the project, because it was in the Mezzogiorno[5]. [They were going to pay] nearly all, it wasn't going to cost BP a lot."

As with Shell and IFP, BP only gradually came to interpret the oil price rise as a permanent feature of the world economy rather than a hiccup (1-2 years). The BP board were similar to ICI in only being interested in this technology because they originally saw it as long term with many generations of plant. Peachey described what would have been other stages of development had all gone well.

> "As one stage was starting to mature, the next stage was becoming obvious, being thought about and worked on. One used to say, in 5 years time what will we be doing?...It would have depended on jumbo methanol plants in the Middle East for us. Then you would have had to build your plant out in Kuwait. There must have been thought like that."

The possibility of licensing the plant became the over riding reason for continuing waiting in Italy[6], after the mid-70s realisation that the project would not be viable in Western Europe. Peachey thought that,

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[5]The Mezzogiorno is the southern, impoverished half of Italy.

[6]At one stage BP had advanced plans to build a plant in Venezuela, but a condition for its purchase was the demonstration that the Sarroch plant could work.

> "There was considerable interest being shown by the USSR and the Middle East, definite possibilities for licensing the process in both areas. I feel that is one of the reasons for their going ahead. I think there was a lingering hope that the soya price would keep on climbing. Wishful thinking. The economics were always equated with soya."

Peachey thought the economics were not hopeless in the period after 1973. It depended on which economic scenario was adopted, and there were a number of these available to the board.

> "The sums worked out to be a negative-positive balancing act, with the high feedstock price. I don't think anyone would have gone ahead with a highly negative product price. But there were these potential carrots for the future (prospect of licensing)."

But Peachey thought that the reasons given were still insufficient to explain the board's decision to proceed with the construction of the Sarroch plant.

> "There must have been other reasons, because BP doesn't chuck that sort of money down the drain, just because they don't want to fold up a bit of research. They've folded up lots of research. Must have been reasons."

7.75 Board Diversification Strategy Affects Toprina Research

As a result of the oil crisis the board of BP decided that the company needed to diversify further. Peachey thought that,

> "At that time they were wondering where BP was going. With these forecasts of oil running out in 1999...There was a general worry that it might. It was all over the company. The diversification phase was the most interesting time for ideas. There were all sorts of things we could do with Toprina. We went through polyhydroxybutyrates, you could make practically any organic chemical, all the things the Japanese had patented. Or take the protein, dry it and make buttons from it. We looked at the semi-moist animal food market, to give to people like Spillers who would put it into Kennomeat meaty chunks. That folded up...we had a whole meaty chunk set up at Grangemouth that must have cost a whole lot of money...We were looking for other product areas...a very central idea, to diversify."

When asked what came out of the diversification effort, Peachey replied,

> "I don't know, a good question. I suspect that someone did some sums, looked at the market...and knocked them on the head. Within the research department there has always been a group for economic appraisal. Either something can be knocked on the head by a simple bit of delving, or if its promoted a little bit more it will be knocked on the head after a bit of research."

As described in chapter 4, once the Sarroch plants had been built BP only wanted to demonstrate that the process worked in order to be able to license the technology to countries such as Venezuela. This the Italian ministry of health never allowed them to do. Leivers and De Fabiani thought that at the very end, when the board had tired of waiting for approval in 1978, the board may even have been pleased to use the ministry of health ban on production as an excuse to get out of the project. They were then able to suggest, without naming companies, that the soya industry interests had caused difficulties. But Leivers was certain that in BP,

> "No-one in BP will admit to a mistake. No-one at the top will break this rule."

There were rumours current in the oil industry about why BP withdrew from SCP in Italy. Payne believed what Lewis saw as a rumour, that the American federal government had made an informal deal with the BP board. BP could exploit the Alaskan oil reserves if they gave up their SCP activities. When this was suggested to Lewis he commented that,

> "Well, there was some talk at the time that they could only get American government approval if they didn't continue with SCP. But only someone in BP could tell you, you hear rumours, when you mention what Payne said, I have heard the rumour, from elsewhere, that was in the 70s.""

With the end of the Toprina project BP withdrew from all fermentation and most microbiological research. Fishlock (1982) wrote that the BP board were in a state of emotional shock after the end of the Toprina project and that that was why they withdrew from the fermentation technology associated with Toprina. Others who have tried to talk to senior BP managers have come to a similar conclusion, for example Sharp[1] commented that he had succeeded in obtaining meetings with former board members and he believed the board was embarrassed by its involvement and reluctant to disclose their past thinking on Toprina. The only positive long term benefit that BP gained from the Toprina project was the creation of BP Nutrition. BP Nutrition was originally part of BP Proteins which was the division set up by BP International to manage the development of Toprina. BP Nutrition was originally part of BP Proteins and had the function of acquiring feed companies in order to give BP Proteins in-house nutrition expertise. Cooper Nutrition and Hendrix were feed companies bought and managed by BP Nutrition. BP Nutrition turned out to be profitable in its own right and when BP Proteins was run down after 1978, BP Nutrition remained and continued to grow. According to Peachey, BP is now the second biggest animal feed company in the world.

It can be seen that the BP board controlled the SCP projects quite strictly and were involved in the detail of the decisions taken. The story of the projects' development is a story of the board's decisions, but the managers interviewed were interpreting and guessing the reasons for the decisions they made.

7.8 Conclusions

7.81 Relationship between R&D and the board

[1]Private conversation, 1988. David Sharp was gathering material for his forthcoming book on SCP.

This chapter has examined the relationship between R&D and the board, mostly from the R&D perspective. On the whole the board appears to be perceived as a conservative influence and in most cases a remote influence. There appeared to be very little interaction between R&D and the board as a group in any of the cases, however they did have a sense of how important they were within the company. This sense ranged from an exceptional view of the R&D department spearheading the diversification of the company as in T&L, to the view that R&D was a mere holding operation which would only be turned to in a time of crisis. This suggests the following synoptic table.

Shell	R&D a holding operation Research exists "in case" company ever decides to use it
BP/LQ	R&D supports commercially based projects, a necessary supporting function
RHM	R&D valuable function of company
ICI	R&D a vital and commonplace activity that provides future businesses

T&L	R&D with very high status and with responsibility for changing core business of company

The R&D managers often referred to how parts of government influence the board or higher management decisions. In two cases, Hoechst and Liquichimica, the government was heavily involved in creating and funding the project. In the others governments were giving grants to support plant construction and exerting an influence on the board.

7.82 The Commercial Role of R&D

There appeared to be various perspectives on the commercial role of the R&D department. There was a tension between the outside view of R&D as a cost, a "pit into which we keep throwing money" and the R&D departments belief that in the long term the company relied on them to develop new business.

This chapter anticipates chapter 9 which deals with the special role of individuals in promoting SCP whereas in this chapter it can be seen that powerful groups within companies can perform the same function.

CHAPTER 8 TECHNICAL CHOICES IN THE DEVELOPMENT OF THE NOVEL FERMENTATION PROJECTS

Introduction

This chapter examines the key technical choices that the R&D department were faced with as they developed the novel fermentation technology. Until a full scale plant was built the majority of the personnel employed and money spent was in the R&D department of each firm.

8.1 The Costing of the Project

It was not possible to cost SCP development before some of the key choices were made. As a particular process took material form a progressive shift into more exact quantitative estimates could be made. For SCP Akinin (Shell) described the initial basic calculation,

> "The equation...is made up of a number of different bits...the changes in the world price of protein is one. You can do a calculation which shows that in order to achieve a certain price, assuming you can operate on a large scale, you've got to achieve a certain growth rate of organism, you've got to operate at certain cell densities within the liquid. The heat generated by the process must be within a certain level, because it becomes very expensive to cool beyond a certain point. The oxygen demand has to be capable of being satisfied by technology that exists, cheaply...and so on."

The R&D department might cost a project and want to proceed, but there could always be disagreements with the business. Thomas described how he worked with the business side on the ICI end of the mycoprotein project.

> "I'll write programmes then people will criticise and say, well, that's a more pressing problem. So I then say to the business, well you define to me what the priorities should be and I'll research them. There's always arguments there because there are so many priorities to the business, that getting 1 2 3 4 is quite difficult. And as soon as you think you've got one of them down, it just slips through your fingers...so it's never boring, never boring."

In this way the projects took on different forms. The substrate and organism differed but so did much of the detail of other technology such as the fermentation and harvesting technology. The following sections describe some of these differences and the managers views on them.

8.2 Novel Food Research as a Fashion

Work on novel foods and SCP was in fashion from the late 1960s until the end of the 1970s. A part of this idea of a "fashion" in scientific work was that research was done simply because everyone else was doing it. Solomons (1983), ex-BP SCP researcher and research director at RHM, thought that,

> "Once SCP research became fashionable and because it is a very easy subject in which to start research, a plethora of ideas appeared in the literature over the last 12 years or so." (Solomons, 1983 p31)

Solomons uses the idea of fashion without being highly critical of the SCP research field. The more critical Moses and Rabin refer to a "bandwagon" effect,

> "Once the bandwagon began to roll it gained so much momentum as to become unstoppable by rational arguments based on the unreplenishable nature of reserves of liquid fossil fuels." (Moses and Rabin, 1982 p68)

Cowen (T&L) did not think such a bandwagon effect was novel to SCP,

> "Partly true, a bandwagon effect in any area of science. If a university starts work, appears to be successful, then lots of people jump on the bandwagon."

In the case of SCP it was the determination and success of BP in developing the technology that convinced many firms to start their own research. Peachey (BP) said that BP encouraged SCP conferences to promote SCP and the BP SCP projects. The conferences and the industrial effort going in to SCP research made the field attractive to hundreds of university and government research institutes.

Garoffalo and Marks also agreed that there had been a bandwagon effect with novel food research and Marks linked SCP to other microbial research topics,

> "I think that's right, it wasn't just SCP, it was a whole lot of other microbial processes, at the same time SCP people were talking about using polymers for tertiary oil recovery by fermentation...they were taking about updating processes...like citric acid and about going back to processes which historically had been used in the second world war to produce alcohol etc...so it was a whole combination of things that were happening. But at the heart of it was a wish to develop sophisticated fermentation technology..."

SCP had certain potentialities, certain scientific attractions to microbiologists. They saw it as a complete alternative to the models of existing agricultural practice and therefore exciting as a research topic. Akinin gave an example of this when he described how SCP technology could avoid nature's "nitrogen cycle".

> "Its simple and its basic. You've got your nitrogen in the atmosphere, youv'e got routes by which that is fixed and in the soil it is oxidised to nitrate, and that is well known. But the important step is biosynthesis, in a green plant, to make plant protein...that is what man wants. You are absolutely tied to that bit which is the green plant growing in the field taking inorganic nitrogen from the soil and making protein. But its perfectly obvious...there is another way of upgrading

> these things to protein and that is because there are a hell of a lot of organisms, bacteria, yeast and moulds, that are capable of getting their energy, not from sunlight but from a whole series of other chemical reactions, whether they are growing on sugars or whether they are grown on inorganic materials which they are oxidising to release energy."

Most of these organisms could synthesise their proteins from inorganic nitrogen using chemical energy. SCP technology would give man the ability to by-pass the green plant protein synthesis step. This, combined with the world food shortage forecasts was the source of many scientists' enthusiasm for the SCP and novel food projects, and hence a partial explanation for the bandwagon effect. What could generate scientific enthusiasm was the existence of a simple technical model which could displace a more complex natural one.

According to Fishlock (1982), the Pruteen project accounted for over a third of all ICI spending on "biotechnology" and Antebi and Fishlock (1986) refer to the ICI venture as the largest investment made by a single firm in biotechnology research. Despite this historic importance of SCP in industrial biotechnology, the number of references to SCP and novel food research drops to near zero after 1984. For example many general biotechnology texts, Silver (1986), Knorr and Sniskey (1986) and Olson (1987), fail to refer to SCP or novel food fermentation at all. Prentis (1984) mentions SCP, but only to say that it "obviously makes good sense" since SCP provides an alternative to dependence on green plant protein synthesis.

Daly (1985 p14) does refer to the RHM work, but as a further development of SCP technology and as a "fungal SCP." As Treeby has said, (See Chapter 4), RHM do not want Quorn associated with SCP and he believes it is technically wrong to refer to it as SCP since it is multicellular. Daly's comments confirm the view that SCP and Quorn have been closely associated during their development and have shared so much basic science that they can be regarded as a group of fermentation innovations.[1]

The lack of references to novel food fermentations after 1984 shows that the fashion for SCP and novel fermented foods was mostly over, but while it was in fashion some interviewees claimed their companies gained benefits simply by being seen to be active in such a socially beneficial technology. Cowen thought that T&L benefited in this way.

> "One major value for T&L, we did it when it was quite popular, quite a "with it" thing to be doing. We did acquire a pretty good reputation as a result of this, and this undoubtedly helped the overall image of research within T&L. No question at all, on that basis alone, the money was well spent."

In Dansk Bioprotein (1988a), Villasen refers to the enthusiasm among academics that the project engendered,

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[1]In fact the 1984 British Biotechnology Directory which lists current biotechnology research in the UK refers to the Rank Hovis work under the heading "fungal single cell protein". It has only been since Marlow Foods was created that there has been an attempt to distance mycoprotein from SCP.

> "It has probably also been important that the project with its quite obvious social perspectives has inspired scientific researchers at the University of Odense."

Villasen actually links this enthusiasm to what he calls the astonishingly rapid progress of the Dansk Bioprotein project.

The pattern of activity within the novel food projects also changed over time and an example of this was "village technology," fermentation. Peachey told of the time when this was in fashion,

> "There was this daftness of...there was an era where we went through village technology. You could chop up your locust beans, stick them in a fermenter, in Africa, make protein. If you look at some of the older SCP tomes, they talk about SCP from all sorts of biomass...bagasse...but you really can't run that sort of fermentation without really high technology. The stuff has to be made safe for the animals to eat, it's got problems."

The fashion and the enthusiasm for SCP was based on its perceived social benefits. Commercial motivations may have been paramount in the companies, but even here and especially in the academic institutions, there was a non-commercial motive to the development of the technology.

8.3 Scientific Networks

The common skill base of the SCP projects resulted in many of the scientists in the R&D departments being friends. Marks (ICI) referred to,

> "...a group of people in the UK who had been working on areas highly relevant to SCP production and they all knew each other from the academic community. Then all of a sudden, they went to work, over a period of, 3,4,5 years in the Shells, the ICIs the BPs of this world. Clearly they still knew each other. So there was interaction between them, because they still went to the same scientific meetings. But the commercial aspects are never discussed."

Garoffalo expressed the same idea,

> "Technologically its a small world. I knew the people in Shell...I worked with the people in ICI and so on...not on those particular projects necessarily. Yes, with Hoechst I had specific dealings with them, or some of them...all the people in the UK that have been involved in it (SCP), know all the others...we went to the same universities."

The personal network of contacts had its base in shared scientific interests and in Bettley's view the informal personal contacts were more important than official titles. When talking about the personnel changes that occurred when the Pruteen project ended he commented that,

> "...that's rationalisation. What companies call themselves and how they appear to the world is one thing, the people are the

same and they have to a large extent remained the same in both JB and ICI...I'm still talking to the same people, but our job titles change regularly, it doesn't mean much."

8.4 Selection of Organism

8.41 The Organism Screening Process and the Selection Criteria

This was the important first step for all the projects. Marks thought that the characteristics of the organism were,

> "probably 90% responsible for dictating what the product was going to be...but there were ways of manipulating growth to just tweak up a few other things."

Small variations in organism characteristics were expected to have a large impact on profits, so the selection process [illegible] more rigorous than any previously performed for industrial purposes. The time spent on this phase of the projects could be up to 6 years, (see Treeby above).

Johnson (1982) believes that the techniques for selection had to evolve with the research. The selection criteria that most suited the company had to be fixed and then a trawl for all possible organisms could be carried out, then the selection criteria could be tightened to whittle the candidate organisms down to one. Treeby described how RHM chose its fusarium fungus.

> "When we decided that what we needed was texture and that was synonymous with some member of the mushroom family, we identified up to 3000 organisms world wide as possible candidates to provide the combination of structure, texture and high growth...Out of that initial characterisation came a handful of organisms that seemed to meet the criteria...and then only two of that handful. One was a penicillin, which are probably the best understood fibrous organisms. After 3 or 4 years of research there just wasn't any way that it was going to give us the high yield growth characteristics that we were interested in.[2]"

An organism was selected by criteria which were supposed to predict how it would ferment on a large scale. But this could not be known until it was fermented on such a scale, and at this point it would not be possible to change the organism. Swindall described the problem,

> "It's a bit of a chicken and egg situation, because you select the organism on criteria which are based on the desired product specification...(then) you learn more about it at the pilot plant stage and so on. You get to a stage where you are committed to the organism which you have chosen relatively early in that development process... it's necessary to choose early because of the need to do all that toxicological work...you are testing organisms for characteristics which you think will be important in the large scale process but you need to

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[2]Seven years after their project began RHM changed from the penicillin to the A3/5 fusarium strain with which they have worked ever since.

> know the characteristics of the large scale process to do that. Its based very much on how you conceptualise the process at an early stage."

So the end product specification was used to determine the selection criteria during the organism screening phase. When product conceptions changed so did the criteria for a "best" organism and this is what happened in the RHM research. Spicer (1971) talks of the advantageous amino acid profiles of fungi compared to those of yeast and bacteria. This quality was only advantageous if the product was being developed to provide a third world protein supplement, not a first world alternative to meat. In the latter case a good amino acid profile is almost irrelevant to success. Weight for weight mycoprotein is higher in essential amino acids than chicken, but this is not expected to increase consumer sales, although it might have persuaded third world governments to license RHM technology rather than another company's.

The RHM organism is now grown on the Pruteen pilot plant and this was not designed for a filamentous fungus. The fungus grows, but ICI and RHM are having to investigate how changing fermentation parameters might change the product characteristics. Thomas described the situation,

> "...optimal growth for the organism might not give you the raw material at the end of it that is optimal for food quality. And this is what we don't know at the moment, that is what all the research is going in to, how to characterise it, how to make it optimal."

T&L and the smaller waste-SCP companies did not screen so many organisms as ICI, BP, RHM, Hoechst, and IFP and the selection of organisms was more ad hoc. T&L chose a fungus because fungi can grow on a range of substrates, could be harvested by simple filtration and had relatively low RNA content. Fungi also tolerate acid pH, something that bacteria are sensitive to, and so T&L could use an acid fermentation which approximated to sterility. However when T&L tried to operate their pilot plant in Belize the fermenter was frequently infected with other organisms, in particular a yeast which grew at temperatures over 46 C and competed with the T&L fungus, Aspergillus Niger. This forced T&L to move to a solid state fermentation rather than a liquid fermentation.

The key criteria by which organisms were judged were given by Bett (Shell) and by Hamer et al (1976 p67) as the following:

Produces toxins, pathogenic?

Yield, eg in grams of product/grams of material consumed

Concentration of organisms in medium, eg in grams/litre

Growth rate eg as cell mass doubling time

Productivity eg in grams/litre/hour

Stability of the culture

Resistance to contamination

Thermo-tolerance

There were other criteria such as the percentage of cell mass which was nucleic acid, the percentage of cell mass that was made up of useless mineral salts, (described as ash).

A condition for granting a patent for the organism was that a culture collection was filed with the patent office. The result of patenting was that the organism was generally available and most of the SCP companies ran comparative tests on each others patented organisms. This tended to reinforce confidence in the original choice, because the different organisms matched each company's idea of its own process and product requirements[3].

8.42 Some Selection Criteria Problems

For an SCP process to have a chance of being economic many of the "accepted" values of these criteria had to be radically improved. Hamer (Shell) gave an example,

> "...a lot of the research went on getting high productivity cultures, remember, very few [people had grown organisms to any sensible density at that time. Most people regarded 1 or 2 g/litre as a high density of organism. Before you could ever think of being economic you had to have 20-30 g/litre, an order of magnitude greater."

Hamer thought there was an over emphasis on yield coefficients in the literature as a means of comparing the relative worth of different organisms. This was because yield coefficients varied for the same

[3]For example, Marks pointed out that ICI's organism had the highest growth rate and yield of any company and that this tended to show that ICI had the better process.

organism under different conditions. For methane or North Sea Gas based processes the problem was the waste of feedstock.

> "It's very hard to get a high feedstock conversion...everyone tells you what the yield coefficient is, how many Kg product for how many Kg of substrate utilised. But substrate or feedstock supplies, the story is very different. In fact you have to achieve something like 80% conversion of the methane...most processes will only give you 30-40%, some considerably less than that. A serious problem."

Hamer pointed out that this was the major block to all the algal and hydrogen based SCP processes, since they also relied on gaseous substrates, (carbon dioxide in the algal cases). At 80% conversion of substrate to cell mass it was possible to enrich the wasted gas and burn it in the spray drier, or to dry it, remove carbon dioxide and recycle it to the fermenter. It is interesting that Hamer thought this problem so acute, and the methane to methanol step so difficult for the organisms, that,

> "...at the end of the day, ICI probably had the best hydrocarbon orientated route."

ICI had begun to investigate the natural gas route to SCP in 1967, but only a year later they chose the methanol route. Their reasons for doing so are especially interesting now that Dansk Bioprotein have chosen to continue with such a route. Swindall's explained ICI's reasons as, 1 The solubility of methane in water was very low.

2 The organism oxidised methane to methanol anyway, but slowly and inefficiently.

3 The low feedstock utilisation required the recycling of air and methane, a potentially explosive mixture.

Both Shell at this time and Dansk in the 1980s have used mixed cultures of methane utilising bacteria to increase the rate of conversion of methane to methanol. There are necessary because the methane utilising bacteria can produce toxins, formic acid and formaldehyde as well as methanol. These toxins are responsible for slowing the rate of fermentation down. In the mixed cultures there are bacteria that consume these toxins and so allow the rate of fermentation to increase.

ICI chose not to go down the mixed culture route, but it would be interesting to know whether their feedstock conversion rates were the typically low values that Hamer refers to, if so they would have been forced to face up to research on recycling their substrate[4]. They saw that this would be something of an engineering nightmare, as did Shell. But they had the "easy option" of chemically produced methanol on site which was unavailable to Shell and which drew them into the methanol route.

8.43 The Search for Thermo Tolerant Organisms

[4]Dansk Bioprotein are able to ferment around 80% of their natural gas in one fermentation cycle. The remaining 20/% they arrange to be burnt as fuel in an adjoining process in another company. They therefore replace the engineering problem of how to recycle with the partly organisational problem of finding another company to take the waste natural gas.

Another major aim of research was to find thermo-tolerant organisms. A success here would have enabled the projected capital investment to be lower because there would be less need for cooling the fermenters. The organisms produced waste heat from their metabolic processes and this would have to flow out of the fermenters to the environment. The Dansk Bioprotein organism had an optimum growth temperature of 46 C, high by the standard of the researchers of the 1970s. The Dansk process still requires cooling, but less than the BP organism required. The BP organism had an optimal growth temperature of 30 C and this was so little different to room temperature that the costs of cooling were relatively large and a question hung over how the plant would operate in typical Mediterranean temperatures of + 30C. BP actually found a strain which would grow at a higher temperature which they could not use because the plant was already being constructed. According to Peachey this was a shame but,

> "The economics weren't critical, but it was at the stage where we were honing the process and were interested in 1% improvements in production. That was a margin that could contribute to profits."

Most organisms have an optimal growth temperature in the range 15-45 C. According to Hamer, Phillips Petroleum found a thermo-tolerant organism with an optimal growth temperature above 50 C. Hamer recalled that there was something of a technical debate at the time over whether these thermo-tolerant organisms could be used effectively.

"Everyone used to say, oh, well, the solubility of methane or oxygen goes down with temperature...but of course if you put pressure on the system it doesn't make that much difference. What everyone also forgot, was the diffusivity of gases in liquids will increase with temperature and this almost compensates for the loss of solubility."

Nevertheless, the effort put into the search for such organisms was large.

"ICI put in, a 100 man years maybe, I suppose Shell put in 20, 30, 40 man years of effort looking for these organisms. Everyone said, this is a false claim in the patent literature by Phillips. It wasn't a false claim, I can tell you that. I had at least 10 or 12 methanol utilisers that grew well at 50-55 C here (ie Zurich Polytechnic)."

Hamer believed that the search techniques in general use at that time were not capable of showing up the thermo-tolerant organisms, although Phillips Petroleum must have been using a more innovative procedure.

Some research paths were not followed by all the companies. An example was the aim of understanding the organisms' biochemical pathways. ICI, Phillips Petroleum and BP investigated such pathways and Peachey described the BP position.

"We started from zilch knowledge. In 1964 there was very little published. I mean to the end we still didn't know the details of the metabolic pathways. ICI had a toxic substrate so they had to be careful."

ICI and Phillips used their knowledge of pathways to genetically engineer more yield efficient organisms, but such a possibility was not open to BP at any time because of the absence of gene manipulation techniques until the mid 1970s.

8.44 The Choice of an Aseptic Fermentation Process

An aseptic fermentation is one which is resistant to infection by foreign organisms. The novel food production processes had to be reliably free of pathogenic organisms to produce a sterile product. There were a number of approaches to obtaining a consistent and safe product.

1 Fungi tolerate acid pH but bacteria do not. Since most pathogens are bacteria the choice of a fungus in an acidic medium would tend to exclude the possibility of bacterial infection. The fermentation could then be open to the environment, as was the T&L process.

2 Choosing a substrate upon which microorganisms grew with difficulty. The Shell and Dansk Bioprotein processes based on methane are the principal examples of this.

3 Engineering to sterile standards. BP and ICI used this method to guarantee that no foreign organisms could enter their fermenters.

Toxicological monitoring of the product was a part of the process, especially for the first two options.

Sterile engineering was expensive. Both Jorgensen and Dansk Bioprotein (1988 p9) claimed that the non-sterile nature of their process was one of the factors that enabled them to reduce construction costs of a full-scale plant to 10% of the cost of "earlier designs", by which they mean the ICI Billingham plant[5].

Bettley (John Brown) explained that,

> "Essentially ICI could see that they were going to get very high carbon conversion, but they could only do that with this particular organism, and it was sensitive to infections. Sterility was not the requirement of the product, but of the organism. The high dependence on feedstock cost made it important to have high conversion efficiency."

Selfridge (IFP) described how IFP worked with both yeast and bacteria,

> "...and we finally chose yeast. We continued to keep our view that if we worked with bacteria we would be obliged to work in sterile conditions, with yeast you worked with, clean, but not truly sterile conditions. It would have been easy to keep this [bacteria based] laboratory process sterile, but not a plant or even a pilot plant."

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[5]Although Hacking (T&L) and Pickles (ICI) found this hard to believe, (see appendix 8)

There was another reason for choosing the most rigorously sterile process. This was the need to convince sceptics that the novel product was completely safe. Among microbiologists there was some doubt that a process that relied on routes 1 or 2 (above) was above suspicion. There was always the chance that some organism previously unknown and rare would find its way into the fermenter and survive to contaminate output. Then safety would rely on the detection of contamination by the firm. Sterilisation of inputs to the fermenter combined with sterile engineering would remove all doubt about contamination and it was a guarantee of the absence of contaminating infections. The issue of sterility was especially sensitive for ICI because they had seen how minor scientific doubts had been exploited to BP's disadvantage in Italy.

Riviere (1977) describes how the BP Lavera process used control of pH, temperature and dilution rate to control sterility and Payne thought that the importance of high standards of sterility was over emphasised by some bacteriologists and microbiologists.

> "You see it's psychological...we did it in Lavera (septic fermentation) and it worked! At the very beginning I enquired about contaminants at the pilot plant. I decided to see if the bacterial contaminants were toxic and if it was stable or not. It was innocuous and the bacterial population was absolutely stable. So why bother with asepsis?"

Payne suggested why the scientific community continued to have doubts on non-sterile biomass fermentation,

> "Biomass production is a unique problem. Usually companies producing metabolic products, biotechnological processes, optimise their strain by genetic engineering, mutation and so on, for them it is essential to be aseptic. The only exception is when you want to produce biomass."

The common industrial experience was of a need for asepsis and so there was a critical attitude to non-aseptic processes.

8.45 A Mixed or Pure Culture?

Payne described another division among scientists at the time which was linked to the need for sterility and may have affected the research projects. This was the question over whether a pure culture fermentation was better than a mixed culture fermentation. Payne remembered a conversation he had once had with an eminent bacteriologist.

> "...the father of penicillin, Ernest Chaim, he told me that any industrial process using bacteriology should have a pure culture. I asked him why, he said it is obvious, but I told him you are denying the existence of cheese. In my country peasants produce Camembert every day and it never turned out that the next morning they have Cheddar. Cheese shows that a mixed culture, when very carefully set up, is absolutely safe...you know, bacteriologists spend all their time with test-tubes and have no imagination..."

Bett described the differences among scientists.

> "One of the big debates of those days was whether a monoculture was necessary or not. A supposed danger of mutations. If the process was either sterile or with one extra culture, there was a high certainty of the output. However that would be very expensive, stopping and starting the process to refill etc."

The suspicion of mixed cultures was that perhaps genetic material could be exchanged between the separate strains or that over time the relative proportions of one strain to another would change as mutations occurred. It could not be proved that such things would never happen so the debate could not be resolved. According to Jorgensen, another microbiologist who supported the industrial use of mixed cultures, scientific suspicion of mixed cultures persists today. Leivers gave the principal reason for believing that mutations were not a serious problem,

> "When the conditions for production are strict there is no reason for a mutation, if there is one it is maladapted so it dies."

The two principal mixed culture processes were the methane based projects of Shell and Dansk Bioprotein. ICI, RHM, Hoechst, IFP and BP at Sarroch used pure cultures. If the BP Lavera process was not sterile the other organisms present during fermentation were very few and not essential for the process to take place. Akinin described how researchers at Shell tried to obtain a pure culture that could grow on methane.

> "We made a number of fairly basic discoveries and one of the important ones was that...you did indeed get cultures that utilised methane, but as you purified them more and more, they would reach a point where they became much less active...it proved to be very difficult to get any sort of pure culture of a bacterium that would use methane that would grow at any sort of presentable rate. But just before you got to that point you got a mixed culture that grew extremely well."

Shell found that the methane utilising bacteria produced methanol as a first step and that methanol inhibited its growth. So a second organism was necessary to mop up the methanol and allow rapid growth, (and other organisms were necessary to consume by-products such as aldehydes). Shell isolated several synergistic mixed cultures of this sort; the Dansk Bioprotein mixed culture is another example, (see Bushell (1983) for a description of the Shell mixed culture)). Shell were investigating these bacteria without hope of developing an SCP process.

> "More or less up to that point we had been thinking of taking methane and making some attractive chemicals, rather than SCP, the reason being that if you looked at the growth rates that were reported in the literature, they were pathetic, the yields were very, very low. It didn't seem that SCP production was at all realistic. But when we discovered this interactive thing...we realised we were getting growth rates in the right ball park to make SCP a possibility."

On a methane substrate a mixed culture offered the only possibly economic route to SCP production. The other companies were using substrates with a wealth of possible organisms, and so could choose a pure culture, avoiding some of the doubts about the reliability of such processes.

8.5 Fermentation Choices

The low profit margins on the SCP products required that continuous fermentation be achieved. "Continuous" fermentation meant longer fermentation runs than were at that time common in the brewing and pharmaceutical industries. The prevailing mode of fermentation apparently led to the belief that this kind of fermentation was not possible. Northgate thought that this was,

> "...where a lot of woolly thinking came in, and the pharmaceutical companies had a lot to answer for. In forming attitudes. First to continuous fermentation, then to continuous aseptic fermentation."

Treeby commented on what these attitudes were and the RHM research team's achievement,

> "...they applied some frontier breaking, front rank science. Had you asked anyone in 1970, can you grow anything in a continuous culture, everybody said no. Nobel Prize winners said forget it, stupid idea that. We did it."

The form of the fermenter varied between projects. The major choice facing the SCP producers appeared to be between the traditional stirred tank or an air lift fermenter. Bett described Shell's comparison of the two types of fermenter.

> "A major engineering study for scale was performed and there was an oxygen delivering problem...the economics came out for a stirred tank, what they've been using in brewing for hundreds of years, but it has much greater flexibility than ICI's. If we had scaled up we would have had a dedicated plant with a stirred tank."

Dansk Bioprotein have chosen to use a series of $50m^3$ stirred tank fermenters rather than attempting to scale up to the capacity of the BP, ICI or planned Shell fermenters. The $50m^3$ fermenter can be bought from equipment suppliers whereas the large scale fermenters have to be designed and built to order.

BP chose the stirred tank for the gas-oil and normal alkane fermentations. Northgate commented that compared to ICI, the BP Sarroch plant had,

> "A totally different fermentation style, but BP were doing massive scale fermentation 5, 6, 7 years before ICI, 2000 hour runs. Totally uncontaminated, monoseptic, truly continuous. The fermenter was based on the traditional Rushton stirred tank, S-bars, agitator driven. The old equipment brought up to the highest levels of aseptic operation by BP engineers."

Peachey commented that,

> "Personally I get a bit sniffy when people go on about the ICI fermenter."

Peachey explained that this was because the total fermenter capacity at Sarroch was greater than that of ICI's single fermenter. Each of the three Sarroch fermenters was of $1000m^3$ capacity, served by three compressors, equivalent in power to a Boeing 707 engine. This arrangement worked as well as the ICI process in that it too produced a safe protein product. Her implied criticism was whether the advanced technology of the ICI fermenter was really necessary as part of the process to produce a safe and economic SCP product.

Liquichimica chose the same type of stir tank fermenter as BP but with the difference that they had two fermentation stages, for economic reasons. This meant that the yeast was allowed to continue to ferment in a second fermenter without the addition of further n-alkanes[6]. One result of this was that in the toxicological debate in Italy this feature of their product ought to have been to their advantage. Zamgrandi did remark that the Health Authorities had made official depositions noting that Liquipron contained less residual n-alkane than Toprina when used as a feed.

8.6 The ICI Fermenter

[6] So converting more n-alkane to cell mass.

The ICI fermenter was the most complex of those used for SCP fermentation. It was called a pressure cycle, or airlift fermenter and Bettley (John Brown) described it as,

> "60m high, the largest continuous fermenter in the world...still is. So we are talking of the sort of technology that verges on atomic reactor technology in terms of the amount of metal and the accuracy with which it had to be put together. Monoseptic operation with guaranteed continuous fermentation for a year at a time. What that meant was that nowhere could there be a hole of equivalent diameter to 1 micron. The sterile envelope didn't just consist of the fermenter, which is large and complex enough...the metal that went inside there weighed 600 tonnes, because there was something like 100 Km of pipe in there to inject the methanol, in about 20 000 different places. All internal to the fermenter envelope."

The reason for building a large fermenter of 1000 m^3 capacity was given by Marks (ICI),

> "It was 75 000 t/a, the thing that dictated that was, one, the relationship between scale and cost-effectiveness. Once (past a certain scale), you are not going to get any more cost benefit form it, no matter how big you build the plant. So ICI took a point on that curve (price per unit production versus fermenter capacity) which was dictated by the fact that we'd run a pilot plant for many years at $45m^3$ and we wanted to go up to 1 500 m^3 and that scale up factor was the most comfortable that people were willing to take a risk on."

Bettley described how ICI designed the fermenter,

"They had in their midst quite a brilliant mathematician, who was able to devise a mathematical model for the ideal way in which a micro organism could thrive on methanol, which is toxic at any greater than very small concentrations. So what was necessary, they soon found out in the laboratory, was to feed a microorganism with a carbon limitation in order to achieve a high carbon conversion efficiency at very low concentration of the substrate, but with no restraints with regard to oxygen or heat transfer. Now that was a tall order and it really meant a new approach to fermenter design. And this fellow devised essentially the prototype of the pressure cycle fermenter, in which air is injected at the base and because of the very high head, there is a very high driving force to dissolve oxygen into the solution. Provided there is good mixing and it is present in sufficient concentration that organism can take up the oxygen very rapidly. It's getting the oxygen in that is the problem, always has been with fermenters."

The fermenter consisted of essentially two columns of liquid,

"A riser column of a mixture of gas and liquid and a descender column. Providing you keep on injecting air at the riser base then the power you put in is quite efficiently converted to circulating movement in the fermenter, which provides all of the power for oxygen transfer and mixing. So mixing was the other problem."

The mixing problem required more exceptional mathematics,

"Deguraniss, the mathematician, devised a modular concept in which the liquid would have to go through orifices such that larger bubbles would be broken up without forming very fine bubbles that would be difficult to disengage at the top. At the same time there was a point just below each orifice at which methanol could be injected and efficiently mixed."

The bubbles were therefore constrained to the optimal size for gas exchange to the liquid and for disengagement at the top of the riser. As the liquid-gas mixture approached the top the width of the riser increased so that there was,

"an enlarged area with baffles that I won't even attempt to describe because it takes too long."

In this area the liquid flowed more slowly, the shear in the liquid decreased and the bubbles coalesced and finally disengaged from the liquid.

Greenshields and Rothman (1986) remark that foaming was a problem in the ICI fermenter. This would have resulted from the bubbles of gas not having coalesced sufficiently by the time they reached the top of the fermenter, so that they did not disengage from the liquid. The orifices which were designed to constrain bubble sizes were probably redesigned to solve the foaming problem at the same time as the methanol mixing problem was solved. Bu'Lock (ICI & BP fermentation consultant) was most critical of these technical problems.

> "A major and very technical clanger...early on in the ICI scale up...it could have been anticipated from the small scale experiments, but it wasn't and it resulted in lots of work which normally you would have expected to have been done at the beginning. Now it had to be done half way through, many modifications to the fermenter were necessary, and it was already built. Ultimately, these were scientific oversights."

Warsop (ICI) described the main problem as poor mixing of methanol and water, which slowed the rate of fermentation in certain parts of the fermenter and Bettley described the technical solution,

> "I think it would be fair to say, and this is confidential to some extent, that they went from 1000 to 20 000 nozzles...from a large number to an even larger number...and that involved a lot of detailed work of cost optimisation; the cost optimisation comes in what techniques do you use for fabricating a nozzle, techniques for siting a nozzle and piping up a nozzle. And how to cut the holes and baffles...we looked at a whole range of fabrication technologies and put them together in a way that hadn't been done before."

However Bettley remarked that the plant was commissioned in 3 years, which was only 6 months longer than originally planned. He considered this to be a "fast track" performance considering the novelty of the technology involved.There was more novel technology in the design of the sterilising equipment (for sterilising the fermenter inputs), which was engineered to higher sterile standards than any achieved before.

> "When we first got involved (John Brown), we knew that we needed kill ratios of 10 to the power of 23. In sterilisers you can't in fact totally and absolutely kill all infections coming through. What you can do is to design for a ratio of how many come in and how many get through. And our ratio was about a million times better than anyone else normally attempts."

The complexity of the technology added to the reasons for building big.

> "It was recognised that there would be an economy of scale with such fermenters and in order to produce SCP in quantities to satisfy the feed market fermenters would have to be quite large. That would result in high capital investment and a demand that the plant should be kept running for very long campaigns."

The energy consumption was huge and added greatly to costs when the price of hydrocarbons rose in the late 1970s.

> "We had a 10 MW compressor pushing air into this fermenter. What we were doing was imparting the momentum equivalent to a Concorde moving supersonically...the same amount of momentum was in there...over a 1000 tonnes of liquid moving at 3 m/s."

8.7 Harvesting the Biomass

Harvesting was the process of separating the cells from the fermenter liquor. For the yeast and fungal processes this was relatively simple since yeast cells were large enough to centrifuge out of solution. They could then be spray dried and were ready for packing and sale[7]. Harvesting bacteria was a more difficult task because the cell size was so much smaller than that of yeast cells. ICI and Hoechst devised new ways to separate the bacterial cells from their growth medium. Bettley described how the ICI process administered a temperature and pH shock to the cells.

> "You can't just put them in a centrifuge or a filter, nothing will happen...they are about a micron and a half long and half a micron wide... So you've got to make flocs, which are perhaps 0.1 mm. The idea was that the temperature shock would open up the cells to some extent...and the pH shock would change the isoelectric point whereby the cell proteins would tend to coagulate...and the addition of acid and depressurising...meant a lot of the CO_2 would come out in the form of very fine bubbles together with the populated biomass, which would form a float."

This float was scraped off the surface of the growth medium in a sterile fermentation tank, degassed, centrifuged and then dried. It was this treatment of the bacterial proteins with acid, and then heat in the drying stage which rendered them almost insoluble in water. This

[7] In harvesting yeast and fungi, Peachey recalled that the main problem was educating engineers to design equipment such as the centrifuges for the minimum chance of infection of the biomass.

property was useful when the proteins were to be animal feed, when there was a need for feed to resist rain and wetting, but it rendered them useless as a human food protein. Thomas (ICI) commented that when ICI were working on human food applications of Pruteen, a major aim was to make the proteins soluble once more by hydrolysing the proteins with enzymes.

Hoechst were trying to develop human food proteins from their bacterial fermentation process from the beginning of their project and so tackled harvesting differently. A major additional problem, if the protein was to be used as human food, was the removal of the bacterial nucleic acids, for which Schlingmann (Hoechst) developed the "Schlingmann process" which Hoechst patented. Liesser (Hoechst) described this as,

> "This process he invented, very simple, much, much better than any other kind of way of destroying the nucleic acids that other patents did. He treated the cells with a methanol-ammonia solution, this opened the cells. The nucleic acids were soluble in the methanol solution, the proteins were not, so the nucleic acids could be washed out...We had 90% total protein after, compared to 70% before...less than 1% nucleic acids."

Hoechst and ICI discussed the possibility of using the Schlingmann process on the Pruteen biomass.

It was stated earlier that the gas-based processes had a problem with feedstock utilisation. Shell and Dansk Bioprotein achieved near 80% utilisation, but this left the question of what to do with the remaining 20% of gas. Hamer described the engineering possibilities.

> "Recycling the methane for reuse to avoid the low utilisation rates cost money, and you compressed a mixture of methane and oxygen. You can do this, but there is the possibility of explosion, you have to extract the CO_2, need to dry it...yes, you can, we worked on methane recycling, obviously, you can do it easily on the lab scale, but on the scale of a commercial plant...but all these costs..."

Because of the costs of recycling Dansk Bioprotein are apparently not working on recycling the unused 20% but instead either vent the gas to the atmosphere, flare the gas off or pass it on to another utility for use as a fuel. Their documentation states that,

> "Less than 20% of the injected natural gas injecte. is released to the environment." (Dansk Bioprotein 1988 p19).

The Dansk Bioprotein plant will incorporate centrifuging equipment from Alfa-Laval which is capable of separating bacteria from solution and so avoid the flocculation step. It is likely that these centrifuges were not available to ICI at the time the Pruteen plant was constructed. The centrifuges give a 10% dry matter concentrate which is then filtered to give a 30% dry matter suspension, which is heat treated and then spray dried. The Dansk Bioprotein spray driers incorporate scrubbers to minimise the release of microbial dust to the environment, a temporary problem with the BP Lavera spray driers that BP had to solve on site. Jorgensen describes the spray drier equipment manufacturers as having adapted to a "general trend" in demand.

8.8 Toxicology

The companies that built full scale plant wanted to be sure their products would be considered safe when they were ready to produce them. They had two major problems.

1 There were no standard government procedures for the testing of novel foods.

2 The microbial nature of the foods led to greater doubts of the safety of these foods compared to agricultural sources of food.

This made the toxicity testing of the products more difficult. Treeby put the cost and time that RHM was involved in toxicological and nutrition tests at £20m over 13 years. Swindall put the cost of toxicity trials at a third of the total research cost on the Pruteen project.

8.81 Test Design Affects conclusions on Toxicity of Product

An example of how test design affected results was the potassium (K+) deficiency of Pruteen.

> "For example...there is no K+ in Pruteen, but conventional feeds contain 1% of K+. We need a base in production, but the cost difference between sodium and potassium hydroxide is so huge

> that we use sodium hydroxide. This doesn't matter at all provided the mineral balance of the diet is adjusted to...have the same concentrations of both minerals. If no K+ is added to Pruteen it will fail to perform satisfactorily in feeding trials. This is very specific knowledge, but we convey it to potential purchasers and these precautions are normally taken."

A scientific conception of the product enabled ICI to forestall criticisms of Pruteen's performance.

The ICI toxicity and nutrition tests lasted 8 years. Swindall told how it was important that the product they had shown was safe was seen to be the same product that ICI produced.

> "As the process was perceived to change, either because of engineering requirements or nutritional reasons, we would carry out further toxicological tests to compare the new product with the old to demonstrate whether any significant biological changes had taken place which would affect product safety."

8.82 The Choice Between In House or Contract Testing

BP had most of its testing performed in independent research institutes while ICI did its tests in-house. Northgate commented on the BP strategy, "BP...set up vast animal and toxicological testing facilities at Vaagen Ingen, Netherlands. That was a small independent testing organisation, but by the time BP went in with its requirements it had grown massively. It was independent, despite other people's questioning of that. A no win situation, if BP had done it themselves they'd have been criticised, equally when they funded and built up a big independent laboratory...all new and massive facilities...you are talking about multi-generation chickens and pigs."

Private testing facilities were just not large enough to cope with the quantity of work that was necessary. ICI and RHM had an alternative strategy of developing a good relationship with the regulatory authorities and performing toxicity tests in-house. Swindall compared the effects of this strategy to the Hoechst method of farming out testing to other research bodies.

"They had to share out work to government institutions and labs, Hoechst not having the right expertise and so they were not able to discuss with the Universities how their product might be tested. A specific example was a series of tests carried out by the Institute of Nutrition of the Veterinary School of Munich. They included Probion and Pruteen in fish diets up to 70% as the sole protein source and showed a subsequent depression in the fish growth rate. This was published as a biological deficiency in the product, and it was the first publication on Probion. However there were 2 or 3 previous ICI publications which already admitted that about 10% addition to diet was OK for fish, but greater than 70% led to depressed growth. This was important because it established ICI's reputation for veracity. Also because the FDR would be receiving reports from their own institutions , not Hoechst, that were critical of the product. Bad for the government-Hoechst relationship."

8.83 A New Testing Regime has to be Established for Novel Feeds

The test regimes for the novel food proteins were recognised to be far tougher than those that agricultural foodstuffs had to contend with. Sherwood (1974) observed that the EEC Commission restricted the levels of copper and zinc allowed in yeast feeds, but made no such restriction for animal feeds in general. Another general observation was that it was common for soya and fish feeds to contain aflotoxins and levels of bacterial infection unacceptable in SCP feeds, which were effectively sterile. Saxton remarked that ICI,

"...did more for the animal food tests than are done for most human foods you eat. We were just thorough. The regulatory people around the world did not know how to test Pruteen. Most drugs, you look for a minimum of residue in tissues. With SCP you want a maximum."

ICI and BP were not simply negotiating test procedures in a neutral environment, they had to show that the assumptions behind tests for drugs were inappropriate for novel foods. Swindall stressed that the design of toxicity tests was critical given the absence of test protocols.

> "It all boiled down to this, that with a novel product you must look at it carefully before testing. If it differs significantly from conventional foods you cannot test it conventionally. You will get poor results, not due to the material's quality but due to incompetence in designing the experiment."

The RHM testing procedure was even more rigorous than for the animal feeds. Treeby described the differences between the two.

> "...it's easy with animals. You just give it to them and see what happens...Before you could get permission to test on experimental volunteers you had to show a much wider range of tests running through lifespan studies to many species, multi-generation tests, across a number of different species. At the time, not required anywhere else, but something we had involved ourselves in, was the whole teratological testing on the unborn. A series of tests that tried to chart the equivalent biological value of the food, in terms of the diet that a human being would have, not just a bulk building diet you might give to an animal...it's all very standard now...one of the things that come out of this project was to help the government define its set of tests for new and novel foods. Much of the Committee on Novel and Irradiated Foods has as its genesis the mycoprotein project. That is one other big benefit that I think has come out of this project for UK Ltd."

The benefit to RHM of this attitude to tests was a certain reputation with the government.

> "Having got clearance we could point to substantial clearance. And a reputation with MAFF that is substantial. And obviously that has helped our other food interests. We have shown ourselves to be a major, reliable, ethical food company, who is prepared to do with food the right things in the right way. Difficult to put a value on that, but I think it has a value."

With an established test regime for novel food products, it is easier for Dansk Bioprotein to test their product. Jorgensen (Dansk Bioprotein) described his comapany's approach to the Danish regulatory authorities as one of "negotiating for supplementary approval to Pruteen." In their documentation Dansk Bioprotein link the only completed toxicity tests done on their product by Steingass at the West German University of Hohenheim, to ICI's work.

> "ICI has produced bacterial protein basically from the same raw material...the results of Dr. H Steingass are in close agreement with results of an extensive experimental programme carried out by ICI in Germany and England and involving more than 300 000 animals. From this we conclude that Bioprotein and the ICI product are immediately comparable." (Dansk Bioprotein, 1988b p6)

Long term feeding trials have been started with a Danish feedstuff company, but Dansk Bioprotein are making an insignificant effort compared to ICI in terms of cost and time, because they are not having to establish the basis of the tests themselves. In addition, if they also succeed with their argument that their product is comparable to

Pruteen, they will have cut out research that was a major part of ICI's costs.

8.84 The Toxicity of the Substrate and of Nucleic Acids

There were two issues in particular that were important in the tests. One was the toxicity of the substrate and the other was the effect of nucleic acids on animals or human beings. Most managers believed that a pure substrate was desirable for an SCP process, the only exception to this was Payne who defended the Lavera process based on gas-oil. Even Peachey (BP) had doubts about using such a substrate, although there were no specific incidents for which SCP from the Lavera plant could be criticised. Peachey agreed that the Lavera product was safe, but thought that using a mixed substrate "wasn't the done thing." Selfridge (IFP) expressed these doubts,

> "When you introduce a new product into the human food chain I believe it is always necessary to start from well defined starting materials. And if there is a product that is not well defined, it is gas-oil. It is a mixture of products of different families and that poses great problems.[8]"

The nucleic acid problem was only a serious problem in Italy, where it was another issue used to attack the safety of Toprina and Liquipron.

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[8] It is interesting to note that SCP from Lavera was approved by the French government and consumed for 3-4 years by French farmers, but the Italian plants, based on the purer paraffin substrates were publicly attacked because paraffins contain tiny proportions of carcinogens remaining after their refining from the truly mixed substrate of crude oil.

There was a whole literature on human and animal response to different levels of nucleic acid intake, the problem being that the by product (uric acid) of nucleic acid metabolism causes gout in people if it is produced in large enough quantities. Payne commented that,

> "The famous problem of nucleic acids...that is a complete nonsense. Nucleic acids are already being metabolised by all animals. It may be a problem for direct human consumption."

Treeby said that UNPAG eventually set an advisory maximum of nucleic acid content for human food products of 2% by weight, a limit which was exceeded by all the novel food fermentation products. Hoechst solved this problem with the Schlingmann process, but RHM had a more difficult problem in that they needed to preserve the texture property of their product. Treeby likened the problem of getting the nucleic acids out of the cells without destroying the product to getting a car engine out through the grill in the front without opening the bonnet and he thought RHM had succeeded in doing this.

If SCP was used as an animal feed, higher nucleic acid levels could be tolerated because SCP would only be used mixed with other feeds. No extraction of nucleic acids was necessary. However, some toxicity tests were designed to examine the response of animals to high percentage SCP diets, and then toxic effects could occur. Bett (Shell) thought Shell had found something amiss with Pruteen,

> "...in the trials there was a major hiccup...there was a problem with Pruteen, it caused liver necrosis in chickens, due to the nucleic acids. We published this finding in an obscure journal

to avoid embarrassing ICI. For legal reasons we published. You know you pick a little read, second rate journal, you give the article an obscure title, no-one's ever going to find it. We talked to ICI about it, they had missed it somehow."

Marks (ICI) commented that,

"...there was worry about the acids in the company, but then we did a hell of a lot of toxicity trials to show there wasn't a problem."

8.9 New Opportunities Open Through the Development of Novel Foods Technology

As the companies built up their science and technology base in the pursuit of a commercial SCP process, other technical and commercial possibilities arose. Companies differed in whether and how they exploited these avenues. Whether or not they decided to develop such side issues, which were not strictly necessary to the development of SCP, there was always a legacy of fermentation related skills and expertise.

8.91 A General Contribution Towards the Development of Biotechnology

There was a consensus among managers that their SCP work had helped to develop the industrial skills and the projects that form today's biotechnology industry. Saxton, Peachey and Marks thought so.

Selfridge[9] (IFP) expressed the same view for biotechnology in France.

> "I believe that the development of SCP has allowed the development of biotechnology in France. Because many of the teams that were created at that time have gone on working. Biotechnology is a small world, and one person in ten has worked on SCP. It allowed the development of this sector by training people. From this time the manufacturers were looking to develop electrodes resistant to sterilisation, pH electrodes, electrodes for oxygen, etc, since oxygen was the main limiting factor in yield. A huge amount of engineering work, to create huge fermenters and sterile conditions...we learnt much about the scaling up of fermenters."

Hamer believed the Kuwaitis gained from their efforts to build up enough independent research expertise to be able to judge the various SCP processes on offer from ICI, BP, Shell.

> "They have not closed down what SCP really gave them. The research facilities still exist with the personnel and the expertise, they have a resource...They are now orientated towards making biosurfactants for in situ cleaning of large oil tanks. They would never have got into biosurfactants if they had not had the physical and the manpower situation on the ground."

Although the skills that the companies built up were seen to benefit biotechnology in a general way, companies differed in the way they

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[9]The researcher's translation

managed the skills that were left to them.

8.92 Shell - Biotechnology as a New Research Topic

Brewed (Shell) felt that a reorientation of research into the biotechnology area was a gain,

> "I'm not sure what, when you come to the crunch, what the experience gain was, more important was a feeling that...a knowledge that biotechnology was interesting. Not a bad word, quite a good word. SCP got us interested in biotechnology. It gave biotechnology a coat hanger...catalysts, enzymes etc. It could have gone the other way if there had been costs of £50m, they would have wanted to disassociate as rapidly as possible."

8.93 BP Runs Down its Microbiological Skill Base

BP project differed from the others in that few successful or continuing developments evolved out of it[10]. The idea that the BP board reacted against the idea of biotechnology was referred to in chapter 7, but it took some years before BP disengaged totally. Peachey and Northgate thought that after the end of Italproteine and the transfer of most of the R&D personnel to the BP Sunbury research centre, the biotechnology skills were progressively lost. The first effect was that a Biological Sciences group was set up to hold the researchers, many of whom had been seconded out to the Epinay research centre in

[10] Although many firms only entered the technology because of BP's example.

Paris. Peachey thought there 7 or 8 microbiologists in this group at the Sunbury research centre.

> "For a number of years we ran a much broader remit, with 2 or 3 colleagues at Grangemouth, but for the first 5 years a fermentation project remained. The remnants of the bacteria methanol process, we kept an interest in that. We were interested in a biopolymer, same as Shell had done. Then we got interested for a couple of years in microbial products...and fuel-ethanol, because all round the world people were saying, make fuel from renewable resources. So BP decided, we need to suss this out. We said, you need to do some research, and 2 or 3 years of nice interesting work followed. Still fermentation, but different systems. But in the last 4 or 5 years that has also gone."

The result of the research on fuel-ethanol was that no project was found to be economic. This left a dearth of possible projects that linked BP's core business to microbiology and by 1983 the position for biotechnology in the company looked bleak. Peachey described BP at that time as a company which knew where it was going.

> "BP Nutrition, doing nicely, no need for research. No easy niche for biotechnology, which was what microbiologists were now called. There isn't a BP biotechnology process. What do they want with surfactants? Enhanced oil recovery? Well, we have to compete against chemical products. We looked at enhanced oil recovery, but it's not on for the kind of wells BP

has. Only for watered out, shallow fields, where it doesn't matter if it goes wrong."

The Biological Sciences group was finally disbanded in 1987. Peachey was the last microbiologist and now has a literature monitoring role. She felt that if they licensed the plant tomorrow to Russia,

> "...perhaps we could get 3 or 4 engineers back, if we paid them enough. My God, they'd have to pay me a lot. After 10 years it's too difficult...They could have put it together again after 2 years."

After the liquidation of Italproteine BP had made the technical designs for the Sarroch plant into a collection which they still offer for sale at £100 000. Peachey commented on this collection,

> "The real innovations of the BP process were chemical engineering ones. The microbiology was relatively simple. But for those times there was the newest this, the biggest that. And a lot of that has still not been published, it still constitutes what BP considers it might still sell. The 10 volume tome. It's a pity, they would have been better to donate it to a sensible chemical engineering department 5 years ago. It would have helped biotechnology a bit...how the whole thing was set about, how you arrive at this absolutely amazing, huge plant."

8.94 ICI - Waste Treatment, Biopolymers, Genetic Engineering and the Creation of a New Department

The Pruteen project was seen by all ICI interviewees as the essential base from which emerged Biological Products, the existing base for biotechnological research and some of the former Pruteen researchers continue to work within this group. ICI were also vigorous in following up potential "spin off" technology. An example was the "Deep Shaft" project which Swindall described as,

> "...a Pruteen fermenter buried in the ground, using a multiple collection of organisms as a culture...which carries on a non-specific fermentation which has a high mass transfer."

Warsop (ICI) thought that Deep Shaft had been quite successful,

> "...about a 100 licensed. Now we do a little research to provide information to the licensees. The rights have been sold to another company involved in the effluent disposal business. Better to leave it to an established waste treatment company than to put in all the management time involved in learning about a new business."

Pickles saw Pruteen as having built up a team who then started developing other opportunities, one of which was PHB, polyhydroxybutyrate, used as a biodegradable plastic. Swindall and Smissen thought that this development began because Peter Harwin had done a PhD on PHB and brought this interest into the company, where it remained when Harwin left[11]. The PHB work has now been "spun off" into a development company called Marlborough Polymers.

ICI and Phillips Petroleum chose to experiment with the genetic engineering of their organisms[12] and the Israeli SCP researcher Goldberg called this the largest scale application of genetic engineering to date, (Goldberg 1988).

Marks described the ICI work.

> "The programme was implemented about 1978 when the main plant had already been built and people were only just realising what the implications of genetic engineering were...We did more research on that organism probably than any company has done on any organism. We understood it very well, its biochemistry, its physiology, and we found pretty early on that there were 1 or 2 things in the organism, which had they been the alternative, you would have seen an increase in the yield...So what we did was to establish a facility at Leicester University, the ICI Leicester Lab. It's still going. Where the genetics of the organism would be worked on. We also established a facility at ICI Corporate Lab, Runcorn, for

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[11]The technical link to SCP is that certain bacteria, especially hydrogen-utilising species, can be fermented to form granules of PHB in their cells if their growth is oxygen, nitrogen or phosphate limited.

[12]In the BP project Solomons (later head of R&D, RHM) was a project leader who wanted to begin work on the genetics of the BP yeasts. Peachey described the BP conception of where the research was going as very clear and difficult to deflect down odd alleys, although this was an attempt. After a year and a half Solomons left to join RHM, who would fund genetic research on their organism.

> genetics work on the organism. We also placed a contract outside with a genetic engineering company. In fact ICI succeeded in doing it...it was published in Nature in 1980, I think. This newly genetically engineered organism was produced. It never went into the commercial plant because it's one thing to produce it, another to test it."

Work continued on this organism into the 1980s eg Bull, Holt and Lilly (1982) report the successful transfer of an energy conserving gene from E Coli to the ICI bacteria. According to Warsop, even had a more efficient bacterium been used it would have increased dry mass yield by only 1-2%.

Bettley believed John Brown Engineering benefited from the Pruteen project. They had gone on to design, but not build, fermenters even larger than the Pruteen fermenter for other companies. Their biotechnology skill base had been built up in all the key chemical engineering skills; project engineering, sterile equipment design, instruments, piping and to Bettley (John Brown),

> "Effectively what that means is, you can wrap up all the technology in legality...but you can't take away people's experience. We have well over 100 people in this office with dozens of years of bioprocessing experience each, mainly starting with SCP, that have gone on to other things."

8.95 RHM - Process Control and Sensory Evaluation

Treeby saw the mycoprotein project as the vehicle which had brought process control into RHM.

> "Most of it started there, it was the need to control the particular fermentation process, an order of magnitude tougher than any other process, which was the basis of all that learning. That learning and those people who are now are applying it to other industries in RHM are guys who cut their teeth on the mycoprotein project."

Other techniques specific to the food industry were brought into RHM with the mycoprotein project,

> "The point at which sensory evaluation, as a front rank technique within RHM, and with it taste panelling, taste profiling, really started, it was this project, because we had to say, what will people think?"

8.96 Hoechst - a Third World Non-Sterile Fermenter, and the Use of Fermentation Skills

Uhde, the engineering construction company cooperating with Hoechst, suggested a 3rd world application of their SCP technology. This would be a non-sterile fermenter utilising a variety of natural carbon sources, such as sugar cane and molasses. The fermenter consisted of a paddle wheel in a transportable tub, to which the substrate and inoculant would be added. Then the fermented mass would be decanted and fed to animals. Liesser thought you could end up with a good quality yeast.

Uhde hoped that if it was run in 3 or 4 different places in the 3rd World they might get some orders. This project was again funded by the West German government,

"The whole unit was sold to the German Ministry of Foreign Development. They wanted to use this plant as a political tool. Their responsibility, not ours. They wanted to give help to sugar cane production on the upper Nile. And Sudan would have been the next step. You could move it from place to place as the harvesting is done and examine the conditions for fermentation in different places."

However the project was not a success.

"It ended in the first place. It was mismanagement and a wrong decision to give it to Cairo University. Because an Egyptian professor will never touch an engine like that. Never. Too academic. So it was a nice toy to look at, but it was never used...No, really, it was just built into the sand, so the next sandstorm that came along, it was not working any more...then they needed an air pressure gauge for something on a different plant, so they took it out...it was a very simple tool of development aid, that was misused."

The Hoechst pilot fermenter had been funded by the West German government partly as a means of exploring fermenter technology. From the beginning of the project Hoechst were using this plant to investigate fermentation as a means of producing enzymes, although the main purpose was always to investigate SCP production. From Liesser's impressionistic account it would seem to have been an unusually innovative project for its scale. If this was partly due to government intentions, it was also linked to growth in the biotechnology department in the late 1970s.

> "At that time the department of biotechnology of which Prave was head, was growing and we were thinking, we should not think in terms of only producing SCP, but to use this pilot plant for other purposes also. It could be used to break down the nucleic acids into their nucleotides, which could afterwards be used as spices. Another was lipids. What could we do with them?...We had a lot of different clever ideas coming from the chemists and microbiologists working on the unit."

Hoechst embarked on the same path that BP and ICI followed, for different reasons, of looking for alternative uses for the microbial biomass. They, too, produced proteins which could be used as gelling, foaming and viscosity increasing agents. They had a protein extender for addition to hamburgers and even began texturising the biomass through the development of a spinning process. They used the industrial contacts of two of their food chemists to approach Nestle and other food companies to find out whether these proteins were of interest. Just as BP and ICI had done before them, Hoechst found that there were always lower priced alternatives.

Liesser believed there had been some real fermentation spin-off applications in Hoechst's antibiotic business. Liesser doubted whether the aspects of tank design which were transferred would have taken place without the SCP project.

8.97 T&L - Advances in Fermenter Design

Cowen thought the outstanding spin-off from the T&L SCP project was the development of a new type of fermenter, the tower fermenter. It was,

> "T&L's money, my energy, that took it from being just a nutty idea to a genuine alternative method of fermenting. It is now in use commercially in the manufacture of things like vinegar, citric acid. And in Japan, many antibiotics. I don't claim personal credit for any of that, except that I was one of the catalysts, with Haydn-Davies and a guy called Garreth Morris. There are a series of key papers on the use of the tower fermenter for SCP, we got it to grow Aspergillus Niger as pellets. Basically it's a tube on end, you pump your substrate up at the rate it is consumed. A steady state reactor. The mathematics is fearsome and I don't pretend to understand it, but we had a chemical engineer who did. That work led directly to a lot of those commercial processes, not by us, but by those other people. In the overall sense, not the T&L sense, it had a lot of economic benefit."

8.10 Conclusions

8.101 The Social Construction of Technology

This chapter takes us beyond the debate about the synoptic model referred to in chapter 1 where the function of the research department is to "apply science" to a market need and so produce technology. In no company was innovation simply a matter of "applying" the basic science of microbiology to an industrial problem to produce new technology. The material of the chapter rather shows how technology has been socially constructed by the industrial scientists and managers of the R&D department.

In each example where there was technical choice, non-technical and technical concepts were being used by the managers to guide the construction of the technology. In the case of mixed cultures (8.44), aseptic fermentation (8.5), the tests required to "prove" the safety of the products (8.8), it was what constituted safe practice that was at issue. Selection of organisms on criteria of yield, growth rate, productivity and cell density (8.4), was a process of matching organism characteristics with economic objectives. The fermentation technology was a result of a combination of choices relating social and economic assumptions to what was technically possible or available, and in ICI's case partly the result of the belief that developing the fermentation technology beyond the immediate requirements of SCP would be of future benefit.

8.102 The Pattern of Selection

There is a pattern and a structure to the debates and the selection of the technology. This structure derived from social structures, that is of the company and its resource and the external environment, which directed the scientists to certain technical areas and certain debates, but not others. Shell, for example, had huge gas resources and Shell's ownership of this resource directed R&D to developing an SCP process based on gas, which presented them with a different selection of technical, social and economic choices to other SCP projects. Shell was not going to develop a methanol based SCP process, - no choice here for R&D and so the debate on pure and mixed cultures became crucial to them. In ICI, which had access to both methane and methanol, they could choose between the two and their choice of methanol was guided by the debate on mixed cultures, sterility, speed of fermentation, all technical criteria which have social and economic values.

8.103 Commercial Motivation Results in the Creation of New Knowledge

In this chapter it can be seen that commercial motivations led to the creation of technique and knowledge and hardware that did not previously exist. The examples range from the techniques for selecting organisms to the design of fermenters. In these examples there is reason to believe that academic microbiology would not have been cap[able of developing some of this knowledge. These reasons range from the simple matter of funding to the technical possibility of avoiding mixed cultures, which always exists for the academic microbiologist, but not the industrial microbiologist seeking to work within bounds such as those described for Shell.

8.104 People Form the Knowledge Base of the Firm

In chapter 1 there was some discussion of Teece' idea that the firm represented a knowledge base embedded inn a technological trajectory. Part of this thinking was that it was difficult for the firm to change its knowledge base, and that the technological trajectory served to define the firm's activity.

In this chapter it has been seen how the acquisition of people with microbiological skills and the integration of microbiological knowledge into the standard knowledge base of chemical engineering represents a shift in the firm knowledge base and the movement onto a different trajectory. As this shift took place many of Teece' characterisations of technical knowledge were evident. The most obvious one was how knowledge was transferred through transferring people, as Bettley commented (8.94), "you can wrap the technology up in legality but you can't take away people's experience," and in John Brown's case this meant that they were able to use the Pruteen experience to help them on other projects no matter what the legal agreements with ICI were.

Peachey gave an example which showed how the result of this transference differed from the combination of two sets of formal, written knowledge. Her role in BP was to educate the engineers. This involved working out when microbiological considerations should affect engineering design. The resulting knowledge is a selection from the two distinct disciplines that preceded. The process of selecting out the relevant parts of the knowledge bases can only be done by people. The creation of a modified firm knowledge base requires the identification and solution of problems not part of either the old firm knowledge base or the academic science.

8.105 The Value of an R&D Department

Treeby cited the stereotypical commercial view of R&D, to show that companies that spent money on R&D survived while those that did not, slowly withered. This is an example of a belief that leads to undifferentiated support of R&D activity, but Peachey described how each project run by BP central R&D had to be paid for by a BP business division and if a particular technical or scientific field was not able to contribute to current commercial needs, it tended to wither, as did microbiology. Sittingbourne people commented both on their academic freedom on the one hand and the unlikeliness of any project being developed on the other. R&D does not have intrinsic merit, but its merit depends on the detail of what it is doing and how this connects to the commercial activity of the company.

8.106 Physical Artefacts Embody Human Knowledge

The structure given to artefacts by people represents their thought in physical form. In a sense knowledge is transferred from people to the structure/pattern of things. Buying the artefact in effect buys embodied knowledge. This can then be changed, the knowledge can be increased. When Dansk Bioprotein bought spray driers, sensors and centrifuges, they were buying embodied knowledge that had not been available to ICI or BP. They needed accurate sensors for monitoring fermenter oxygen levels and spray driers incorporating efficient microbial dust removing apparatus. BP had had to redesign and modify its spray driers in the 1970s because they did not extract sufficient polluting dust form the exhaust gases[13]. It is difficult to see how

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[13]It would also be fascinating to investigate the reasons for the equipment suppliers innovations in biotechnological processes. At least in the case of spray driers, Jorgensen felt that the biotechnological "line" of research (we might say trajectory) had been established after the suppliers became aware of the needs of the

a company organised as a capital venture company like Dansk Bioprotein could have attempted to produce SCP 15 years ago, since they would not have had the in-house resources to produce their own equipment innovations.

The development of new technology partly depends on the embodiment of knowledge in physical form.

Of course new technology also consists of new technique and new knowledge. In the chapter it was seen that the new regulations represented technique developed from the toxicological work of BP and ICI. The thermo tolerant selection techniques that were finally developed and used by the Max Planck Institute represented more innovative technique. In both cases, Dansk Bioprotein benefitted from this knowledge, this time expressed in language.

Finally, in this section we have been talking about the social, economic and technical considerations which drive R&D, but of course it is the people involved who bring these ideas together. Throughout this chapter (and indeed the thesis), the comments of the managers show their enthusiasm for the project and their commitment to their objectives. They were not involved in "just a job" but often a creative process in which they were emotionally involved.

SCP processes.

CHAPTER 9 - PRODUCT CHAMPIONS AND PRODUCT PATRONS

Introduction

In the present research initial attention was drawn to the idea that there were project champions by the frequent references by ICI managers to the role of Hart in the Pruteen project. The idea of "champions" was then pursued in interviews concerning other projects, from which the idea of the "patron" developed. Chapter 9 is an analysis of what the term "project champion" meant to the interviewees and how the champion affected project development.

9.1 Product Champions, Product Patrons

Harwin (ICI) first referred to the influence of Hart on the Pruteen project as very important. When the idea that Hart was a champion of Pruteen within ICI was raised with other ICI managers they supported the importance of the champion idea and specifically of Hart's having successfully promoted the development of Pruteen. Smissen (ICI) thought Hart and the Pruteen project represented perhaps an extreme case where the champion was very closely personally identified with the project and its technology. He defined a product champion in this way,

> "...someone who works and fights for a project and takes every opportunity. He becomes identified with it. Most projects need championing or the inevitable difficulties will squash them into oblivion. They are needed from very early on."

There is an idea here that the emotional commitment of individuals is necessary to override difficulties that less motivated people would allow to end the project. This description also suggests that project difficulties do not have straightforward effects on a project; the significance of a "difficulty" has to be interpreted by managers and that interpretation depends partly on their emotional commitment to the project. The idea that particular individuals can decisively affect a project's development recurred in many interviews, here from R Pickles,

> "Who champions what is immensely important. Things happen because they are made to happen...not because they are right or wrong."

This comment also suggests that if there is a sense in which a project can be seen as "right or wrong" (good or bad for the company) that may not be sufficient grounds for its development to take place. Development only occurs because individuals commit themselves to a project, not because a project is self-evidently a good project for the company.

The idea of a champion and its importance has now impinged on the question of what motivates individuals, and champions. This was commented upon by D Swindall,

> "...guys like Hart want to move into an area of technology that's growing...or they get frustrated. His internal motivation was, he wanted to leave a mark. I argued with him often, but respected him as an enormous driver and motivator, a

leader of men. We were very targeted and very motivated, we had a great product champion...he motivated us."

Hart's personal ambitions involved doing something out of the ordinary, beyond the usual requirements of the company; to leave a mark. He was able to communicate his belief in the value of the Pruteen project to many of those around him, but he was seen as the origin of the belief, the motivator, which made him the project champion.

There is no evidence from the interviews that a product champion was someone who was easy to identify or consistently important at all stages of a project, or that there need be only one champion for a project. The next section examines some of the typical project features where individuals were able to make a personal contribution and so begin to become associated by name with a project.

9.2 The Contribution of a Product Champion

A champion was described as the originator of ideas, as someone who gave decisive support when a project might otherwise have closed down, as someone who by changing the organisation of the company enabled the project to develop. A project champion "emerged" the more frequently they were seen to have individually contributed to its success. These contributions can be characterised as the sort of contribution that the formal structure of the company could not guarantee. They are extraordinary contributions and so are linked to the names of those who made them.

9.21 Originators

Lord Rank (RHM) initiated and then protected the mycoprotein project for economic and philanthropic reasons. According to Treeby (RHM),

> "In truth, the real reason RHM got into this area was because its chairman Lord Rank essentially combined two views of the world. The first view was attached to the fact that he had something of a philanthropic view of life. He and the Rank family had made significant investments in various methodist charities at home and abroad. One of the areas that made an impact on him was what he believed to be an impending world food shortage, which he interpreted as a protein shortage...He had an emotional commitment to doing something about that. The other thing was that he was a very, very hard nosed commercial individual who appreciated that he had a series of flour mill investments...the likelihood was that they would be producing surplus starch. He was looking for a use for this starch."

Because of his authority in RHM Lord Rank might better be referred to as a project "patron." It was the use of this authority to favour the mycoprotein project that earns him his title of "patron."

Thomas commented on the effect of the patron's support,

> "It was Lord Rank's pet. It wasn't somebody at the bench writing a project proposal and saying, have a look at that, it was actually the chairman, his hobby horse, and once it evolved, once it got past a certain time, it probably took a great deal of guts to say, no more, back!"

Treeby not only attributes the origin of the mycoprotein project to Lord Rank but explains Rank's personal motivation, part of which was certainly non-commercial.

Lord Rank then approached the research department with his idea and the head of the department, Arnold Spicer, took it up with enthusiasm. J Treeby links Spicer's enthusiasm to his background.

> "...Arnold Spicer wasn't basically a scientist, he had a PhD but it was an honorary PhD, he was actually a businessman who had made money taking clever bits of science that no-one else seemed to understand and make them service a product requirement."

Lord Rank and Arnold Spicer then protected the mycoprotein project in its early stages and Spicer's part in protecting the project earned him the label of co-champion from Treeby. This same protective role was taken up by Edelman and Reynolds, the next research director and chairman of RHM.

Champagnat (BP) is referred to by many press articles as the originator of the BP yeast-hydrocarbon processes, (Laine and Snell, 1976). His name is also often referred to by managers recalling the start of the Toprina project. However Payne suggests that it was BP's desire to minimise his role in the early stages of the research that led BP to present Champagnat in this way. BP would see Payne as a non-BP scientist and therefore would not do his role justice. Payne would see himself as the general father of SCP, since it was BP's example that drew so many oil firms into SCP research.

> "From the very beginning I never patented my ideas, because if I had done so, I was afraid they would put it in a drawer and never go ahead with it. And they were afraid I would do so. One day an important person told me, we don't want a new Mr Gulbenkian, a Mr 5%, who claimed to have 5% on all oil produced in the Middle East. Then one day Champagnat wrote a book saying the idea came from him...he had never heard about microbiology before." (Payne BP)

The accepted BP version of the story has Champagnat as inventor of the idea when he was working on ways of dewaxing crude oil. This was the view of all those interviewed except for Payne. Payne believes that Champagnat had the idea from himself during a long luncheon after the successful conclusion of some collaborative work on biological waste disposal. Certainly both men were important to BP in the initial stages of the research.

The different views of BP managers and Payne are similar to academic scientific disputes over priority of discovery and derive from much the same motives of personal ambition and the desire to be associated with a success. Payne identifies himself as the father of SCP and feels that BP went to extraordinary lengths to minimise his role. Whether or not he is believed, his views are important here, because like the comments in the rest of the chapter they use the power of individuals to explain company behaviour. Payne believed that BP built a third research centre at Epinay, Paris, which,

"...was the idea of Champagnat. It was always important for BP not to depend too much on me. Hence Epinay...I have no resentment against that. I did not belong to the staff of BP, I was independent. You can understand that they wanted a separation."

Leivers (BP France) confirmed that any scientists who were not a part of BP would quickly be out of any project they were working on and claimed that Payne was of little importance after the first few years of the project. But she was also brisk in dismissing Payne's claims to have been the originator of the idea of SCP.

If Payne is right then BP "romanticised" the story of the origins of Toprina to retain the credit of discovery. This "origins story" is quite fascinating and appears to give an insight into how scientific discovery is made, reminiscent of the anecdote of Fleming's discovery of penicillin. This story recurs in many different articles, (See for example, Laine and Snell (1976). Payne' view is at least consistent with BP's desire to link themselves to the project and use it for publicity purposes, something they were keen to do in the 1960s. However BP managers and scientists like Peachey and Leivers did not see Payne as having played more than a minor role in the development of the BP projects. Payne saw that early role as critical and therefore his personal role as critical. There are different perspectives of Payne's importance from the BP managers and the independent researcher Payne.

9.22 Decisive Support from Product Champions

A number of projects would have been closed if not for the protection of a patron or a champion. Treeby describes how Edelman and Reynolds protected the mycoprotein project inside RHM.

> "These two guys shared the vision, that without being able to say exactly what the market would be, without being able to say exactly what the economics would be and why the hell they should be doing it, they had an innate feeling, or belief, that this project was different, was worth continuing. And they just protected it from all comers for 15 years. Nobody got near enough to cancel it. Had we asked the Board, "What do you guys think, should we continue with this?" They'd all have said no. Boards are the great bastions of conservatism, as you know. These two guys said, well, we just won't tell them."

Treeby did not consider this kind of behaviour unusual.

> "You go anywhere near the other big decisions and you'll find somebody who put themselves in front of it and said, "this is mine, you are not going anywhere near it."

Treeby used Pilkington and the float glass process as another example where the champion, Pilkington, defended his research against internal criticism and because Pilkington was powerful enough, he succeeded in protecting the float glass project.

This example shows how powerful individuals are able to impose their judgements over company rules and the formal decision-making structure. The fascinating question of what was their personal motivation remains unanswered.

The SCP project on carob bean husk substrate was kept alive by Chuck Finlay (T&L). Cowen recalled that,

> "I inherited a SCP project. I entered a situation with a new job where it was very clear that I could not stop it. So I tried to modify it. Certainly, scientifically, that was a successful strategy. Economically and politically the numbers don't change. No market for the thing from the beginning..."

The project eventually faded away, but,

> "...we could have decided that earlier, had Chuck not been such a champion. Almost as if you have to accept, when you run the personality cult, which is what we are talking about, that the man at the top, precisely because he is so dominant, precisely because he can get the funding, can be your champion, at the same time, will have his own pet projects, they may be non-runners. You just have to count that as part of the cost for the winners."

So the reverse side of the champion who fights for successful projects is the champion who retains hopeless cases, protecting these with his authority in exactly the same way as he can protect those that turn out to be successes. In this case Cowen believed that the carob project was evidently non-viable early on. He suggests that Finlay' personal motivation for retaining SCP was connected to his personal relationship with a Greek Professor, Mitracos, who was an expert on

Mediterranean agriculture. They were both of Greek extraction and scientific colleagues. When Finlay became head of research,

> "...one of the first things he did was to go and see Mitracos and more or less on a back scratching basis said well, OK, I'd like to put some money in here to help the University, what can we do?"

Finlay was adding a personal motivation to help a colleague or friend to his aims for T&L research. Finlay' view of how companies choose projects was as follows,

> "You see I think text book analyses are often too stereotyped. Things don't happen in companies according to strict rules...and we decide we're going to do this and therefore that happens...it doesn't! Its very often the players and the game - the players in the company decide these things and then the players change, personalities change, and companies really reflect the people who are running them."

The extent of T&L's help to the Greek university was the donation of some fermentation equipment and the loan of two technicians.

Hart (ICI) was an agricultural board director and important in the process by which agricultural division won approval for construction of a full scale plant from the main ICI board. Swindall described this process, "The critical days were in 74 and 75 when the capital expenditure proposals were made and there was a continual visitation of Main Board directors to Billingham. They came in their ones, twos, at monthly interviews, you are continually giving them the story, the background behind it, and it was orchestrated, John was the first butt of any questions, it was he who had to evaluate the pros and cons. So by 76 when the expenditure proposal went forward he presented the case which represented the majority of the views of the people who were working on the project. He represented those views to the Board, all the presentations from 74 onwards."

Hart was crucial to the development of Pruteen by his real interest in all aspects of the project. Swindall commented on how he took a close interest in the toxicological research for which Swindall was responsible.

"Hart was interested in our research. In 24 hours he would know the result of our meetings even if he wasn't present himself. He would get the staff to sum up results in a 5 minute conversation."

Hart's close interest partly explains the motivation of managers working on Pruteen. Hart did not have the authority to take an investment decision himself, but his enthusiasm and commitment to the project were thought to have helped persuade main board members to support Pruteen. Within agricultural division he would have been able to support and protect Pruteen, but there were no "life-threatening" obstacles to its development within the division.

Rothschild (Shell) made SCP research possible in Shell, according to Akinin,

> "...he of course came from a biological background and had a lot of contacts in the biological fields. His idea was certainly to upgrade the level of basic scientific research in Shell."

This he did by building up two research centres,

> "the one down at Sittingbourne was very much oriented towards enzymology, biotechnology, microbiology, biochemistry, and yes, he saw obvious opportunities for developing the biological sciences in Shell."

Work on the methane fermentation project was carried out at Sittingbourne. Rothschild was described by Akinin as taking a close personal interest in the SCP project, as encouraging it. But he played no part in the research decisions themselves, nor was he needed to protect it within Sittingbourne, as a research project. Managers disagreed on whether he was a champion or if there was anyone who championed this project. When asked if Rothschild was a champion, Akinin agreed enthusiastically. Bett had doubts about who was a champion and linked the need for champions to the time when a project should leave the research stage,

> "they will only allow you to nurture a project for so long before they begin to ask questions...we had to find a home for it...a lot depended on having champions. I suppose Rothschild was one, but you need to have one at a lower level. Probably no-one after Rothschild. Even if Rothschild had been here he would have asked questions. He was in no position to authorise investment in any case."

So Rothschild was critical in creating an enabling environment for SCP research at Shell, but he wasn't seen to commit himself personally to its development. He can be seen as a "partial project patron," and this example demonstrates that many personal contributions are necessary for any project.

9.3 Loss or Replacement of a Champion

Sometimes the champion would move on from a project, sometimes the project would be closed despite his personal involvement and he would leave. Lewis (Shell) was certainly identified with the Shell project but was unable to stop its closure. According to Lewis,

> "I left because I had fought so hard for the project, I was known as Mr SCP. If SCP did not exist, it was rather hard to maintain that existence. I left because there were no career opportunities within the company. They treated me, always extremely well, I could never complain about salary, but where do you go?"

Lewis should perhaps be seen as having the commitment but not the authority of a champion. His being so closely identified with a failed project gave Lewis some career problems, since he was unable to convince the company that he was more than just an SCP specialist and worthy of promotion. In order to progress he felt he had to leave the company. This was not an easy option, because of what he described as the attitude of academic institutions to Shell,

> "Whenever I applied for a job in the academic sector people said, you can't possibly want to come here, the resources you have are second to none in the world. All you are doing coming here is to get us to give you an offer so you can bid up your salary. They wouldn't even make an offer, (the academic institutions)."

So Lewis found it very difficult to escape SCP. John Hart was also someone who was widely perceived to have suffered from the failure of the project with which he had come to be identified, with one manger from outside ICI commenting that,

"John Hart carrid Pruteen through and when it failed, he got it in the neck. He was booted out on his backside and made the President of the CIS. If you speak to John Hart now, he'll say, it was the right decision. Because without it, ICI would not be in Biological Products. Yes it's true, people sponsor absolute lulus."

Harwin thought that Hart had had ambitions to become a main board director and that he had thought the success of Pruteen would ensure his success, so if Pruteen had succeeded Hart might well have remained in the company. The identification of a personality with a project appears to tie the career of that individual to the project very closely.

The T&L carob project gives an example of the converse: a project dying away when the sponsor moves on to new tasks. Fraser Cowen had felt that he had no choice but to run the carob project he had inherited from his head of department, Chuck Finlay. He modified it so that it was a scientifically interesting project for himself and his staff, but,

> "What really happened to SCP was that long before T&L said we are closing down all this it died the death anyway. The champion in the shape of myself was busy doing something else."

He was sure that the carob project would have gone in the great squeeze on research after 1979, but it happened anyway because,

> "the man who took over from me with responsibility for the fermentation project was a guy I had recruited, Renton Garoffalo, and Renton was a different kind of microbiologist from me. He had come from Glaxo...he was left with SCP. He de-emphasised it rapidly. He had to finish his commitment, he did a fine job on the Belize project, writing it all up...I was not going to be a scientist any more so he imposed his own research thinking. Within Chuck's framework. Renton was picking up the leftovers, and the last thing he wanted was SCP."

According to Cowen the great research run down in T&L prompted Finlay, the champion of the research diversification policy, to leave the company,

> "...Chuck Finlay left a year later, a consequence of this surgery, since he had been the champion, and since people like me had already gone, I think he took the view that he would take honourable retirement."

9.4 The Social Context of Champions

Managers modified the prominence of the champions they were describing by accounts of the network of advisors they used, part informal and part formalised. Hart took an unusually close interest in the research on Pruteen, but he also had a more formal network of advisors. Marks (ICI) spoke of this,

> "There was a team advising him, he had a team of people on all aspects of the project. They met regularly to discuss it. He took a very, very close, day to day interest in the project. So he was not making decisions in isolation, but on the basis of what he was told by research, business area, economics, engineers, everyone."

Arni (Cellulose Attisholz, see appendix 1) also referred to the need for good supporting advice to the key person when talking of the founder of Cellulose Attisholz, Dr Sieber. He contrasted this to the possibility that a group of shareholders could have made the same decisions as Sieber,

"...you need someone with the foresight, who is influenced by others from R&D and marketing. But the man at the top has to choose the right people to have around him. Needs a vision. It is possible that a group of shareholders could have chosen someone as good as Mr Sieber..."

The quality of the group advising the champion is important. Few of the decisions of the champion will be uninfluenced by those around him, even if these advisors have less prominent names and lower profiles.

The importance of the champion's social context erodes the idea of the champion as a unique and remarkable individual. It suggests that the champion can also be a collator and a centre for the exchange and sorting of information rather than a "heroic" leader forging decisions from his own resources.

9.5 Concluding Comments

Projects are only given form by human action and that action is taken by individuals. Product champions are managers who become personally identified with a project, perhaps because they exceed the expected level of commitment. Patrons are likewise identified with a project because they use their authority and power in the firm to encourage its development and to protect it.

Product champions are important not only at the "giant project" level, as with Pruteen. The case of Cowen and the carob bean project suggests that there is often a degree of personal support required for a project to continue on the experimental, low cost level and that this will vary depending on who is in charge of a group of projects or a department.

Champions are probably better thought of as "emergent," that is they cannot be said to be champions other than in connection with a particular project. On this project they come to be seen as stronger champions the more frequently they use their influence to advance the interests of the project. So the process of becoming a champion is a gradual one which requires that the project advances within the organisation and that the champion continues to give support for the project. There can be intermediate levels of commitment and "partial" champions.

However Swindall (ICI) referred to Hart as a personality type who would look for a project to champion. There would seem to be two reasons for a manager developing into a champion. One is the Swindall view, that there is something fundamental about the champion-to-be's character, for example a high level of personal ambition. The other is that the champion's world view or, in Weick's (1979) terms, his causal map differs from other members of the firm. This cannot be entirely separated from the "character" idea, since personal motivation will be necessary if the champion is to fight for his world view within the organisation. It is in the champion's causal map that we can expect to find the reasons for the champion's selection of a particular project to champion.

The champion is committed to a project because they see that project as high value compared to other projects. The commitment follows from the high degree of match between the champion's rules of thumb for the selection of a successful project and the agreed characteristics of the project. Because other managers have different causal maps, ie different selection rules for high value projects, they are not the champions of this particular project.

In the case of Hart we can list three stylised beliefs that predisposed him to choose Pruteen to champion. These were,

1 methanol would become an alternative world chemical feedstock to ethene with consequent long term drop in price

2 a protein crisis would develop in the long term as protein demand outstripped supply

3 fermentation technology was a key part of the developing cluster of biotechnologies and the development of an early lead could lead to huge business opportunities for ICI in the future.

Some of these were common to other managers, but the combination was unique. We can also add the one personal motivation that has been identified that led Hart to commit himself to the propagation of his world view and his choice of Pruteen.

4 A desire to become a member of the main board which required him to have been seen to have made an extraordinary contribution to the company's welfare.

Many other criteria exist which affect the champion's thinking, but most will be common to many other managers, eg a background training in microbiology, an acceptance of commonly available market size estimates for the new product, soya market, a knowledge of how a project is perceived by senior management.

However these are arranged in the champion's causal map in a unique or at least rare way. In these four stylised beliefs and personal aims we have the beginning of an analytical understanding of why Hart emerged as a champion of Pruteen.

This explanation does undermine the idea that champions are solely personality types and the related idea that they could be selected by psychological testing and then given a project "to champion." It allows for the "emergence" of champions as a project develops that fits with their picture of the world and their personal ambitions. It is also compatible with Elger's (1975) picture of the organisational world as based on a micropolitical process where the champion is seen as a champion only when he tries to convince others in the firm that his way of seeing the world is right, or better than the alternatives. This view also gives us an insight into the difference between champion success and project success. A successful champion will have persuaded his company to develop his project, but that does not imply the project will be commercially successful. It only tells us something about the micropolitical process in the company. The project may go on to fail commercially and by doing so affect the champion's position in the company.

Weick (1979) also referred to this micropolitical process when he suggests how negotiation within the firm tended to homogenise the firm's view of the world, ie establish a common interpretation of events, a common causal map. Part of the evidence above is that this process is never completed, nor is it likely to be. It is evident from Harwin's comments and others that Hart's view of the Pruteen project was not shared by all managers, but they accepted Hart's view as one which was guiding their work. A shared causal map is not necessary for one causal map to come to dominate the organisation of a company activity.

This model of the champion's place in the firm makes it easy to imagine how projects would develop without a champion. Some of the conditions for the emergence of a champion are purely internal firm characteristics, for example the difference between the champion's view of the best selection of project and other views. These internal conditions might be absent, as it appears they were in BP. The example of BP suggests that when the highest levels of the company back a project from its earliest stages, individuals do not tend to become prominent at lower management levels. To a degree the champion exists because there is the opportunity for persuading sceptics, perhaps sceptical senior management of its value. If this is done successfully it gives him increased status and prominence within the company. The decision to develop Toprina was a board decision and required no lower level individual to argue and push for the higher levels to support the project. This view is reinforced by the prominence of Laine on the Toprina project. He was recognised as a high quality manager who went out of his way to do a good job, but he was not seen as a champion because he did not have to commit himself personally to defend or advance the project.

There is no reason to expect champions to be independent of company structure and culture, but too few examples have been studied here to comment on how these factors might encourage the emergence of identifiable champions. The comments of a number of managers stressed the importance of the social context to the functioning of the champion. For example, Hart in the social context of ICI, could promote Pruteen as the vehicle for the development of a strategic set of technologies. It is likely that such an argument would only be accepted in a company like ICI. We can extend that reasoning and suppose that many of the champion's beliefs will have been formed through a process of socialisation within the firm.

9.51 Champions and Patrons in the Innovation Literature

The understanding of the product champion outlined above and summarised in the figure 9.1 can be contrasted with the "heroic" entrepreneur model of innovation development. This idea has been referred to as prominent in certain types of business and economic history in chapter 1. Schumpeter's "mark 1" model of innovation, summarised by Freeman (1982) also relied on this uncomplicated idea of human behaviour to explain innovation through entrepreneurship.

Without a prolonged discussion of the development of this idea, probably related to rational concepts of the nature of man from classical economics, we can point to some major failings which have been partly remedied by what we might call the "organisational champion" model of the last section, ie the champion who works inside a large enterprise and who is partly formed by that enterprise. These failings are:-

1 The personal motivation of the entrepreneur is simply the desire to make a profit

2 How the entrepreneur comes to pick one innovation over another is not dealt with

3 There is very little attention paid to the "organisational entrepreneur"

In the "organisational champion" model there is both an explanation of how organisational champions select projects over others and a more flexible interpretation of why they champion these projects within the firm - ie their personal motivation can be related to internal firm factors.

The organisational champion model also implies a redirection of attention from looking for champions to place in charge of projects, to a study of belief systems and more effective ways of testing and refining these. It is project success that is most valuable to the firm and at a social level and we have found that the existence of champions is not unproblematically connected to project success.

The opposite of the belief in the heroic entrepreneur as the agent of innovatory change is framed by Gilfillan (1963), as one of his principles of invention.

> "There is no indication that any individual's genius has been necessary to any invention that has had any importance. To the historian and social scientist the progress of invention appears impersonal." (Gilfillan, 1963 p10)

This comment is made in connection with the observation that many key inventions appear to have been made simultaneously and independently by different inventors. This suggests that there is a common social evolution of technical problem for economies at the same stage of development and that often similar solutions will be proposed.

This view does not contradict the organisational champion model, which establishes a framework of why particular individuals become important on projects. It does offer us a guide to the limits on the champions possible causal maps of the world, a limit to the number of projects that could be supported.. All innovators, whether entrepreneurs or organisational champions or boards of directors, have only a finite range of choices open to them at one time. They are all involved in a sorting process, trying to find the characteristics of successful innovation. Gilfillan's comments return us to the idea of long term "trajectories," within which choice of projects is guided. The micropolitical process in the R&D department concerns the selection of the technical criteria which will guide project selection. The champion merely represents an individual with a deviant set of selection criteria.

If we return to the micropolitical process inside the firm, Freeman has referred to the use of forecasting methods and project estimates in such a political process.

> "Empirical evidence confirms that decision-making in relation to R&D projects or general strategy is usually a matter of controversy within the firm. The general uncertainty means that many different views may be held and the situation is typically one of advocacy and political debate in which project estimates are used by interest groups to buttress a particular point of view. Evaluation and technological forecasting, like tribal war dances, play a very important part in energising and organising." (Freeman, 1982 p167)

The use of such formal cost control methods is entirely consistent with a micropolitical process. This process gives rise to product champions. The case for firm-support of a particular project may never attain the status of a consensus, but support may be given because of the ascendancy of a champion or a coalition of interest groups.

However there has been some writing on product or project champions that has implied that they are a necessary condition for project success. For example one of the results of Project Sappho (SPRU 1972) was that commercially successful projects were linked to the activity of a champion more often than commercially unsuccessful innovations. This chapter has distinguished between success in gaining the support of the firm for a project, which is linked to the presence of a champion, and eventual commercial success which may or may not follow. The following is probably as strong a statement as is possible about project success and champions from the evidence here.

> "a necessary condition for project success is that a part of the firm with authority (board, patron or champion) believes in a project so that they will support it against short term set backs."

Our final comment must be that the concept of the product champion should be treated with care. If a project is successful, someone will have had to involve themselves in it - but are they a true champion? The "champion" is the extreme case where one individual makes an outstanding contribution to the fight for a project inside the firm, but individuals are always making contributions towards projects. Projects are selected and developed through a micropolitical process in which the reasoning and belief system of those taking part is more important as a guide to project commercial success than the question of whether there is a champion or not. If a project has a convincing logic behind it there will be no shortage of "champions" willing to support it.

Fig 9.1 PRODUCT PATRONS AND CHAMPIONS

- patrons may use their power in a company to advance a project, they take "personal interest" in a project
- champions commit their time and careers to advance a project by persuading others in the company that it is worth supporting
- champions and patrons are identified with a project because they work for it more actively than is expected
- they are seen to be personally responsible for advancing a project and gain or lose personally with the project's commercial success or failure

Reasons for a champion's personal commitment

- personality - they may have personal ambitions or personal reasons for their commitment to the project
- their personal interpretation of the project's nature and value to the company (their causal map) may differ from their colleagues' interpretations

Nature of a champion's belief structure

- "belief" in a project, or level of personal commitment mediated by rules of thumb and selection rules which constitute their causal map
- the greater the matching between the causal map rules of thumb and the project's nature, the greater the personal commitment to the project

Champions are emergent

- they do not necessarily exist as "personality types" before being linked to a particular project ie they emerge as champions as a project continues
- they need not be dominant throughout life of project
- there could be several outstanding and identified personal contributions made to a project in its lifetime, or one, or none
- if the value of the project is widely accepted in the firm then no individual may be outstanding in their commintment to the project, hence no champion
- selection and championing of projects is part of the continuing micropolitical process inside the firm

Morals of the champion phenomenon

- a wide range of potential projects can only be conceived, or brought into the firm for discussion by individuals with diverse ways of seeing the world, ie a diversity of causal maps
- belief in a project by the board, a subgroup within the firm or a champion is a necessary condition for the project to be developed by the firm, irrespective of commercial success or failure
- it is the quality of the reasoning behind the selection of a project that is related to its success or failure
- commercial success or failure is part of the feedback process that leads to modified causal maps and a different range of belief structures within the firm
- these modified causal maps lead to a change in the prospective future selection of projects and champions

CHAPTER 10 - CONCLUSIONS

Introduction

This chapter begins as an examination of the findings of the thesis as a whole, a review of some of the major chapter conclusions and an exploration of some of the connections between these and the literature referred to in chapter 1. In 10.2 there is development of a general model of innovation within the firm which is consistent with the findings of the thesis and which is linked to some of the features of the macroeconomic models of technical change which were discussed at the start of chapter 1.

10.11 Methodology

Insights have been gained in this study which justify the choice of novel food fermentation as a case study and the use of semi-structured interviews to explore it. It was possible to allow people to describe how they constructed the technology in their own words and so the managers own priorities emerged. The use of early interviews to condition later interviews allowed a focus and then investigation of issues that the managers themselves raised and the analysis retained these priorities.

The material that was gathered was very rich, and this richness is retained in the thesis and reflected in the many items and themes which appear, but are not developed, for example the recurrent themes of politics, (4.7, 7.3, 4.133), government influence, (appendix 1 and 2, 4.7), management emotional involvement in the projects, (4.82, 7.61), national culture, (8.96, 4.7). These issues were not found to be common influences on innovation and so do not command chapters of their own, but appear scattered throughout the thesis as secondary issues. The pattern in the material is a result of the focus on how innovation occurs in the firm, with a different focus other material would have been collected and comparative analysis would have yielded different categories addressing other issues.

10.12 The Reference Market

The principal concept to emerge from chapter 4 was the idea of the reference market, (4.8). This came as a result of probing into how the market for a novel product can be conceived by management before the product is actually marketed. In the case of SCP it was seen that the market was basically the existing market of animal feed but with additional "elements of understanding" added to define the market for novel proteins. Hence the idea of the reference market, a market which already exists and approximates to the innovation market, but which requires modification to fit the innovation exactly. It requires the attributes from existing market concepts (there may be several) to define the idea of the new market and in the case of SCP, the attributes of the animal feed market were used to structure the new technology. This idea of the reference market could have general validity.

10.13 Competition as a Socially Negotiated Concept

In chapter 5 we were looking for examples of how firm competition and cooperation influenced the projects. What was striking was the lack of a clear mechanism by which the idea of "competition" could influence the projects. There was no straightforward "cut throat" market share competition in SCP development, rather competition occurred at the same time as cooperation did on other issues, (5.1). On specific issues companies would compete and be secretive, (5.31), on others they would cooperate. Managers were having to negotiate an understanding of which of their activities should be secret, which could benefit from cooperation, (5.33). These are grounds for thinking that what is thought to be of competitive significance is a matter for negotiation and interpretation.

10.14 Firm Culture and R&D

The idea of firm culture gathered together those values that served to characterise a firm and its approach to the novel fermentation projects were not part of the formal structure of the firm, (6.13). The background training of managers and researchers was perceived to influence how they approached the project, (6.2) and to characterise the firm as a unit. There was also a perception that different firms approached projects with similar technology in different ways, (6.32), based on their industry of origin and firm experience.

The R&D department's perception of its role within the firm varied greatly between the firms. A common theme was the tension between the clearly commercial objectives of the firm and the perception that the R&D department had of itself as having a long term role and responsibility for the future development of the company. The latter was always the case, whether the commercial side of the firm accepted the view, (T&L, 7.1), or not (Shell, 7.2). The boards as a group controlled R&D and projects financially, and their understanding and judgements of the commercial value of the project was conditioned by the information they received from R&D management, (7.4). The boards did not make the choices which brought the technical and commercial objectives together, (8.41) but they could sponsor and back a project, (7.7) as could a single patron, (9.21). Sponsorship was evident within lower levels of management, with the emergence of product champions, (9.22).

10.15 Technology as a Form of Socially Structured Knowledge

In this chapter the technical choices necessary for the projects were examined. They were found to be closely related to commercial and social considerations, (8.41), so that managers and scientists were giving structure to the project technology. For example, the technical design options for the fermentation plants were not unique and obvious, but they had to be negotiated and defined by the managers on the projects, (8.5). The resulting different technical approaches taken to plant design within the different companies showed that there were many ways in which the technology could be given structure by the firm. Structure was given to technology by drawing on firm culture, strategy, conception of the market, the technical base of the firm and even influenced by the background and experience of certain individuals, (8.6). Another way of phrasing this idea of giving structure to technology is to say that the technology is socially constructed.

10.16 The Process of Innovation

The chapters as a whole support the idea that the process of innvoation is one where market and technical considerations are brought together to structure new technology by the managers of the firm. Chapters 4 and 8 together show that managers obtain their ideas of what is technically possible from the technical base of the firm while their market idea are selected form a range of existing market concepts. It is the assembly of these ideas that defines the project.

However, the selection of these ideas is conditioned by other influences, such as the culture and structure of the firm and the competitive environment. These form the framework within which the process of matching technical possibility and market need continues. In chapter 1 reference was made to Gold's criticisms of the synoptic model of innovation and how it was an oversimplification, (1.51). In this thesis it has been shown that the process of innovation is complex, but comprehensible. It is complex because there are multiple influences on innovators, but understandable because categories can be developed to permit analysis, as has been done in the thesis.

The process of innovation could be put in terms of cognitions and cognition classes. The idea that people use their own theories to interpret and understand the world was discussed in 2.2 and in 2.4 Turner, (1981) suggested that theory generation is a process of assembling new cognitions into a coherent framework. The process of innovation as described above can be described in terms of these two ideas. Innovators continuously select cognitions from the market and technical base of their firm and continuously create a coherent project, whose technology will link technical knowledge to market need. They are aware of constraints on their freedom to do so, in terms of cognitions such as elements of firm culture, structure of the firm etc. This argument is expanded in 10.2 to form a model of the innovation process in the firm based on people.

Finally, this thesis has been a study of what the innovators say, how the scientists and managers who work with innovative technology see their own work. No historical study, no set of graphs could portray so clearly that technology is created by people.

10.2 A Micro Model of Innovation within the Firm

The conclusions in 10.1 can be further developed to provide a micro model of innovation in the firm based on an understanding of technology as socially constructed knowledge. The argument will be that the process of social construction of technology is one of assembling cognitions, which are ideas, into coherent groups, where coherence is judged by rules of thumb which come from experience.

10.21 People are Cognitive Theorists

In chapter 2 we adopted Weick's view that individuals had to model the world around them which meant that each individual has, to an extent, a unique understanding of the world. Individuals act as their own theorists since they are continuously engaged in interpreting new events by their old understanding, or in Weick's language they enact their environments and select and retain in their causal maps events of significance.

In chapter 2 it was claimed that this model required the idea of units or elements of thought which were referred to as cognitions. Cognitions are the single events or objects which are enacted by the mind and a selection of which make up the causal map.

Fig 10.1 shows how a cognition can simply be an object, a spray drier. As an idea in the head it doesn't matter whether this is represented by the word or an image or something else. The "cognition" is simply the linking of some mental device to the physical object. What is then

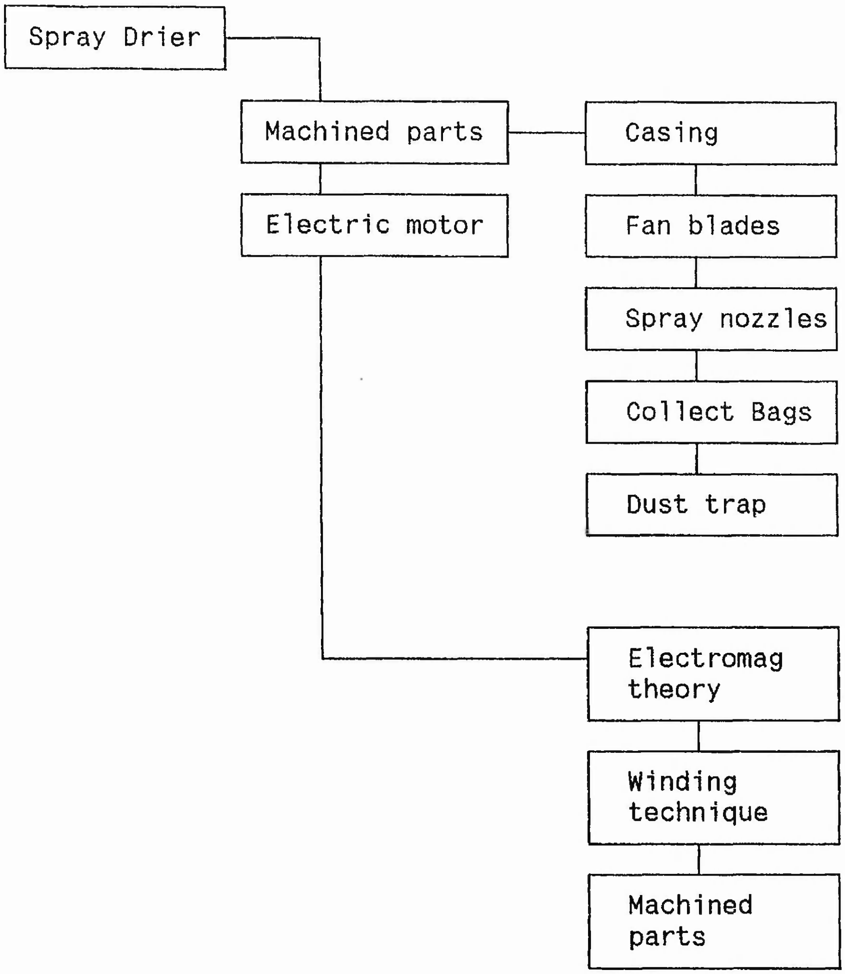


Fig 10.1 Cognitions as elements of thought.

The cognition of a spray drier can be broken down into other cognitions. As a physical object the spray drier embodies the knowledge represented by all these component cognitions. This diagram shows two of the properties of cognitions,

1 Cognitions can contain varying amounts of knowledge

2 Cognitions can refer to physical objects or technique

done with the cognition depends on social activity in which people using it are involved. A manufacturer might have a mental map of how the spray drier can be broken down into constituent cognitions, as shown in fig 10.1, while an SCP plant designer would be aware of what the spray drier could do related to the other parts of the SCP process, but not how to manufacture it; so different individuals link cognitions in different ways, depending on the social situation and the cognitions and their linkages represent knowledge. This is little more than a restatement of Weick's (1979) view, only here there is stress on the discrete components of thought which make up Weick's idea of a causal map. Some of the later arguments will involve using cognitions as representatives of technical knowledge, so it will now be necessary to define technology in terms of knowledge.

10.22 Technology

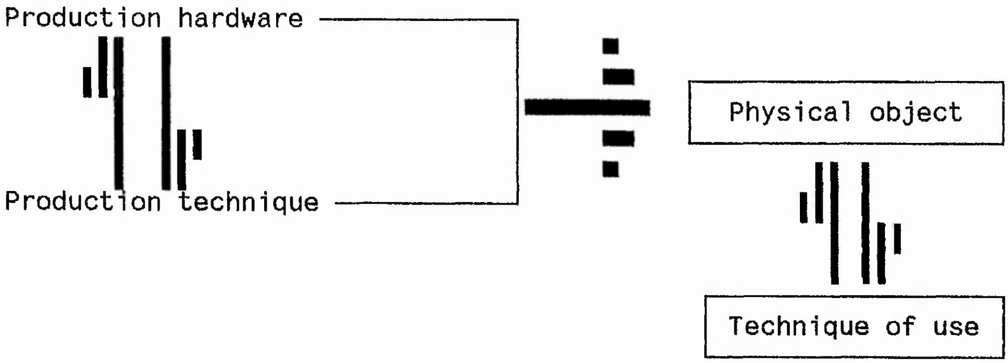
A simple definition is that technology is knowledge related to some physical object, or more precisely, it is the socially conditioned knowledge of use of an object or tool, that is to say technique. So even "simple" objects like a table or chair require people to have the knowledge of how to use them, which is a part of a social culture, (aborigines or Japanese would not know what to do with a chair before learning from the culture that produced them). If an object were of biological origin this definition would suffice, but most objects in our environment are manufactured, which requires production technology. Production technology consists of the production hardware, eg machine tools, and, once again, associated knowledge of use, or what can be called production technique. It is technique[1], (socially conditioned knowledge of use), and production technique, (socially conditioned knowledge of use of production hardware) which is "socially owned" in the form of causal maps consisting of linked cognitions. However manufactured goods and the associated production hardware also represent knowledge, because they have been given structure by people with the purpose of relating these products to people's technique, ie people's knowledge of how to use them. This knowledge can be thought of as "embodied" in manufactured objects, or represented in the structure given to these objects, (See fig 10.2).

10.23 The Firm Defined by its Technology

In chapter 1 we used Teece's definition of the firm as an organisation which could be defined by its possession of specific technology related to a technological trajectory. The reason this ownership of technology defines the firm is because firms rarely change their technical base and prefer to exploit technical opportunities where

[1]Technical knowledge has a tacit component which makes its transfer difficult by oral or written means and so it can only be partly acquired through the purchase of production hardware and the associated manuals. It tends to be more easily transferred through the transfer of people who have technical knowledge. Just as the aborigines would have had trouble learning how to use chairs from a manual written by someone with tacit knowledge of the social circumstances of western use of chairs, the technical manual is written by someone who has the tacit knowledge of use of an artefact. The knowledge that is not communicated in the manuals is tacit. This is quite a simple characteristic of technical knowledge, as anyone might agree who has tried to describe to another how to perform simple technical tasks, such as how to change a bicycle derailleur. There may be several tacit rules which go unexplained for every instruction in a manual. These can be learnt, through practice, or by an extraordinarily thorough manual - I am assuming that tacit knowledge has the potential to be transferred through language, although the task becomes increasingly difficult as a shared vocabulary dwindles.

Technology is knowledge related to a physical object; it is the knowledge of how to use a specific object.



Manufactured objects are given their form through the use of production hardware and technique. These are then used by people who have the necessary technique of use.

Fig 10.2 Technology as Knowledge

they already have specialist knowledge.[2]

In fig 10.2 the definition of technology in terms of knowledge is combined with the definition of the firm in terms of ownership of production technology. This diagram shows how production technology resides in the firm while the knowledge of use of the product is possessed by those who make up the market. The individuals who make up the firm carry and express all the beliefs, values, cognitions and rules that have been described by the preceding chapters and these systems of belief are linked to how the firm organises itself around its production technology.

10.24 Technical Innovation in the Firm

So far we have described how technology is knowledge which partly resides in physical form and is partly possessed by the individuals who make up firms. Now we need to look at the why technical innovation occurs and how it happens.

When the firm is the principal unit of social ownership then technical innovation will only be introduced when it serves the perceived interests of the firm.[3] Technical innovation is a means to these social

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[2]The difficulty of changing the technical base of the firm is due to the cost of acquiring new production equipment and the cost of acquiring new technical skills, which are partly tacit in nature, (see chapter 1). Firms therefore tend to "stick" with a particular set of technical skills and physical production hardware.

[3]"Firm interests" could be said to be the non-technical, "social" objectives of firm survival, growth and profitability. These interests have to relate to the interests of the individuals in the firm whose support of such "interests" is likely to be conditional and to vary between individuals

ends and will not be made to happen unless it is perceived to serve these ends. This perception may govern the support of innovation, but actual innovation may have unintended consequences and will not necessarily benefit other social groups (it is certainly not meant to benefit rival firms), the wider society or even the firm itself. In addition, the creation of the specialised R&D department highlights the problem of how to choose projects that best meet the perceived needs of the firm, and introduces the possibility of the R&D department selecting projects for internal, departmental reasons[4].

The one common social constraint which may encourage the firm to adopt innovations of benefit to those outside the firm is the position of the firm in the competitive market system, which separates the firm from control of its market. This should result in the firm tending to introduce technical innovation which it believes will benefit user groups.[5]

The question of why the firm should innovate has been discussed and it has been said that innovation is made to happen when individuals in the firm believe it will bring them benefits, which may or may not be the same as benefits to the firm as a group. The innovation process itself

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and sub-groups in the firm. Firm interests do not exist as unambiguous statements or goals, but they have to be related to courses of action. It is how the firm will achieve the aims of growth, profitability etc which is problematic and which is the subject of politicking within the firm.

[4]For example Shell's Sittingbourne R&D centre versus Shell senior management on the value of fermentation research, as well as all the other examples where projects were influenced for political reasons and reasons internal to R&D or sub divisions of the firm; T&L, Belize decision, Ag Division and ICI etc.

[5]This is perhaps the most exciting and valuable feature of the free market system.

will now be described as a process of socially constructing technology.

The personnel engaged in managing an innovatory project are involved in selecting the appropriate cognitions and rules of thumb to define the project in relation to the firm and the firm's objectives, and these cognitions and rules of thumb are drawn from a wide range of "cognition classes." These classes range from the environment and market to strategy, culture and the personalities of individuals in the firm. These are of course the classifications developed in the thesis. Cognitions from any of these classes may be selected as relevant to the development of the project by managers. the selection defines the project and evolves through time as conditions change and the project develops. The project definition has a degree of coherence between individuals because they negotiate a consensus on such definitions.

The project begins as something which is entirely a series of linked mental cognitions. As it develops and as the relevant cognitive relationships are brought together to enable estimates of the degree of social need for the new product, some of the mental cognitions are assembled in physical form. There is a process of buying in existing knowledge, such as that contained in, for example, a spray drier, where the cognition exists, but the company does not have the organised technical production knowledge to produce a spray drier. There is also the process of generating new cognitions and rules of thumb of which consists the new knowledge of innovatory products. These new cognitions and rules of thumb are developed as part of the project and added into the ensemble of cognitions which define the project.

The managerial process of selection of cognitions and rules of thumb can be related to our base definition of technology. In fig 10.3 the firm, product and market correspond to production technology, artefact and knowledge of use of the product. When the firm embarks on an innovatory project it is with a developing understanding of the likely changes in the market, which involves understanding the changes in how the product may be used. At the same time the firm must adapt its technical base to these perceived needs of the market. It is an iterative process of definition of the market-technology relationship, managers using a market definition to select the development of new technical routes and refining how the market will be affected by their choice of technical development. However the choice of technology and of market is conditioned by those other features picked out in the thesis, such as firm culture, strategy and government.

This is the process of technical innovation in the firm which combines the ideas of individuals thinking cognitively, technology as knowledge and the firm defined through its possession of production technology, to describe how managers develop radical technical innovation.

10.3 The Consistency of the Micro Model of Innovation with the Macro Level Features of Techno-economic Paradigms

The previous section has described a cognitive micro-model of innovation which deals with how projects are selected and defined by the managers within the firm. It is based on the idea that technology is socially constructed, which is not a new idea but which in the thesis flows naturally from the material and the way it is presented. It is rare to

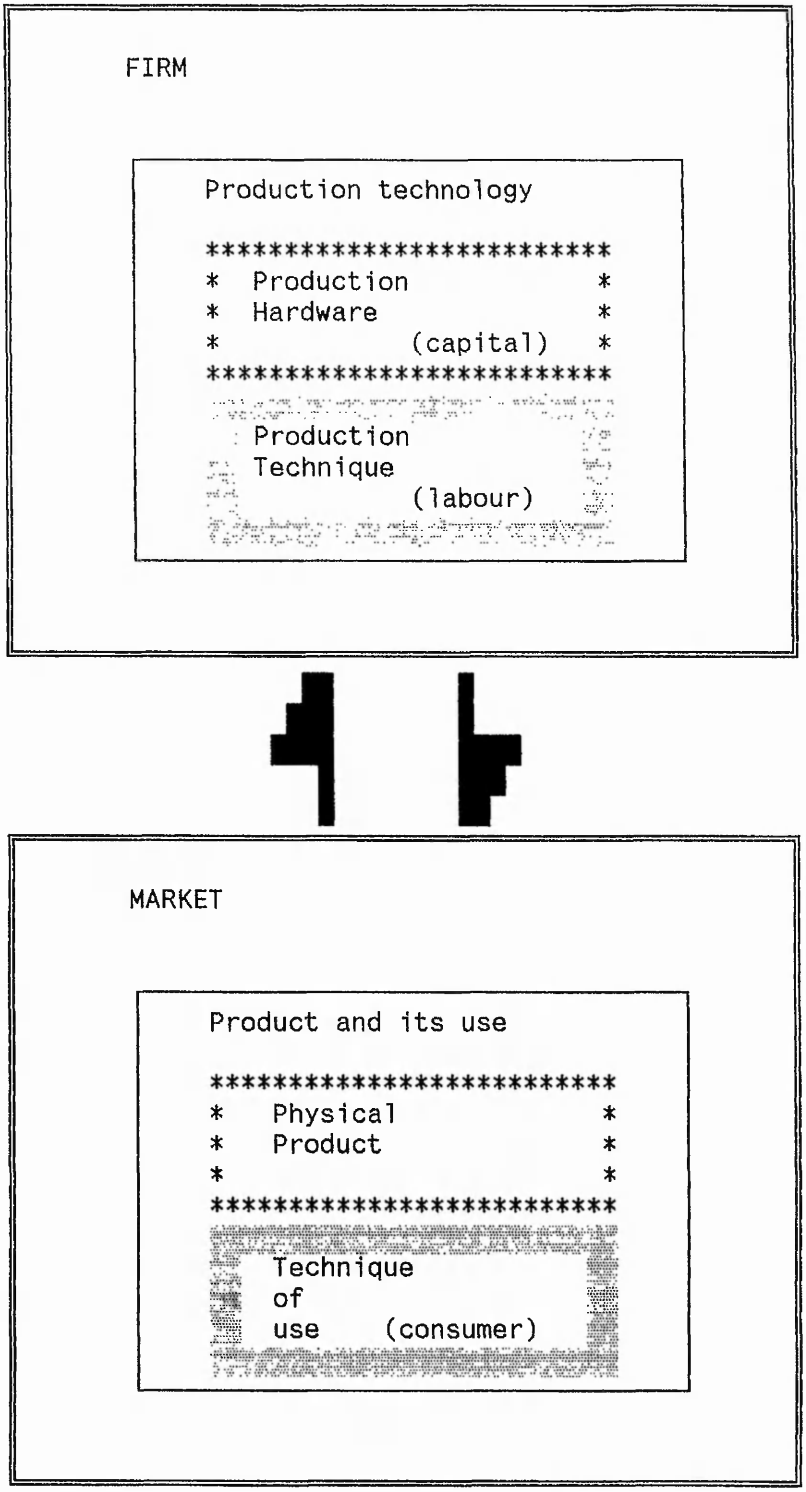

Fig 10.3 Relation between firm, product and market in terms of technology

that an attempt is made to link such ideas with economics, but if this model of internal firm behaviour is useful it should be consistent with some of the economic observations upon which are based the "macro models" of technical innovation discussed in chapter 1. In this section it will be shown that a belief in the social construction of technology is consistent with two important features of long term economic change, the rise in the material standard of living in the OECD countries and the pattern of long "waves" of economic development.

10.31 The Long Term Increase in Standard of Living

This is at least possible with our micro model. In the model technology is socially constructed, the construction detail being set by the selection of cognitions and rules made by managers, constrained by the firm culture and strategy. The standard of living is related to the degree of control of the natural environment and an increase in the standard of living requires an increase in human knowledge in the form of technology, ie models and rules for describing the environment and physical hardware that embodies this understanding. This process is limited by the ability of human beings to store increasing amounts of technical knowledge, but is far less limited by the ability of structured physical objects to act as stores of knowledge[6]. Now the structuring of physical artefacts is equivalent to the transfer of knowledge from human beings into physical form[7] and it is this

[6] Increases in population, length of life and the division of labour increase the sophistication of the knowledge stored in people.

[7] Such structured physical objects act as a "knowledge sink" that can store greater amounts of knowledge while the people that created it have more limited capacity to store knowledge.

progressive embodiment of knowledge in physical form that allows the standard of living to go on rising. The rise in standard of living is equivalent to an increase in total knowledge stored per head of population, where much of the increase in knowledge stored is in the form of physical artefacts. It can be said that the rise in living standard is also accompanied by an increase in the proportion of knowledge stored in physical form to that stored in people.

In certain instances of innovation this is clearly what is happening. Labour displacing automation substitutes capital for labour and the process of automation can be said to be one whereby technical knowledge is progressively embodied into physical form. Radical innovations such as SCP may also increase the complexity of physically embodied knowledge compared to the processes which they replace, in this case an agricultural system of production.

In either of these cases there has been an increase in the knowledge embodied in physical form. The continuation of this process over time and repeated in many firms would result in increasingly complex and sophisticated production technology and artefacts, admittedly with a necessary evolving knowledge of product use in the user populations.[8]

This argument shows that the idea that technology is socially constructed is consistent with a long term rise in living standards. It has not been shown that such a rise would necessarily occur, or under

[8] At the same time it could be argued that the technical production knowledge (knowledge possessed by people) has increased in complexity, (the difference between agricultural techniques and the technique of operating a giant process plant) but provided the knowledge embodied in physical form increased by more than that learned by human beings, the average material standard of living could rise.

what conditions it would occur and these questions will not be dealt with here - it is enough to observe that in the last three hundred or so years there has been such a rise in the material standard of living.[9]

10.32 The Discreteness of Long Waves

Another feature of the structuralist models of macro level change is the discrete nature of the long waves. There have been four fairly distinct waves and each is associated with a characteristic pattern of technical innovation and this distinct character of a wave can be related to the social construction of technology. The structuralist models described in chapter 1 link clusters of characteristic organisational and

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[9]However, a reason for this progressive shift of knowledge into physical form could be suggested as due to the competitive structure of the firm environment. The section on the social construction of technology by the firm suggested that the free market system tended to encourage firms to adopt progressive technical innovations and this was linked to the firm's commercial objectives, where technical change was one means of increasing control over markets and introducing products which more precisely met perceptions of user need. It is partly the degree of constancy through time of this "socio-commercial" motivation of the firm which results in the systematic and progressive accumulation of knowledge in physical form. The firm is not offered a straight choice between capital and labour for performing set production tasks - the physical capabilities of human beings are set biologically and do not change greatly. The physical capabilities of production hardware however, are socially structured and therefore less limited, since they depend on the creativity of the people who design and construct them rather than on the physical attributes of people. The embodiment of knowledge into physical form therefore suffers fewer constraints than the reverse process, which is the substitution of labour for capital. There are constraints, principally on the creative possibilities available to innovators and these will be discussed in the next section.

To sum up the argument, physically embodied hardware is socially structured and therefore is limited by creative possibilities, while production via human beings is limited by their fixed physical structure. While the technical knowledge linked to physical hardware may grow with successive innovations it is therefore unlikely to outstrip the rate at which knowledge is embodied into physical form.

technical innovation to changes in the volume of investment, which in turn changes the the pattern of employment in the economy.[10]

Private investment is "triggered" when economic opportunities are perceived by firms. These economic opportunities are likely to consist of combinations of cognitions, as were the novel food fermentation projects[11], and these collections of cognitions which define a project will be referred to here as "ensembles," see fig 10.4. However, the number of perceived economic opportunities in the economy as a whole may depend on relatively few, but highly important cognitions in the "ensemble" of project defining cognitions. when these key cognitions change, investment can be triggered in "sets" of projects. The project defining cognitions and rules differ from each other in that some are general conditions in the economy, some are specific to the firm or to individuals. Many of these cognitions and rules will apply to other sectors of the economy, and will have conditioned the social construction of old technology, as well as many current innovatory projects. It is as an ensemble that these cognitions and rules define a particular project - a project is not made up of unique defining cognitions, as was seen with the case of the novel fermentation technologies.

[10]This argument is necessarily shortened and will not explain all the economic ideas on which it depends. Briefly, a number of economic indicators are used to show the long term variation which defines the separate waves, but volume of investment is probably the key economic variable. Changes in employment structure are probably a result of changes in investment patterns and we therefore need an explanation for long term changes in the volume of investment, (see Freeman, 1984 for arguments about the long waves and investment).

[11]That is, assumptions about the evolution of factor prices such as protein, oil, methanol, assumptions about how fermentation technology could be advanced by the firm etc

An ensemble of cognitions defines a project. Innovatory projects are defined by one or some of the cognitions being innovations, or if a combination of old cognitions is original.

```
.................................. environment
.  .     * .......................... market
.  *          * ..................... strategy
 .                                ......... culture
 .*             *..............   ...... technology
 .                                 .
 .. *          *.................
              *.......................
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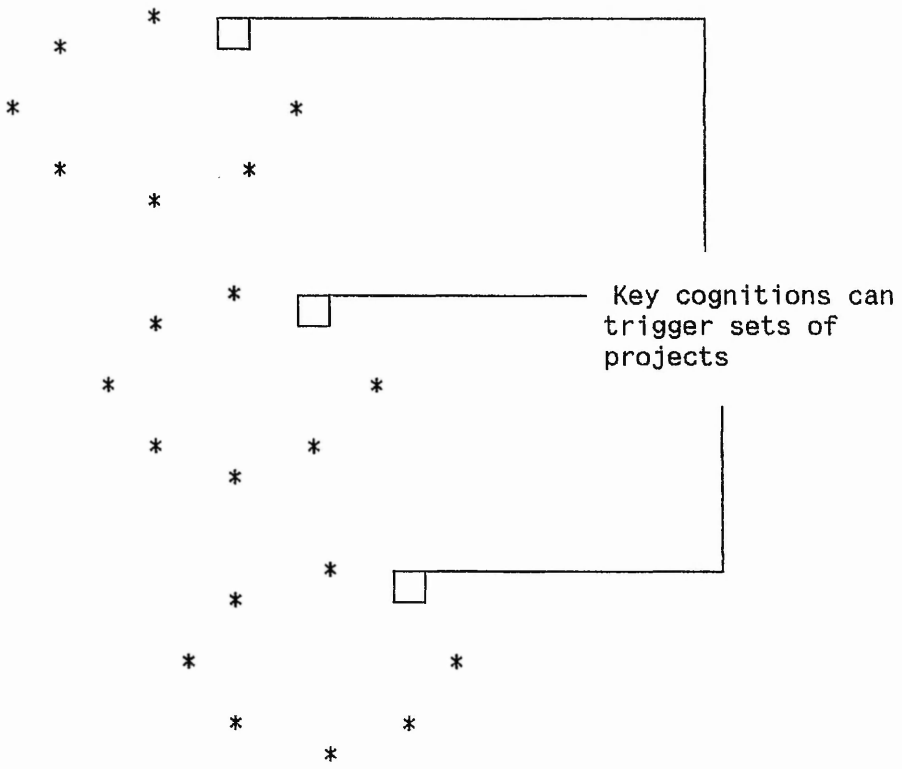
ENSEMBLE

Changes in key cognitions can create the possibility of a set of innovatory projects, which may lead to a set of innovatory products and processes. Investment in these projects may lead to the economic conditions characteristic of a long wave upturn.



<u>Fig 10.4</u> <u>Innovatory projects are composed of cognitions, long waves can be triggered by changes in key cognitions.</u>

If we continue with the example of the novel food fermentations, there were base assumptions essential to the creation and continuation of all the projects. The most obvious were the assumption of the continuation of low hydrocarbon prices and the assumption of a forthcoming rise in bulk protein prices. Although necessary conditions for the attempt to commercialise SCP, the hydrocarbon condition is also a common component of thinking in many of the innovations of the fourth wave - eg it is common to all the synthetic fibre and plastic innovations. The protein price affected a smaller sector of the economy, but forecast changes in protein prices stimulated innovation in a range of alternative protein sources besides SCP. The contemporary state of the art in fermentation technology was fixed by the activity of the bakery, brewing and pharmaceutical industries, and this "state of the art" served as a starting point for the SCP and novel food innovations. To repeat this point, although a particular project is made up of a unique ensemble of cognitions and rules of thumb, most of these recur throughout the economy in other ensembles, although to differing degrees.

It is as an ensemble of cognitions that a potential radical innovation will be judged as worthy of investment or not. It is possible that evolutionary or dramatic changes in a few cognitions which are general and part of most ensembles could make whole sets of innovatory ensembles economically viable. This could trigger large scale investment with the consequent economic and social effects of a long wave. Changes in cognitions which are included in only a minor proportion of the ensembles of the whole economy are associated with radical innovations - such as SCP, (anticipated changes in protein prices), see fig 10.4 for diagrammatic illustration.

The argument so far has been that periods of irregular investment may result from changes in relatively few, but common, cognitive elements in the range of project proposals in the economy. The range of available elements changes as a result of innovation. It has been said above that key cognitions can be price factors (eg of hydrocarbons) or products (eg spray driers). In both these cases technical change has been partly responsible for the creation of the cognition in its modern form. In general, one wave's ensembles will become embodied in a range of products and processes, which change the cognitions available for new ensembles in the next wave, for example by providing new commodities, (as SCP would have been) or new products.[12] We have returned to the idea that it is the process of embodiment of cognitions or knowledge in physical form that allows a new wave of investment to have radically different characteristics from the previous wave.

This discussion has linked two of the most important features of long wave models of technical change to the micro model of innovation described in the last section. In summary the connections are as follows:-

[12]If this were not the case it would be possible that, say, a long term oscillation in the hydrocarbon price could trigger repeated bouts of investment, each bout separated by several decades, which change the economy from a synthetics-base to a natural product base and back again. Investment and employment would oscillate with each bout of investment but no material rise in living standard need take place and the wave characteristics would be the same for each switch. The progressive transfer of knowledge into physical form allows successive waves to differ from each other.

1 Macro - The long term rise in the material standard of living

Micro - Progressive embodiment of knowledge, in the form of technical and non-technical cognitions, into physical hardware of production technology and associated product

2 Macro - Long waves of economic development associated with a techno-economic paradigm are discrete.

Micro - Clusters of innovations associated with a TEP are composed of cognitions, many based on former waves. Key cognitions, common to cluster serve to define character of innovations and so define the wave. Evolutionary or radical changes in the key cognitions can be responsible for triggering large scale investment in a range of radical innovation.

APPENDIX 1 - SCP FROM WASTE SULPHITE LIQUOR

APPENDIX 1A - THE PEKILO PROCESS, FINLAND

Based on telephone conversations with Dr Forss, Finnish Pulp and Paper Institute, Dr A Kolsaker of Boregaard and Dr Ted Bettorn of Metsa Selva, another pulp processing firm in Finland and company literature.

Steinkraus (1980) in a review of SCP production from waste sources, refers to lignocellulose as,

> "the world's largest reserve supply of renewable carbohydrate." (Steinkraus, 1980 p137)

Lignocellulose is basically wood, and the by-products of pulp processing for paper production offer the largest potential of any waste carbohydrate material for SCP production. The by-product or waste termed "sulphite liquor" is produced by only one type of pulp processing plant, the "sulphite" wood pulp plants. Sulphite liquor typically contains 28% sugars by weight. It is the major tonnage carbohydrate waste produced in Scandinavia where the Pekilo process was developed. The Pekilo process is the most important SCP process to be based on lignocellulosic wastes in Western Europe. A major advantage of lignocellulosic wastes is that they are consistent in quality and are produced at a constant rate. This makes a consistent quality SCP product a possibility.

The Pekilo process was developed by the Finnish Pulp and Paper Research Institute at Helsinki, with 25% support from the Finnish government. This is a private collaborative R&D institute that is headed by Dr Forss, who also headed development of the Pekilo process.

> "All R&D at the Institute is privately funded. We had 26 member companies at that time (1960s). We have to offer our inventions to these member companies. Six companies decided to sponsor this research on Pekilo."

The research was begun in 1963-1964 and sponsorship of development work began in 1968. The 6 companies all owned sulphite mills, but only two Pekilo plants were eventually built. During the development phase a new another pulp producing technology had become a more economic proposition than the sulphite process. Pulp companies began to build the new Kraft mills and close their sulphite mills, so the interest in the Pekilo process began to wane. Although two Pekilo plants were installed, only one still operates, producing 8 000 t/a yeast fodder. This plant is operated by the Tampella company at Jamsankoski, Finland, and uses sulphite liquor from a nearby United Paper Mills plant. The Tampella company was also responsible for constructing the plants.

This Pekilo plant encountered some unexpected technical problems. The central tube fermenter functioned at only 60% capacity for a time because of "dead spots" where the rate of fermentation slowed down. There was also a problem with heat exchange, leading to a redesign of this equipment, Romantschuk and Lehtomaki (1978). Forss commented that the plant was commissioned a year later than planned and was probably an economic disappointment.

Romantschuk (1975) performs an elementary economic calculation whih shows that the plant could just break even with the variable costs, repeated here.

Value of Pekilo protein	$110/tonne
Cost for loss of heat value of liquor to pulp mill plus power and steam consumed in process	$50/tonne
Nutrients	$18/tonne
Utilities	$11/tonne
Labour	$11/tonne
Maintenance and packaging	$20/tonne
Total costs	$110/tonne

Power consumption 1250 kWhr/tonne

Source: Romantschuk (1975 p348)

There was no government subsidisation of plant construction

In the alkaline Kraft process the sulphite liquor is evaporated to a dry waste and then burnt. This supplies more than enough energy to run the plant, so that a Kraft mill is more economic than a sulphite mill with a Pekilo plant installed. Kraft mills are also larger and more automated, typically producing 400 000 t/a of pulp compared to 100 000 t/a for a sulphite mill.

There was a second reason for the Pekilo process having wider use. This was that ethanol and SCP were rival fermentation products from carbohydrate rich wastes. Boregaard is a Norwegian pulp and chemicals company that installed an ethanol plant based on yeast fermentation of sulphite liquor before the second world war. Kolsaker described how Boregaard had repeatedly examined the benefits of SCP production as an alternative to ethanol production,

> "Every time the ethanol price tumbles we have considered using some kind of SCP process. When the referendum on joining the EEC was negative in 1972 we found the ethanol price (went) very low, since there is little demand for ethanol of technical quality in Scandinavia. Import duties on ethanol prevent us exporting ethanol to the EEC."

Even with these special conditions the economics were against SCP production. Boregaard produced feasability studies on SCP production in 1950, 1973 and 1979, each time the result was that SCP would not be economic, despite a tendency for ethanol to be cheaper in Norway than within the EEC and despite the feasability studies occurring at ethanol price lows. So ethanol has consistently offered a better return than SCP as a product from fermenting wastes since shortly after the second world war.

Some SCP is produced as a by-product of the ethanol fermentation. (Aerobic fermentation yields biomass, anaerobic yields mainly ethanol but inevitably some yeast). Boregaard produce 16 000 t/a ethanol using a Sacchoromyces yeast and about a 1000 t/a of fodder yeast.

Boregaard's experience of the economics is probably representative of the majority of carbohydrate waste producers in Europe. Kolsaker thought that even the ethanol plant would not be economic to install now, given the need to pay back capital costs.

However, there is another reason for fermenting sulphite liquors. There is a specialist use for lignose sulphate as an oil well drilling lubricant. This use requires the lignose sulphate to be completely free of the sulphite liquor sugars and fermentation is one way of getting rid of them. Kolsaker linked Boregaard's unusual combination of industrial interests to the fact that they used fermentation in this way.

> "We are a combination of a pulp and chemicals firm and this is a fairly unusual combination. I think with Metsa Selva in Tampella, Finland, we are the only two companies in Europe with such a combination of interests. Metsa Selva actually commissioned a Pekilo plant, but the economic performance was below expectations. It's true that it's because of our chemical operations that we are interested in removing sugars from lignose sulphates."

A final reason for using the Pekilo process was in order to reduce the BOD of effluent. Forss thought the incentive to use the process was greatest in the 1960s when Finnish environmental legislation was tightening up. This trend was cited by Forss as a spur to the development of the Pekilo process, as was the trend of rising protein prices. At least one of the plants appears to have been constructed during the protein price rises of 1973-1975. There was also some idealism involved at the Pulp and Paper Institute.

> "We thought, why should wood be converted only to toilet paper, what about food for the starving? At that time there was lots of idealism. The disaster in Peru, 1972, anchovy disaster, protein prices were sky high. It boosted activities here. United Paper Mills (later merged with Metsa Selva) built the first plant on the basis of these high protein prices."

Ted Bettorn thought he was the manager who had got Metsa Selva interested in SCP production. He had worked in the US in one of the St Regis Paper Company mills that had installed an SCP plant, and this is where his interest in SCP came from. Metsa Selva was similar to Boregaard in structure and interests. Bettorn described the company as always having been interested in the lignin side of their business. Bettorn gave the principal reason for installing their Pekilo plant as environmental. Metsa Selva had a two stage ferementation for their sulphite liquor. The first stage produced ethanol by anaerobic fermentation of the hexoses in the liquor. The second stage consumed the pentose sugars and produced SCP. The only reason for the second, SCP stage was a need to lower the BOD of the effluent which the plant discharged.

> "Since the 1970s we have become highly BOD conscious, legislation is passed daily here, so no salmon in our lakes anymore, and acetic acid is one component of this problem...Water authorities are breathing down your neck all the time."

The yeast fermentation had the advantage that it consumed the acetic acid in the effluent which made a disproportionate contribution to the BOD.

When asked why Metsa Selva built a SCP plant when Boregaard were deciding not to, Bettorn answered,

> "I'm not sure how much I can disclose, but the protein market was somewhat protected in Finland, in that there were some limits on the consumption of imported soya feeds. The price was higher than in the EEC. This made a significant difference to the economics. Also the Norwegians had their fishing industry and cheap fish meal."

Forss did not believe that any more Pekilo plants would be built in the future.

APPENDIX 1B THE LAST SULPHITE PAPER MILL IN SWITZERLAND

Oral material from meeting with Dr Arni, marketing manager and Dr Hoolie, R&D manager Cellulose Attisholz, Switzerland.

Environmental regulation on air pollution is tougher in Switzerland and Germany than it is in Finland, according to Hoolie. The result is that there are no Kraft mills in either Germany or Switzerland. Kraft mills dry and then burn the lignin cellulosic wastes from pulp production and so convert sulphur to the aerial pollutant sulphur dioxide gas. Whereas Finland has a problem with water pollution, Switzerland and Germany also have a problem with acid rain and hence sulphur dioxide pollution. Controls over all types of emissions have made investment in pulp mills of any kind unlikely in these two countries.

However there were many sulphite mills that were established before pollution controls began to increase the costs of pulp production in Germany and Switzerland compared to elsewhere. Most of these have been closed down by the regulatory authorities. Only one sulphite mill survives in Switzerland, the Cellulose Attisholz plant in the Canton of Berne and the following represents a list of this plant's major BOD reduction systems since it was built in 1881.

1881 pulp production begins based on sulphite process.

1914 Sacchoromyces ethanol plant installed, waste liquor burnt

1947 Candida Utilis strain used to produce yeast fodder, waste liquor burnt.

1970s 220 000t/a waste water treatment plant installed

1976 Human food grade yeasts produced on alternating basis with fodder yeast, in response to "developing market."

1986 Pilot plant built to recover SO_2 from burnt waste emissions.

Until the ethanol plant was installed in 1914 there was 100% discharge, with pollution worse than today despite increases in pulp production from 30 000 t/a in the 1920s to 125 000t/a today.

The installation of the fodder yeast plant coincided with the immediate post war shortage of animal feeds, when the real price of feed made such an installation economic. The 1976 upgrading of fodder into human food represents an attempt to increase the value added to a product whose process capital costs have been written off.

The technical reason for the yeast fodder plant installation of 1947 was that the Sacchoromyces yeast used to produce ethanol did not consume the pentose sugars, which were being burnt and Cellulose Attisholz were pioneers in removing the pentose sugars from effluent. At this time, the 1940s, the yeast-fodder technology was the best technical option available for removing pentose sugars and lowering the BOD of effluent. The yeast fodder process and ethanol process were sufficient to control the BOD of effluent until the 1970s.

Cellulose Attisholz designed and built these plants using their own R&D and engineering resources. Research continued over 30 years of operation to improve the efficiency of the plant and several such plants have been licensed to foreign sulphite pulp mills. The principal features of the yeast production process are as follows:-

Thermal pretreatment of spent sulphite liquor in degasifying column

Neutralisation and addition of yeast nutrients

Air lift fermentation with central vat surrounded by circulatory tubes for air injection, (homogenises mixture, cools, oxygenates and allows carbon dioxide degassing)

Continuous overflow of yeast from fermenter

Separation

Multi-stage washing

2 stage evaporation plant, thermolysis and pasteurisation

Spray drying of yeast cream (22% solids) to marketable powder, 7 000 t/a

Source: Cellulose Attisholz (1977)

The Cellulose Attisholz information sheets claimed that yeast production could provide an economic solution to environmental control problems for companies in 1977.

The waste water treatment plant was designed and built by Cellulose Attisholz over 4-5 years, at a cost of 80m FCH. The company patented the design and sold 100-200 similar units for sewage treatment. This treatment plant supplies 25% of the plant's electricity and 60% of the energy requirements of an adjacent waste incinerator plant built to take the excess steam. The experience with designing yeast fermentation plant aided Attisholz in the decision to build this treatment plant.

Arni described the company thinking,

> "...The engineering companies were marketing poor plant. They were not designed to cope with the requirements of microorganisms, they were engineering companies with a poor appreciation of the chemical and biological processes their plant was supposed to be catering for. So using our knowledge of the characteristics of yeast on waste, we designed the plant ourselves; it was twice as efficient (at lowering the BOD) and half the price of our competitors', so we sold one or two hundred."

Hoolie thought the management of Cellulose Attisholz anticipated further tightening of the discharge regulations and so initiated the waste water treatment plant research. The sewage treatment system was a simple version of the sulphite waste treatment plant they were working towards, but the engineering companies with whom they were competing argued with the Cantonal authorities that Cellulose Attisholz were a pollution problem. The authorities then gave the plant 4 years to decrease their effluent BOD, or the plant would be closed. Cellulose Attisholz were able to comply because they were at an advanced stage with their research. Cellulose Attisholz now far exceed the regulatory requirements by cutting the BOD of effluent that flows into the River Aare by 96%.

The company had never tried to comply strictly with environmental legislation, either withthe yeast or water treatment plants.

> "The trend is to become stricter in time. If you meet one set exactly, you are soon asked to improve on them, (although) Switzerland has the strictest regulatory environment in Europe."

This belief underlay the continuing research and development into reducing the BOD of effluent. Before the 20m FCH desulphurisation plant was built Cellulose Attisholz was producing 10% of the total SO_2 emissions in Switzerland.

The existence of the yeast and ethanol plants represent previous economic and technical conditions, since Hoolie thought that neither plant would be economic under present economic conditions. Because of the progressive nature of the investments in waste treatment plant, each stage had been economic at the time it was built. If all the investments were considered afresh at the present time, Arnie believed it would be uneconomic. The viability of each stage depended on the existing plant having been written off in accounting terms.

Cellulose Attisholz R&D are developing a non-sulphur, non-chlorine pulping process, the only option for new pulp plant in Switzerland. This R&D activity has been essential to the solution of the effluent problem and will be essential for the survival of pulp production in Switzerland. Hoolie said there were 40 people in the R&D laboratories compared to the usual 7 or 8 technicians for monitoring purposes in a standard pulp mill. The founder of the company, Dr Sieber, had been a chemistry PhD and it was he that established the tradition of an active and pioneering R&D department. The department had continued to be highly regarded because it was credited with the plant's survival in a difficult regulatory environment.

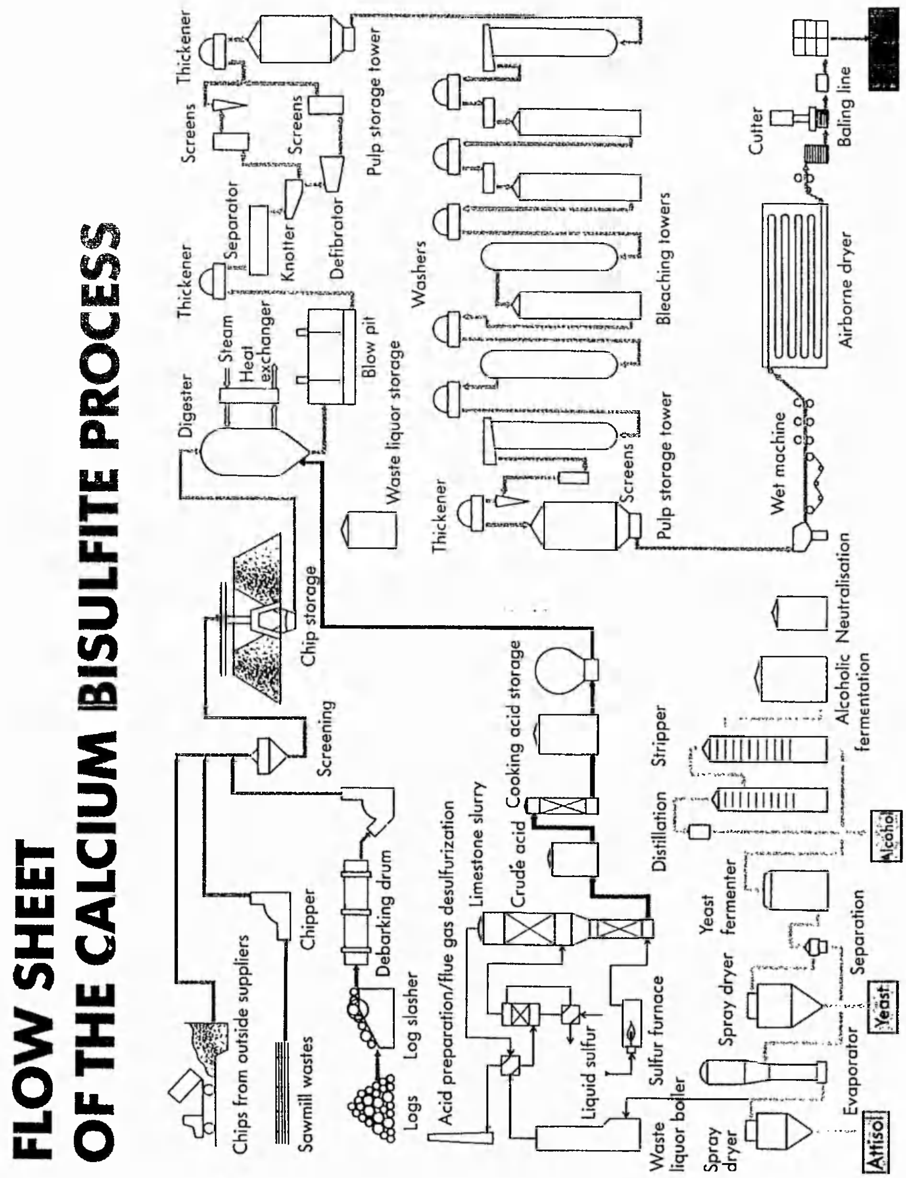


Fig A1.1 Flow Sheet of the Cellulose Attisholz pulp processing plant. (Cellulose Attisholz. 1977)

APPENDIX 2 - SCP BASED ON LACTOSE SERUM - BEL INDUSTRIE, FRANCE

Based on company material and conversation with Dr Dinsdale, R&D manager, Bel Industrie, Paris. Translated from the French

The following summarises the major yeast-fodder related events in the history of Bel Industrie.

1955 research into strains begun in collaboration with Professor Keilling of the Laboratoire National Agronomique de Paris, (LNAP).

1956 Pilot plant built at Vendome and already producing 300 t/a of yeast by continuous fermentation.

1966 Main plant built at Vendome of 1 500 t/a capacity, consumes entire output of serum from Vendome dairy, produces cattle fodder and protein concentrates. Yeast is flocculated and filtered in harvesting process.

1964-1974 Research shows yeast can be used as protein and vitamin supplement in human food. 90% output going to animal feed market.

1974 Plant built at Sable sur Sarthe. Ultra filtration process incorporated to replace flocculating process. Protein now soluble and commands higher price, more human food uses.

Bel has always been interested in having a continuous fermentation process and has worked with the Association des Souches, the

French Yeast Association, to this end. The two organisations developed a mixed culture for their lactoserum which depended on three yeast strains working together to consume the separate products of the substrate and the yeasts' own by-products.

Lactoserum		Byproducts	
lactose	strain 1	alcohols	strain 3
lactic acid	strain 2		

They collaborated with a professor Galdeze at Montpellier University to show that when the culture was contaminated with a foreign strain, then fermented continuously, the same stable mixed culture was always the result. A stream of minor process adjustments continued over the years. The result of more than a decade of fermentation process innovations was an increase in yield from 42% to 53%, (this ratio gives the weight of yeast produced per unit weight of substrate).

Bel produce 18 000 t/a lactoserum annually, which makes them one of the biggest producers in the world. They have tried to market their plant technology, through Speichim, but without success because Dinsdale thought other dairies were just too small for the capital cost to be worthwhile.

It is the more recent history of Bel Industrie's lactic yeast that is interesting since it is one of the few microbial products to be actively marketed. It is not entirely unique of course, since the brewers' yeasts and bakery yeasts are its natural competitors in the market place. Whereas these yeasts are by-products in themselves, lactic yeast is based on lactoserum, the by-product of the dairying industry. The major change in marketing strategy occurred after the 1974 oil price rise.

Yeast production requires enormous amounts of energy for the aeration. drying, separation processes. The hydrocarbon price rise translated into an energy price rise left Bel Industrie unable to compete in their calf feed market. The price of their yeast roughly tripled due to the increase in energy costs alone. This is especially interesting since Bel was using a zero cost substrate, unlike the hydorocarbon based processes.

The oil price rise prompted Bel to begin a search for higher value added markets. In 78-79 they developed a product called Sassiyen which was a milk replacer rather than a crude yeast fodder. This was viable when sold into the calf veal market. The dairy-free food market also began to develop, where yeast could be substituted for milk products in human food.

They now have two factories, one producing Sassiyen, one producing human food and both the animal and human food markets have become increasingly profitable in these last years. Despite their withdrawal in 74-75, the calf feed market is once again of value to Bel. In this market the yeast has value as an amino acid and vitamin supplement. Bel replace about 40% of milk proteins with their yeast product Sassiyen.

Dinsdale thought this replacement market for animal feed was about 50-60 000 t/a of which Bel were potentially capable of producing 10%

of this form one of their two factories. Bel have a total capacity of 10 - 12 000 t/a of lactic yeast, but this capacity is not fully used. According to company literature, Fromageries Bel (1986), several thousand tonnes of Protibel are produced every year.

Bel examined the domestic animal food market and found that there was a small, profitable niche for yeast as a vitamin supplement for improving dog coats. They also have a market for fish feed which is important in Germany. Dinsdale thought that both these markets had high potential value in the future, but that development partly depended on Bel demonstrating the safety of their product. Other openings that Bel are actively considering are aquaculture of fish and prawns in Japan.

Their most profitable market is in producing dairy free products for human consumption and the most developed market is that for dairy free chocolate, sold in Germany, France and the US. Another human food market is as a vitamin supplement. Bel sell their yeast to be produced into tablets for child diet supplements, but here there is much competition from breweries and bakries selling their waste yeast mass. The advantage of the Bel yeast over brewery yeast is that it has a sweet taste due to the lactose substrate. Brewers yeast tends to be more bitter and have the characteristic "yeasty" taste. Some of the other human food applications are in charcuterie, where the water absorbent qualities of the yeast can be used to bind proteins in sausages.

Dinsdale judged the human food market to be largest in the US, then in the UK. However the UK was the most difficult market because of the vast quantities of surplus brewery yeast that was produced and it was in the UK that Bel were least well known. The US market was worth 33 000 t/a, but the problem with all the human food uses was that there were already competitor products in place. Bel also had the problem that lactic yeast was relatively unknown and had to win acceptance. The major problem was to find markets where its different taste would be a positive advantage.

Dinsdale described the technical differences between lactic and brewer's yeast as small but important. The organisms were the same but the production process changed the quality of the proteins and lactic yeast was the only yeast to contain vitamin C. On the other hand brewer's yeast contained slightly more vitamins B1 and B2. Lactic yeast has a clear advantage over brewer's yeast in charcuterie, where its water retaining properties are linked to the presence of galactose in the yeast cell membranes.

In all their marketing activity Bel have been concerned to preserve a number of small markets rather than have one large market. In all cases they sell their yeast on for other companies to market and they have kept individual market size down to around 1 000 t/a, despite offers to buy supplies of yeast at 3 000 t/a.

A major market change to the benefit of lactic yeast has been the EEC decision to cut milk quotas. This has led to a doubling in the price of powdered skimmed milk to 11-12 F/Kg (August 1988) as an animal feed supplement. Dinsdale believed it would go on rising and veal calf producers would be forced to look for alternative milk replacer products.

Dinsdale was aware of Pruteen and considered that lactic yeast had been a competing product. Bel and ICI had both had the same economic problems with their products.

APPENDIX 3 - SCP IN THE SOVIET UNION

Based on Anthony Rimmington's publications, conversation with Anthony Rimmington and an article in "Pravda" reported by Martin Walker in "The Guardian" and comments on the Soviet Union made by the managers interviewed in Western Europe

Anthony Rimmington is a unique source for information on SCP in the Soviet Union because he is the only person to have collated and translated indigenous Soviet material on SCP as part of his work for a PhD at the University of Birmingham. However, his work tends to reflect the "official" Soviet view of SCP in the Soviet Union. Western managers and a recent press attack on one SCP plant are very critical of Soviet achievements.

It is not in doubt that the Soviet Union has become the world's largest producer of microbial protein, with over 1 100 000 t/a capacity in 1985, Rimmington (1985). The entire output is used for animal feed.

According to Rimmington the origin of the state directed expansion of SCP production was the coincidence of a shortage of livestock production with the problem of high paraffin wax oil in the Volga-Urals fields. The initial idea was to dewax the oil and produce much needed animal feed in one process; the same conception that BP used at the start of its projects.

The first plant of 1 500 t/a capacity was built in 1964 at Krasnodar. Rimmington (1985a) believes that the plant used a gas-oil substrate awith separation of the yeast and feedstock after fermentation.

Rimmington reports that the Soviets found the feed to be contaminated with polycyclic hydrocarbons, and that this persuaded them to build a second experimental plant at Ufa with a capacity of 12 000 t/a based on a purified n-alkane substrate. Toxicological testing apparently led to confidence in the safety of the n-alkane based product and a series of giant plants were built in the succeeding years, all using purified paraffins as a substrate.

Ufa	100 000t/a	1968
Gorki	200 000t/a	1970
Kirishi	100 000t/a	1972

Six other n-paraffin plants of similar capacity have probably been completed, while a further 3 with a combined capacity of 540 000 t/a were "nearing completion" in 1985. Bettley (John Brown) commented that the Soviet 5-year plan of 1980 stated a target of 5 million tonnes capacity of SCP by 1985, but that at most they were capable of producing 1.5 million tonnes. This implied technical problems or change of heart over the value of SCP. It is not clear why unambiguous announcements have not been made about when plants have opened and what percentage of capacity is being used.

There appears to have been a debate over whether the levels of carcinogen in the n-alkane SCP product should preclude its use as a human food supplement. Rimmington (1985a) reports that the Soviet Institute of Nutrition has so far refused to allow its use in human food. The furore over the Kirishi plant has resulted in the opposition to the plant claiming that the Soviet SCP from n-alkanes has in fact had very poor toxicological results.

These Soviet SCP ventures have frequently been criticised by western companies like ICI who were involved in negotiations to license their SCP technlogy to the USSR. Rimmington refers to an "informed source" in ICI that described meat that had come from animals fed on Soviet SCP as having "an unpleasant taste and smell," (Rimmington 1985b p37). Rimmington has also found references to Soviet scientists worried about the possiblility of large scale epidemics triggered by the venting of yeast-laden dust from these plants. He reports that dust catching devices with capacities of 1 150 000 cubic metres air/hour were being installed in 1985.

The advent of glasnost allowed some of the problems with these plants to be discussed in the press. An article in the Guardian by Martin Walker summarised a Komsomolyska Pravda article in 1988 on health problems in the town of Kirishi, population 60 000. Some of the key admissions follow.

- the deaths of 12 children have been attributed to Kirishi plant emissions
- 100 permanent invalids in the town hospitals
- incidence of bronchial asthma is 10 times higher than the Soviet average
- "the most appalling account of Soviet industrial pollution since the Chernobyl disaster," translated by Walker (1988)
- 12 000 people have demonstrated against the plant, 1st June, 1987
- 300 defects found by health and safety officials.
- 4 000 suffering from "degenerative" allergies linked to plant

Pravda reported that over 2 tonnes of pollutant was settling on the town every day that the cleaning equipment was shut down. The air purification equipment had apparently failed and the scrubbers cleaning the factory exhaust system had been deliberately shut down while the plant continued to operate for a year and a half. Throughout this period demonstrations by the populace had continued with the effect that Kirishi was repeatedly visited by the minister for bioindustry and given promises that the pollution would stop. This ministry was originally given the task of planning SCP production and SCP remains the principle Soviet bioindustry.

A meeting of doctors from the surrounding region has condemned the plant while the authorities have responded in a confused manner. Those who have spoken against the plant have been repeatedly criticised and this article claimed that attempts had been made to silence protesters, (Komsomolskaya Pravda, 1988). The Pravda article also refers to 20 year old toxicological tests on the plant's product, "Paprine" which showed that 2nd and 3rd generations of animals fed large doses suffered from reduced fertility and disease immunity. Another report from a hospital authority descibed meat from animals fed on Paprine as undesirable for human beings, with stomach and bowel disorders common amongst people fed on such meat. Pravda also contains the cost of the attempts at lowering plant emissions - 500 million roubles, approximately £500 million, apparently to reduce emissions from this one plant by a factor of 6. (Komsomolskaya Pravda, 1988)

Pravda also reports a reluctance by farmers to use the protein concentrates from the plant, with the farming ministry of the Byelorussian republic banning their use as feedstock. Apparently thousands of animals have died from eating food yeasts from the Kirishi plant. A collective farm in the Leningrad area had banned the use of "BBK," another name for a form of the yeast feed, in spring 1987. The response of the plant authorities to this loss of consumption has been to direct their product to fur farms. Once again, there were animal deaths, supposedly related to the yeast product and the Kirishi plant biochemists were sued, unsuccessfully, for £60 000 by the collective authorities of the fur farm.

Peachey (BP) had read the Guardian article, which was rather mild compared to the original Russian.

> "My God! They must be doing something bloody awful, totally incompetent."

She also commented on the BP-Soviet negotiations for the BP technology and what BP found the Soviets were asking for.

> "They didn't seem to be able to do simple things like pour out large slabs of concrete. [Although] it was difficult to find out anything about the licensing negotiations. But they seemed to be needing inputs in some astonishingly simple things. Like making decent stainless steel...apparently they couldn't do it...One has doubts about their ability to operate.

There is other evidence that the Soviets have had trouble with the operation of their production technology. Rimmington (1984) collects various reports of Soviet approaches to western equipment manufacturers where the nature of the purchase implies they are not satisfied with indigenous equipment in their SCP plants, in particular centrifuging and separation equipment. There have also been suggestions that the Soviets used their negotiations with BP to pick up technical information they should have been buying. According to Northgate (BP) the Russians did not exactly "pinch" anything because,

> "they didn't have to. All the Russians kept doing was saying, we're very interested in your SCP technology, it will require a bid and a process design from you...so we designed a number of process plants for the Russians. And every time it wasn't quite what they wanted, so there was a redesign. At the end of the day the Russians had got chapter and verse on the SCP plant, supplied by BP. 3 years later they announce to the world that they are fermenting paraffins at a million tonnes a year by a process that is remarkably similar to the BP process."

But Northgate was as contemptuous as other managers were of the Russians ability to operate such plant,

> "It's not BP technology...it's BP style of engineering and fermentation. It's typical of massive Russian industry, it's no different, just as inefficient as the rest of their industry...whether they'll ever publish efficiency data is another thing...if they only got one gram of yeast out of it they would say they had a process for making yeast."

In the early 1980s the Soviet planners were concerned that they should develop alternative substrates as the supplies of n-paraffin were thought to be limited. There was a concentration of attention on methanol and natural gas, with the first experimental plant using natural gas completed in 1983. Rimmington refers to Pravda articles talking of nearly 1980 targets of building many plants of "unprecedented" capacity, of 350 000 t/a to 500 000 t/a, based on the new substrates.

It was this interest in developing natural gas as a feedstock that led to the approach to ICI to negotiate over the transfer of Pruteen production technology. Kostandov, the then deputy prime minister, visited the ICI plant at Billingham and Harvey-Jones had talks with Tikhonov, the prime minister, in Moscow, but no deals came out of these talks. Bettley thought that this was because the Russians had developed their own technology for fermenting natural gas to protein which was akin to the Shell process in conception and he commented,

> "Now, I don't want to be anywhere near their plant when they try to start it up. You can go on and on about Russia and the problems they have...because of inefficiencies of one sort or another."

Tomng had visited the Soviet Union and had also criticised the "primitive technology," while Pickles referred to these plants as,

> "...economically grotesque, very low methane efficiency, they want cheap capital costs, not the most modern technology."

The Soviets have reconstructed one of the Ufa plants to operate on ethanol at 100 000 t/a SCP capacity. Other important SCP processes are SCP from hydrolysed wood chips, 500 000 t/a, Rimmington (1984) and SCP from sulphite waste liquor, 140 000 t/a. Experimental substrates have included rice husks, corn cobs, cotton hulls and bagasse. Rimmington has suggested in all his articles that the Soviets were about to launch an expansive programme of plant building, possibly based on methanol or natural gas. For example,

> "A massive increase in SCP production can now be expected over the next 10 years. N-paraffin plants currently being constructed will come on stream, new factories will be built to utilise natural gas as substrate and it is likely that methanol utilising plants will also be purchased from ICI in the near future. Undoubtedly, if these developments take place the Soviets' claim to be world leaders in industrial biotechnology would be strengthened. And perhaps more importantly, Soviet purchases of grain from north America might be curtailed." (Rimmington, 1985b p 37).

This may reflect over optimistic Soviet expectations of meeting the next 5-year plan targets.

The economics of n-alkane SCP production appear to be as marginal in the Soviet Union as they have been elsewhere. The reason for continuing construction of such plants can only be a political decision to reduce dependence on western grain supplies for animal feed, or the inefficiency of the planning apparatus in its reaction to the oil price rises. However Rimmington refers to Soviet animal feed consumption requirements for over 250 million animals and it is clear that even at 1.5 million t/a SCP would be only a small contribution towards Soviet needs. Rimmington (1984 p8) In addition Rimmington refers to figures that suggest only 85% of the raw protein requirement per animal is being supplied, and that this situation has persisted for over 15 years, Rimmington (1984).

Leivers (BP) had wanted the BP Lavera plant to continue to operate after 1976 because it was economic when only variable costs were considered and there was a chance that the Soviets would be interested,

> "because for some socialist countries economics doesn't mean anything."

The Soviets were interested in very large contracts for plant construction, Zamgrandi told how Liquichimica were asked to put in a bid for the construction of ten 100 000 t/a plants. Leivers described the reasons for the Soviet interest in these processes.

> "There was a terrible lack of protein for animal feed in the Soviet Union. It's still the case, they use cotton feed meal of bad quality. They have always used much high protein food of poor quality. They started research on alkane yeasts more or less like us, but either they were unlucky, or were not good engineers or biologists , I don't know what. There were a lot of problems with the quality of the yeast. Edible, but with problems, problems that could not be accepted in a developed country, so they were very interested in our process."

APPENDIX 4A - SAMPLE LETTER

This is a sample of one of the last letters to be sent, when many issues had already been identified. The first interviews were arranged by telephone and did not involve letters, but in the interview I would have a short list of issues for discussion, which I would raise when appropriate. Towards the last of the interviews it proved useful to show the prospective interviewee that I had some understanding of the issues, so that subjects such as the protein gap and economics of the process could be skipped over. The best way was to send a letter in advance of the interview. In the interview, the letter would serve as a "reference," in that we never worked through the questions mechanically from beginning to end, but had a free ranging discussion which occasionally used the letter to ensure that all topics had been covered.

Dear Dr Swindall

Thank you for agreeing to meet me on Wednesday 30th September. What follows are some of the general questions that are in my mind about ICI's experience after having talked to other people involved in scp. I haven't concentrated on questions relating to toxicology because I'm assuming you will cover that issue better than I can here. Of course, if you feel I am missing anything which you consider to be important, please bring it up when we meet. The names of any other contacts who would yield a different view of the whole affair would be particularly welcome.

What was the role of toxicological testing in decisions to progress with a commercial size plant? What were the particular problems in getting UN and Government approval for Pruteen?

What was the exact role of "universal truths" in deciding ICI to develop scp, and were these intensively researched by ICI independently of the FAO, UN etc? (eg forecasts for human food protein shortages in the 3rd world)

How far was scp simply a "straight forward business opportunity", to undercut price of soya? Can you give your explanation of how the qualitative factors such as strategic advantages of developing fermentation technology, were combined with more quantitative factors such as price forecasts to produce decisions?

Was there a bandwagon effect in scp, with so many people involved and researching it, that it became something rivals had to consider getting involved in themselves? Was this effect confined to UK/Germany? Why didn't French companies get involved in it on the same scale? Could this be because of cultural attitudes to food?

Why was biotechnology retained by ICI as an interest after Pruteen whereas BP ditched all interests in biotechnology?

How were relations between R&D and the Main Board conducted..how did PP Hart advance the project?

Did the BP and Kanegafuchu experiences affect decisions on Pruteen at all?

To what extent were there competitive relationships and cooperative relationships between BP, Shell, ICI, and other scp producers? Did they cooperate on establishing UN safety guidelines etc?

Would you agree that Shell, ICI and BP differ generally in the degree of academic freedom they grant their scientists?

What was the importance of the informal, personal relationships amongst the researchers or managers in different companies in transmitting enthusiasm or information between companies?

What were the changes in what was considered to be highly confidential information...was a good example of this growth rates for organisms? Was this of decreasing importance as time passed? To what extent was scp an unusually cooperative commercial research field?

What were the differences between Shell, Hoechst, ICI and BP approaches to scp projects? How far were these differences related to the differences in company culture, rather than difference in process technology?

Dates of major changes or decisions made? Costs of various parts of the project? Of testing Pruteen?

Is the difference between Shell, ICI and BP's finishing dates purely due to differences in technology? What was ICI's view of Hoechst's continued involvement? Of Hoechst? Have you any knowledge of Exxon-Nestle's project?

How did the debate proceed on what capacity to build the first plant to? Can you describe the debate on whether to build a second plant of 300 000 t/a?

What was the purpose and actual effect of the Hoechst technology exchange agreement?

Can you give me a short career outline, with formal titles and responsibilities?

How far can one say that Agricultural Division was remote from the Main Board and able to make decisions on Pruteen that, effectively, could not be judged by the Board?

I hope these questions are answerable, or interesting, or both...and I look forward to seeing you in September.

Yours sincerely

John Howells

APPENDIX 4B - SAMPLE TRANSCRIPTION OF DR SAXTON, MARKETING MANAGER 72-84/5, PRUTEEN PROJECT, INTERVIEW ON 19.04.88

Tell me about your role, you were in the marketing group, what does that mean?

I came into the project in 72 when we were at the pilot plant stage...where we fed 3 lots of pigs and discovered that they would eat it. But we had very little nutritional evidence, nor had we much knowledge of the European market, or even the UK feed market. My initial job was to see if there was a market, who would buy, at what price. From 72 to 82, I progressed from marketing development manager, where we were meeting most Euro feed manufacturers, to understand how they evaluated protein feed ingredients, what tests were likely to be done to prove its value, to derive a values for the product. I was then marketing manager then commercial manager, thought op about 81, when I moved to other biotechnologies in /ICI.

HOw did the market information affect R&D ?

Well there were two aspects of R&D. one is how you make the product, I think , ...a few examples? The market wanted a product highly consistent in analysis,. We has to feed into R&D the need to produce a product that had a specification within quite narrow limits. We began to understand the relative values of the protein, nitrogen, energy levels, individual amino acids. I think amino acids in particular had a lot of influence had a lot of influence on how we dried the product, and the sort of exposure to chemicals and heat that you could expose the product to in harvesting. If you over heat proteins, certainly in the drying state, you degrade a lot of the lysine and methionine, essential amino acids. One of the markets that turned out to be the most attractive was the calf milk replacer market. One had to feed back.... a large programme emerged, of how to tailor the product to suit that market. How fine should the particle size be/ What sort of wetting agents should you use to mix it into milk? Same sort of work that had to go into Coffee Mate. We found you could produce a dust, which for some people could produce adverse effects, we then had to put some cooking oil in to make it acceptable. So those were the sort of things that fed back into research. The other part of research was how do you evaluate the product to show animals would eat it. WE in the marketing side had a very large influence on that, we changed the ground completely, instead of saying , we'd like to do a few things with; ;chicks and pigs and things, we decided what the markets with the best value;e were going to; be, we talked to the companies about the trials and evidence they needed. We had the trials done across the world and received evidence from companies doing their own trials. We put together a package of it being a very efficacious product.

Was it just routine for R&D to fit the products to the market?

There were m,any constraints, we were actually very lucky that this microorganism produced a protein that has very; good balance of protein to energy to minerals to amino acids. But it was very specific, we harvested the dead bodies of the microorganisms and it was typecast in these ratios. You could vary it a bit by how you varied the oxygen and methanol and other nutrients in the system. What we had to do was minimise the number of adverse changes we had by how we ran the fermenter or how we harvested the product. We discovered that it was quite deficient in selenium. At least the amount of selenium that it needed to grow on, we didn't put in much selenium, so the product was low in selenium, so we added a bit of selenium at one stage to make it right for the feed market. We had other test products where we added lysine and pushed it about a little.. but we never developed them fully...

Was that a problem with Pruteen, that if you fed a very concentrated Pruteen diet to chickens they would get deficiency problems rather than a toxic effect?

Well selenium is one of those things that chicks and pigs have to have, but if there is too much or little it kills them. What we found was that people got the right amount from fish meal traditionally, so they didn't have to think about it, but if they replace that with Pruteen if we didn't make it right, they could have a slight deficiency. Then they had to start putting selenium in as minerals, and that caused them problems, so it was easier for us to do it. But Pruteen was remarkably free from imbalances. The other thing we had to put a lot of effort in to was the source of our phosphate. This comes from phosphate rock. Some of the phosphate rocks around the world can contain heavy metals like cobalt , that if you get too high a concentration it caused problems, so we had to be very specific about our sourcing...that was another example of how getting to understand the market led to feedbacks on research.

Does that mean you anticipated it or did you come across it from the feed producers?

Well, you gradually accumulate knowledge. The first time you meet the animal feed industry and talk to nutritionists, you know very little, but you don't get into the business very long...we were tailoring the product to suit the market needs. So you naturally get into conversations with technical managers and nutritionists about what their specifications are. Its a natural evolution. I came from the fertiliser and chemical business over in ;Ireland. Although I had a degree in agriculture and a reasonable amount of nutrition, I had been away from it for 15 -20 years, I came to it with an open mind, you learn very quickly.

Did ICI buy feed companies?

No. We considered it , we wrote papers and we looked at it, its very simple, if you are a supplier of one ingredient going into one market, you can't build a business, if you want a high penetration of that market, by buying your customers. If you buy a feed company you begin to understand more of the market. But you have to let it stand alone and run like a feed company, if you force it to use your products..it may go bust. BP, they bought Coopers Animal Health, and Shell bought C,,,,,. That certainly gave them in-house resources. Shell sold out of it, BP formed a big business out of it. They did the logical thing, having bought Hendrix and Hollad and various others, it is now a major part of their business. ICI never saw going into the ;feed business as part of their business. They owned SAI who had a feed business in Scotland. THey actually didn't like the look of the feed business.

They thought you could understand the feed business just by talking to the people involved.

Yeah. We recruited D Swindall, who was with Unilever and Derek Waterford came from Dibbies. I don't think any failure with Pruteen were to do with not understanding the products relation to the market. It was the difference between the energy price and that of proteins. We got , in the market place, the price we had forecast relative to soya and fish meal. WE got that right. We did nt get the macroeconomics right. The fact that protein has continued for 5 or 6 years at what is something like a 50 year low in real terms. We got that wrong.

But isnt that a fairly small percentage of what prices have been for a decade. A marginal shift?

There was the big hike in 72, then it dropped, then up again when we were building the plant. Our projections were somewhere around.The studies we did were as good as anyone did . I didn't do them , but got a lot of them done. We talked to the World Bank, The USDA, a lot of Universities. A lot of discussions in Europe. Basically I think what we didn't believe was that the world would allow so many millions to go hungry and to starve. The productivity of soya has been reasonable, but it has not been reductions in cost that has affected it, it has been that what exports are done are subsidised, and the fact that the world is prepared for a lot of very hungry people to die. We got that wrong.

What about the increased planting of soya in the last decade. Couldn't that have been predicted in 72-73?

I'm 3 or 4 years out of date, other than looking at prices, and they are still along the bottom. I don't know what has happened to production levels.

Brazil, Argentina etc the States...

At the soya price when we were building the plant, for two years, if we had been running the plant at the efficiencies of 81, we would have made a fair bit of money. If you take methanol prices and protein prices.

What is the difference between what you expected the price to be and what it is now?

You would need a doubling of the price of soya now, probably about $450/tonne, but to make it really attractive , $1000/tonne , you should be able to get a bit over 2 times soya, but that requires soya at $450/t.

When it became clearer that Pruteen was not going to be economic, how did that affect marketing activity?

We viewed the animal feed markets around the world in terms of a pecking order of realisations. There was an inverse relationship to volume, something like that. If you feed it to goldfish you get high prices. There is the laboratory animal market, then the calf milk replacer market. Once you move down to broilers and turkeys and piglets etc, at the top end of that you can get 2-3 times soya price. We were at the stage with the suppliers of M&S, where they liked the product so much that ....you know that M&S get into specifying what goes into feeds. It has no fishmeal taint, very consistent. One of their producers bought 8000 tonnes from us in one year. If the economics had been right they would have liked to have moved all their suppliers of turkey and pig meat to using Pruteen instead of fishmeal. So it was a highly regarded product. The likes of M&S were not so cost-conscious, if the quality was right, they would have been prepared to pay maybe 2.5 times soya in order to be able to put 4% Pruteen into meals. But once into this low soya price, when with every tonne we made we were going to lose money, not even covering marginal costs, we just had to come out of that market. YOu are left with milk replacers, some speciality fish tank things. We had 2-3 years where we looked at things we could do the fractionate it, as a content of chemicals. It looked quite promising for a while. Potentially the lowest cost nucleic acid producers. We had a lot of discussion with the Japanese and Koreans who were getting worried about their own sources of those. A lot of their production depended on waste from the paper industry. That was 82-84. We had a project, we produced nucleic acid, a classic sort of marketing thing, taking samples to the Japanese, four or five times, getting a feel for what they thought of it and then they gradually refined it, could we do this to it , then that and that...we met virtually all their needs. At the last minute they actually took cold feet. They got worried because there had been a fair bit of discussion about the SCP industry in Japan, there was a lot of emotional stuff whenever they had wanted to establish their own SCP industry around safety and that aspect. They had given up in 72.

you were dealing with the companies that had been involved with SCP anyway, shouldn't they have known from the start whether they were serious?

Yes, but there was emotion around SCP. They were putting these nucleotides into food, as a constituent of Japanese food every day. They just took cold feet at the idea that they might have marketing problems. The way the Yen has gone it would have been of tremendous benefit to them.

Wouldn't you have displaced their own industry because of your huge capacity?

Oh yeah. This is true...but we were thinking in terms of a modest sized plant to do this and it depended on what we did with the protein side. We did a lot of work tailoring that protein as a human food protein. What need ed to be done in terms of functional properties , taste, texture...Some of these would have gone to animal use. An integrated plant producing a bit for the top end of the animal feed market, a bit for the human food , a bit for nucleic acids, would have looked attractive. But 2 things emerged. If you are starting to make a human food, I don't think you would have started with Pruteen. It had few functional pluses, a yeast would have been better. But

nucleic acid...a bacteria was ideal. The harvesting process were ideal for the animal nutrition, but no good for the functional properties. I finally came to the conclusion, and initiated the paper that said, we've give this a good go. But there are not enough features of market pull and attraction in the human food protein. The Japanese are likely to squeeze us out if they found a better use...and we cant see these sort of macroeconomic things changing enough to make it attractive...time to call it a day.
The nucleic acid thing needed the human food market to go along side it.

Had you done the toxicology for human food which showed that you I think if the product had been commercially acceptable, I think we hadn't too far to go with a few more...we£d done some of the human acceptability tests, maybe another 2-3 years and another £0.25 m to spend on that. NO real concern about that.

Did you start human food toxicology when you realised the animal market was no good?

We did more for the animal food tests than are done for most human foods you eat. We were just thorough. The regulatory people around the world did not know how to test Pruteen. Most drugs, you look for minim al residues in tissues. With SCP you want a maximum...we had a part in advising the protocols around the world

The Japanese emotional reaction...I'd have thought they would have refused to consider Pruteen as a food source, rather than of going along for a number of years...

It was 2 years...we made very rapid progress, it was rather exciting, to work with the Japanese. I don't know whether they actually said "no", but they didn't give us enough assurances for us to find it worthwhile to go ahead with the next phase of development,we thought there was a risk that if we spent another 2 years and £1m , they would not go along with it. They had real problems in sourcing their nucleic acid needs. The paper industry was in decline, many companies were coping bust. They had a tremendous effluent problem. Basically they grew yeast on paper waste , but then threw away most of that and had a huge effluent problem, they just extracted the bits they wanted. They had real needs. I think we got to the top people quite quickly, we didn't waste too much time discussing the technical things. Maybe we were a bit naive...I don't know. Nucleic acids were increasing in Yen terms, we got a good feel of what their cost structure was... we could have made...not enough to throw away the protein, ...but one of them talked about the possibility of a joint venture to produce it over there...these were the sort of discussions going on.

The skim milk market when the submission was made to the board Was it important

It was discovered about 3 months before I joined the project, most of the thinking had been around feeding pigs up till then, in the autumn of 71 my predecessor had done a bit of work on skim milk It became an integral part along from 72 until the 76 decision. It depended on part of it going to that and part to what we called the granular market. The debate was around the proportions of the 2, obviously there was some extra cost in making a milk replacer product. One, you had to keep a low iron level. You had to run the fermenter within tighter limits, then grind and oil the product. Should you have a 100 000 t/a plant with maybe 15 or 20 000t/a going into skim milk,or whether you should have a 30 000t/a plant with maybe half going to milk replacers. At the decision o build the plant...and I've got to be careful or I may seem to be a bit critical of my own colleagues. In those days Ag DIv was very much a science and engineering company. Marketing did not play a very big part. The vast majority of the employees and the senior managers and the directors had engineering or research background. Basically I think they got mesmerised a bit by the benefits of scale. For myself, in hindsight, I would have been right, I would have gone for a 25 000 t/a plant which one would have been confident you could have sole the output. The engineers convinced themselves and they had the power, that to get the unit costs down, you needed n excess of 50 000 year. Even with the extra capital costs there were a whole lot of arguments around, many items are standard and it isnt that much more, we were in a development area , and there was 52% free depreciation and 20%c development area grant. The amount of cash it cost you was only something like 28% of the cost. With all these arguments...went along with a big plant. I went along with it at the time Ididnt have power to do otherwise, but in hindsight I certainly had in my gut at the time ..it would have been a smaller business...but an argument against the smaller one, was the argument that if you are going to build a world scale business, in a market of 10s of thousands of millions of tonnes of Pruteen you don't build tiddlers, if ICIwere going to be in it they should be in it properly.

gas but they actually did n;out; use it to develop gas using industries, but we looked at Rotterdam, where the world protein markets is, therefore lower distribution costs, at Ireland, where we would have had high development grants. A combination of the factors that it was a big leap and we needed to be where the technology was and with the people that could solve the problems, with the methanol plants with the gas from the N Sea, ...if you had to do it in Europe Billingham was as good as any We spent a year and a half working with the Iranians and got quite a way towards building a project. The way their demand for fishmeal and protein has developed that for them it could actually have been quite a good deal. And at one stage we did think, should we just use Iranian money and build it out there with all the difficulties of servicing.. if it had been built there, with the price they had put gas on, it might have been the best bet. Mexicans were very keen, but then they ran out of money.

But you were trying to license technology to Mexico?

Yes, and the Iranian one was a potential parallel to Billingham, or instead of the Billingham one. I would like to reiterate the fact that...in my last 3 or 4 years with ICI I tried to sort out the biotechnology portfolio. I think you can say we were in terms of technical and marketing knowledge we started off with very little of each. To solve technical problems, we didn't know the marketing side a t all. But it so happens that because of the time scale and the effort put in, we failed because of the protein and energy price wrong. We were sop close to so may of the European feed manufacturers. Me and my staff, we got to know them very well.

How about this organisational change, leading to a more commercial attitude.

I was very close to Rob Margetts...we spent lots of time in planes, in meetings, discussing what we were going to do. I woudnt claim that I was a major player, but certainly party to all those discussions.

Were they based on how can we use our Pruteen plant?

WE started from Rob being an optimist...when e realised we were not going to make it in the animal feed market, his reaction was . Christ, we cant throw away all these skills, the least we can do is to see if anything can be done with the plant. With all this knowledge, although it didn't succeed we still had a lot of knowledge of how to develop and evaluate products and to get in and understand markets. We should not throw this away... We had big research, big engineering depts., quite quickly we realised they were working on the wrong things. When I got involved, there were 31 projects. Some of them there was little being done on. But you could sit down and list 31 things that people were doing worked on. In what was the biological part of the research department. What we needed was a structure that would get that much more market orientated. That would begin to reduce that 31 down into 6 or 8 strategic areas,and get some criteria around which you ;could judge those. Now there was great resentment to actually imposing this kind of thing. But we gradually won them round. What you've got to do is for people themselves to see that this isnt actually going to make anything. If you can get some criteria for whether a project has any chance in succeeding, you get people then to close down their own projects. But in a way that does not demoralise them, sothat they still look for new things.

Why 31 projects, because no-one was really aware of what anyone else was doing?

There was no-one stopping things, they had a few people sitting in reviewing technical progress, but they did'nt have somebody sitting saying, where is this taking us.? If we spend £$200 000 in the next year, where are we likely to be and what are the options? That may seem odd for a company like ICI, but it s typical of British industry. I think we did a fair part to sharpen that whole thing up.

How far was Pruteen a lesson for saying, we should sort research out?

i don't want to overstate my role. Rob was s brought in as general manager of Pruteen, but then within about a year and a half he was made a director but he also got research. He had two groups of people, Pruteen and research which was more or less divided into catalysts and support of ammonia and methanol and biological. Basically he was using the few other people that he trusted to help think how we could bake this thing more effective. What was apparent was that in this day and age you could not have a free standing research activity that set its own targets...the commercial input they had was a couple of blokes from planning and coordination, who looked at the market and assessed the market ...but there was no real executive authority, that resided with the research manager, and they had to fight for his money each year. But a lot was being spent on things which never had a hope in hell of seeing the light of day.

Even with planning people defining the market?

They didn't ...it was a cosy club. They were all my good friends...and still good friends... who sat round review meetings once every 2 months and reviewed all the group projects. But there was not enough steel or hardness about it.

So did you say , on the basis of development costs,. only 7-=8 can be supported so compare and choose?

Well, one of the good things that P Thomass and I did was that we arranged a 5 day session with Manchester Business School, around the Pruteen project...on the process of innovation. And we got through to a lot of managers on or a bit below my level,what the mechanism of innovation is about. You had to have a hell of a lot of ideas, you had to allow people free thinking, but then you had to get rid of most of them. ANd you had to spend a little money on a lot of things. You had to keep doing tests, technical or marketing, without spending too much money, to actually see whether this was something that could fit in with something that can grow with something that fits with your strategy. And you've got to look at maybe a 100 to get 2 or 3 that are worth putting a £0.25m each into. But you shouldnt be too hard on your criteria at that early stage. But people have got to have people realise that when you spend real money you have got to be hard. With £200 000 and 8-10 people full time, you have to believe something worthwhile is going to come out of it at the end. It doesn't have to be that finite, but at least the macro sums have got to be looking OK. WHEN YOU MORE TO SPENDING £1-2 M YOU MUST BE HARDER...EVEN THEN, YOU KNOW THAT TO SUCCEED eventually with 2 or 3 you are going to spend £2-3m that are going to be wasted. But that's the whole business with innovation, which if you ;get it accepted, people can work with things then drop them then move on...they hate their pet projects being dropped, but you've got to persuade them that they should drop it.

Pruteen was something that evolved out of the old system?

Yes, it did in a way...but by the time I came in with a pilot plant built costing..£6-7m in todays money, there was a lot of investment , a lot of people, a lot of commitment to going ahead. And I think I have indicated that I would have queried the decision to build as big a plant as we did. But bearing in mind that those were the soya prices we had then,...(starts drawing graphs again).

The reorganisation would have happened anyway?

Yes, the Pruteen research would have been with the production people. There would have been a little ongoing research, like genetic engineering. A bit of fine tuning around the mineral balance we used...the sort of thing o support efficiency improvement. A little to do with fractionation..Perhaps a case to have a real go at this Japanese thing. But the nutritional thing, we had already run it down, we had people at Jealotts Hill, before the plant was running we had closed that down, some of them out of the company, but we moved some of them up to Billingham...that was inevitable. The catalyst of

Pruteen demise, if you like, was to say, lets put less emphasis on Pruteen and more on biological products. Whatever we do with Pruteen is a part of Bio P. But it is not a big, major thing inits own right. That was politically important within the company, because having a high profile when it is apparently not going to succeed is not politically on.

So you made it part of another division.

These 31 projects were all peripheral to Pruteen?

All peripheral.

Carried on by people brought in to work on Pruteen?

They had their brainstorming sessions, things like cellulose hydrolysis and quite a bit of good modern stuff, the use of enzymes and microbes to generate chemicals..

PHB?

PHB, but then the use of chemical intermediates in the pharmaceutical world, there was a chance of better routes to them by biological rather than chemical means. Then there was the cyanidehydratise, the enzyme for cleaning up cyanide waste, those were the goodies, there was an awfullot of rubbish in there as well, people working on things that were never going to see the light of day.

So some work on biological area anywhere...how far does that weaken the statement that Pruteen was the basis of biological research.

Oh I think that's essentially true. Well, first of all there is the collaboration with RHM. BAsically they had the basis of a good idea, and strengths in getting it tailored for the food market, but in terms of the science, understanding the organism, and scaling it up, they just wouldn't have got anywhere without us.

Technically weak?

Yes, their experience was running 1 metre fermenters, we were able to bring that up to the pilot plant, 50 m cubed, in a very short space of time. It snot only science, its the ability of engineers and biologists to work together, that is a big lot of the strength we got out of Pruteen . To get marketing and nutritionist people to operate with the scientist at the bench and engineers.

What were these problems.

Oh dreadful! People come from different backgrounds, engineers are very numerate, they like the data on heat transfers and rates of growth...they like this well done... biologists...they are improving...but they tend to be non-numerate, the concept of what will work, but when it comes to producing the hard data, they are in a bind...you get prima donnaish attitudes, and ICI are not perfect at it, but a lot better than most.

Any examples of R&D discovering something that then opened up a new market?

For Pruteen the technical push was the whole idea was bugs would grow on methanol..this massive biological factory is producing this huge range of biological ingredients...

That's the technical push part.

but given that there was a 2 way flow of ideas. So marketing was looking for ways of using R&D output?

Well, we were actually functioning...because of the bug we had chosen and the fact it takes 8 years to prove it is safe, we were constrained. It was fine tuning, you could do that at the end, choose the size of granules you made and whether you oiled them or not. Much work tailoring the physical properties of the product to the market...but when you come to changing technical ideas really changing and opening up market opportunities, that is more around what is happening around bio products in the last 4 years. This whole idea of using enzymes to produce chemicals that are almost impossible to make using chemical means..an example, dichloro acetic acids one of the chemicals used n weedkillers. You can get a fairly cheap product that contains the mirror image of it, you ;can use enzymes to' just opt out the other one. That is a simplified version, but his is an entirely novel idea. The one on cyanohydratase..an enzyme which can convert quite massive amounts of cyanide in wastes..1980s technology...from the University of Canterbury. Part of the purpose of B PDTs was to have an antenna into the Universities to pick up such work. good for ICI, and for Britain.

Did you go to R&D and say, can you split itup?

I ran that project for 1.5 years. BP was not set up then, but I had people from engineering, research in a project team. Initially it was seeing what was feasible, getting some crude product, taking it out to Japan, finding out what tests they would put it through...initially they wanted crude stuff, they would clean it up, then they said , oh, could you clean this up a bit, and this, ...w e did this in about 10 weeks flat, then they said, can you take it a bit further,,, that's the way innovation works. We had one team for that, in different depts, there are all sorts of problems over running up transfer costs, overheads, loaning people...One had a responsibility for these people, but when they weren't doing the research they were back in their own ghettoes, so to speak. For BP we tried to get accountability where it can be effective.

How far senior management were involved after approving construction of the plant? What was their involvement?

Well, our (?) was quite good , certainly up to the decision making. Virtually all the executive main board directors came up on their own and spent a day , during which they received a presentation from us. They had opportunities to probe as much as they liked. I can remember when Bill Duncan, who was deputy chairman and Denys Henderwson was his general manager, came up and although we knew Denys quite well, he hardly asked a question all day. He's now the chairman of ICI! So there was plenty of opportunity for the Main Board of directors to get to know, at that stage, what they were letting themselves in for. ICI still wasn't very cleverly managed. It was still Main Board directors had responsibility for one or two divisions, or areas of business. And Alan Robertson was really our link between the Division and the Main Board, between Agric chemicals and Pruteen. A lot of the discussion was really with him. If he approved it, then...in fact my directors were Hart then Rob £Margetts were able to by-pass the Board, the Division Board, and go straight to Alan Robertson. During the first 2-3 years when we believed we could build big plants or license...Alan was supportive, but I guess he didn't expose too much what we were doing to the Board. It would have got maybe a couple of half hours a year, kind of thing. You see, people like him tended to be product champions. Once the likes of him thought, we'll run it for another year, and we'll try and achieve this, once he was convinced that was what we were going to do, he could peddle that. Now, the way ICI's organised, its much more dependent on a business manager, a reporting to a small sub-group of the main Board, with no-one too committed to it. They would all look at it quite objectively.

Before it was up to one person. if they OKd it , that was that?

A lot of planning in ICi was like that, once you had decided to build a new ammonia plant, if the division decided that and Alan Robertson agreed with that, there was no dissent. You know, everyone was all hands to the gun to get the best design , the best price, get it built and get on with it. I think it is much healthier now, reviewed with some frequency, so if they are not doing as they should, they can be changed.

Again, what was the Board's reaction to Pruteen failure, did it change their thinking?

I don't think they knew what to do with it. Alan Robertson, inthe latter days he was ill, he had hip replacements and things like this. I think a lot of the thinking came from Rob MArgetts, and he took a bit off 'P Hart and G Malden , people like this. He had to decide whether we should wind the whole thing up and take ICI out of this biology, or whether we should say there are good things around here, what can we build from it? And its looking a lot brighter.

Do you think I could get to B Margetts?

I doubt it, he has a huge job now. Difficulty getting to Bob. I would have difficulty getting to him , for half an hour in the day.

ANY OTHER S MANAGERS?

Yeah. Turn this thing off for a second there.

APPENDIX 5 - PHILLIPS PETROLEUM AND "PROVESTEEN"

Based on a telephone conversation with Dr Sogo, Phillips Petroleum Corporate headquarters Brussels and "Provesteen" literature.

Provesta Corporation is a wholly owned subsidiary of the Phillips Petroleum Company and it controls the marketing of an SCP product termed "Provesteen" in the US. Some features of its production process are the following:-

Semi-industrial size plant, < 30 000 t/a

Methanol, ethanol or sucrose substrates

Stir paddle fermenter

Yeast is grown at 15% cell densities compared to the more usual 3-4%.

This last feature is significant because it enables direct spray drying of the fermenter product which cuts out the separation and centrifugation stages of harvesting. The information comes from a 1983 article on Provesteen by Wegner, who also made the comment that,

> "A switch to alcohol-based feedstocks is brightening SCP's future." (Wegner, 1983)

The inventor, GH Wegner, was manager of biotechnology processes in the Phillips Petroleum Company in the US. However, Dr Sogo in the company's European headquarters described Phillips as now being "very much out of the biotechnology business". The plant was profitable, but "not in the business of competing with soya as an animal feed." Phillips had developed a number of niche markets which included,

a feeding-cube for pet horses

marine feeds, (aquaculture)

a snack biscuit called "Meal on the Run" for the health food market

However, according to Sogo,

> "If someone came along tomorrow and offered to buy it off us we'd jump at the chance...if we hadn't invested so much time and money we would have closed the plant down."

Despite the optimism of the company literature Provesteen cannot be termed a commercial success. Phillips have no intention of building any more plants, either in the US or in Europe.

APPENDIX 6 - SCP IN JAPAN

Based on an article by Arima (1979) and comments by managers interviewed.

According to Arima (1979) the announcement by BP of the production of SCP from its French pilot plant in the 1960s stimulated research activity by Japanese companies. The following list of events took place in Japan, (abstracted from Arima, 1979).

1968 Ministry of Science and Technology submits a report to the government advising of the importance of SCPs

1962-63 Basic research begun by Kanegafuchi Chemical Industry Co, Dainippon Ink and Chemicals Inc and Kyowa Hakko Kogyo Co

1967-68 Industrial production research begun by Kanegafuchi and Dainippon

1968-69 Commercialisation research and feeding, safety trials begun by Kanegafuchi and Dainippon

Oct 68 Kyowa Hakko Kogyo licenses BP technology

Jun 69 Kanegafuchi signs feed supply contract with National Federation of Agricultural Co-operatives

Aug 69 National papers report nature of health ministry's safety concerns ie the possible presence of mycotoxins and carcinogenic alicyclic hydrocarbons in the three Japanese SCP products

Oct 69 Special Committee on Petro-protein established by health ministry to investigate safety of SCP, toxicological tests begin

1969-71 Ministry of Agriculture sponsors nutrition trials for SCP as a fish feed, eventually announcing that SCP is a safe and nutritious food for fish

Dec 72 Ministry of health announces that Kanegafuchi and Dainippon products are safe if used for animal feed

Dec 72 Protest movements begin to organise

Jan 72 Opposition parties raise health concerns over SCP in Japanese Diet

Feb 73 Voluntary abandonment of SCP commercialisation by Kanegafuchi, and later by Dainippon on grounds that investment was too risky given furore over safety. Both companies continued to insist products were safe. Campaign continues against SCP.

Apr 73 Export of SCP technology prohibited by MITI, excluding established agreements, ie Kanegafuchi with Liquichimica and Dainippon in Rumania

Dainippon Ink and Chemicals had done 12 years research and had laid the foundations for building their plant. They had planned to build a 60 000 t/a plant for completion in spring 1974 with an option to increase output to 120 000 t/a at a later date, European Chemical News (1973). Kanegafuchi Chemical Corporation had similar plans, with an agreement with the Japan Association of Agricultural Cooperatives to part finance their plant and to buy the bulk of its production, (Chemical and Engineering News, 1973).

At least 2 other companies followed these two companies and abandoned their separate projects. According to Chemical and Engineering news the companies official reasons for the suspension of their plans was "vocal opposition from consumer groups", Chemical and Engineering News (1973, p9). The same article reports the companies' private comments that they were given "administrative guidance" to drop the protein projects by the Japanese Ministry of Health and Welfare. This, in Japan, amounted to an order to do so.

The Health Ministry had studied the results of tests commissioned by the prospective producers and finally cleared n-alkane derived proteins as non-toxic when used as animal feed in December 1972. The campaign against the protein products really began at this time because there was a real chance that they were going to come on to the market.

The consumer groups who campaigned against the plants were the "Tokyo Liason Couuncil" and a consortium called "Liason Council to Ban Petroleum Protein". They accused the Ministry of Health of accepting data submitted by the companies rather than commissioning its own studies. This was despite much of the research commissioned by the companies having been done in Japanese University medical departments. The other charge was that low concentrations of toxic material might accumulate in the tissues of animals fed with alkane based proteins to a level where they would pose a significant threat to human health, (the same argument appeared in Italy).

The response of the Health Ministry was to announce that as an animal feed and not a human food, "petro-proteins" were after all outside its jurisdiction. Shortly after this announcement in February 1973 the Minister directed his staff to prepare a new set of regulations on petroleum derived protein products. These were planned to take years and so immediately after this decision came the advice to the companies to suspend their construction plans.

Dainippon and Kanegafuchi both claimed to be continuing product development and to have had complete faith in the safety of SCP at this time. For a time Dainippon continued to promote icensing arrangements overseas and to research alternative feedstocks and uses, such as methanol based SCP and the use of SCP as a pet food.

Government safety tests have continued, one major programme involving > 5 600 hens over 5 generations. The result has been at least two further major Japanese clearances of SCP as a safe product in the 1980s.

Arima (1979) identifies other products whose safety status was withdrawn at this time due to public pressure. There was a continuing series of poisonings and pollution incidents throughout the late 1960s to 1970s such as the Minimata disaster,[1] and Arima describes how public distrust of the government and the chemical and oil companies was at a maximum. SCP was a casualty of this distrust and Arima believes may make a return in Japan.

The debacle in Japan contributed to the problems of BP and Liquichimica in Italy but it is more important that the Italian protest movement was similarly motivated to the movement in Japan[2], ie no-one trusted what the government or the companies were saying.

[1] Both Hamer and Senez thought the Minimata mercury poisoning disaster in Japan had heightened public mistrust of industry. Hamer referred to the chemical industry's reluctance to pay compensation when they were clearly responsible for the mercury poisoning, and industry in general was seen as dirty and untrustworthy. Under these conditions consumer groups were very hostile to any product such as SCP that might be considered toxic on a priori grounds.

[2]Although Senez, who had been invited to Japan several times to speak in favour of SCP, believed that the extraordinarily strong consumer lobbying against SCP in Japan was part supported by the American government, who had an interest in preserving their soya meal export outlets.

APPENDIX 7 - LIST OF INTERVIEWEES AND COMPANY POSITION AT TIME OF PROJECT

Shell	Position on novel food or feed project and location of interview
Dr S Bett	Researcher, Sittingbourne, responsible for running pilot plant.
Dr J Brewed	Researcher, Sittingbourne.
Prof J Akinin	Head of fermentation research, Sittingbourne.
Prof G Hamer	SCP project leader, Sittingbourne.

ICI

Dr G Tomng	Researcher on Shell project, then moved to ICI 1976, about the time the Shell project ended, stayed with ICI until 1981 and was responsible for development of fermentation technology on laboratory and pilot plant scale, then commissioning manager on the full scale plant.
Dr D Swindall	Regulatory, nutrition, toxicology manager until 1986.
Dr P Harwin	Head of research, Pruteen.
Dr G Thomas	Food scientist in Biological Products, working on mycoprotein project, formerly at Unilever.
Dr DWJ Saxton	Marketing manager, Pruteen. Came to project in 1972 and investigated UK, European feed market until about 1981, confidant to Rob Margetts when

	Margetts was involved in reorganising Pruteen work.
Dr I Warsop	R&D manager, Pruteen, on nucleic acid fractionation project.
Mr J Smissen	Presently business manager, Biological Products, in charge of ICI side of mycoprotein project with RHM.

RHM

Mr J Treeby	Since 1980, chief executive Marlow Foods, involved in RHM project since 1971.

John Brown Engineering

Dr M Bettley	Pruteen project manager.

BP

Dr G Northgate	R&D manager for Grangemouth pilot plant and responsible for Sarroch plant specifications and part of construction team in Italy.
Dr J Peachey	Project leader, Grangemouth and head microbiologist.
Dr J Payne	Director of national bacteriology laboratory, Marseille, and consultant to BP France from 1950s until late 1960s.
Dr E Leivers	Agronomist, BP France, worked on BP France Lavera project from 1966 to end of project, then involved

	in Sarroch project until 1978 as translator to BP managers who visited Italproteine to take charge of negotiations with Italian authorities in Italy.

Hoechst

Dr Liesser	Scientist in charge of nutrition and toxicology on Probion project.

IFP & Elf-Total

Dr Selfridge	Manager of SCP research at IFP.

Bel Industrie

Dr Dinsdale	Director of technical research, Protibel.

T&L

Prof R Garoffalo	Research scientist who took over fermentation from Dr Cowen, 1978, now head of R&D, (1988).
Prof C Finlay	Head of R&D, until 1980.
Dr F Cowen	Head of fermentation research until 1978, then head of "New Ventures" until 1979.
Prof R Haydn-Davies	Fermentation consultant to T&L, BP and ICI.
Prof Bu'Lock	Fermentation consultant to T&L, BP, and ICI based at chemistry department, Manchester University.

Liquichimica

Dr Zamgrandi	Scientist and head of nutrition, toxicological programme, Liquipron project.

Dansk Bioprotein

Mr J Rasmussen	Marketing manager.
Dr L Jorgensen	R&D manager.

Norsk Hydro

Dr S Gulbrandsen	research scientist in charge of Norprotein pilot plant in Sweden, now head of Biotechnology division.

Birmingham University

A Rimmington Doctoral student Department of Russian and European Studies.

Cellulose Attisholz

Mr Arni	Marketing manager.
Dr Hoolie	R&D manager.

The following is a list of contacts who gave advice or information, however briefly, by telephone.

ICI

Mr J Scott	ICI statistical information service.
Dr D Hayward	ICI Fernhurst Laboratory, paraquat marketing manager, Americas.
Dr P Hart	Director, agricultrual division ICI.
Mr R Pickles	Business manager, Biological Products Division.

BP

Prof R Whittenburg	Fermentation technology consultant, Grangemouth plant.

Pekilo Process

Prof Bettorn	Research scientist, Metsa Selva.
Dr Rakunen	Head of R&D, Boregaard.
Prof G Forss	Head of Finnish Pulp and Paper Institute, Helsinki.

Phillips Petroleum Co

Dr Sogo	R&D manager, Belgian corporate headquarters.

RHM

Dr G Solomons	Head of R&D, formerly research scientist, BP Grangemouth.

Unilever

Prof M Duckworth	Strategic research guidance, Colworth research centre.

George Bassett

Mr Hartdon	Chief engineer, Sheffield plant.
Mr Lyons	Head of R&D, Sheffield plant.

Nestle

Dr D Farr	Present head of R&D, Vevey, Switzerland

Others

Mrs C Kennedy	Author of book on ICI, interviewer of P Hart.
Mr D Fishlock	Financial Times science and technology writer.
Dr D Sharp	Prospective author of book on SCP.
Mr M Walker	Moscow correspondent for the "Guardian."
Dr G Coton	Food industry consultant.

APPENDIX 8 ECONOMICS OF MICROBIAL PROTEIN PRODUCTION

Based on a book by Hacking, conversation with Hacking over economics of Dansk Bioprotein process and conversations with other managers.

A8.1 Methanol Plants and Pruteen

Andrew Hacking has collected many of the available statistics on the economic costs of microbial biomass production in his unique book on the economics of biotechnology.

The key indices for the economics of the hydrocarbon based SCP processes are the price of the substrate and the retail price. The retail price must fall between the price of soya meal and the price of fish meal to stand a chance of being economic for compounders. In table A8.1 there is a list of the operating costs for a number of projected 100 000 t/a methanol SCP plants. The key constraint is the dependence of operating cost on substrate price, methanol. This was as high as 59% for Pruteen, even before the 1979 methanol price rise. Hacking (1986) considers the prospects of a viable SCP process given 1986 prices.

> "Soy meal sells from around $200/ton and fish meal at $350-400 ...even at price levels approaching fish meal with methanol prices at $150/ton...these plants will barely cover their operating costs. Even during the 1960s, at a time when methanol prices were much lower in relation to protein feeds, the economics of such plants were so dependent on substrate

	Norprotein (%)	CTIP (%)	Hoechst/ Uhde (%)	ICI (%)	SRI International[a] (%)
Methanol	51	50	46	59	49
Other chemicals	19	28	20	17	28
Utilities	16	15	23	24	15
Labour	9 }	7	4	—	2
Maintenance & administration	5 }		7	—	6
Methanol price	550 Nkr t^{-1}	NA	200 DM t^{-1}	NA	107 US \$ t^{-1}

[a] SRI International's evaluation of a process design based principally on ICI patents.
NA = Not available.
(The calculations were made before the OPEC price rises of 1979.)
From M. Ericcson, L. Ebbinghaus & M. Lindblom (1981). Single cell protein from methanol: economic aspects of the Norprotein process. *J. Chem. Tech. Biotechnol.*, **31**, 33–43.

Table A8.1 Operating costs of 100 000 t/a SCP processes based on methanol. (reproduced from Hacking, 1986 p99)

Item	% of total cost
De-watering	19
Off-site services	16
Fermentation	14
Drying	12
Storage and packing	12
On-site services	11
Compression	9
Effluent treatment	4
Raw materials	3

Data from ICI as quoted in D. Fishlock (1982). *The Business of Biotechnology*, p. 104. London: Financial Times Business Information Ltd.

Table A8.2 Capital costs of the Pruteen process, 1980. (reproduced from Hacking, 1986 p101) that maximum conversion efficiencies were essential and all other costs, ie utilities for aeration, de-watering and drying, had to be minimised...when capital costs are considered, the schemes become entirely academic...repayment of capital costs and interest even on a $100 million plant would be in excess of $15 million/a" Hacking (1986 p100)

These capital costs would add more than $150/ton to the price of the product, and it was this addition that pushed the operation into non-viability. This analysis is consistent with the ICI managers' comments. Harwin said that they knew the plant was uneconomic after the 1979 methanol price rise, but with the capital costs sunk in the plant the aim quickly became to license the technology to other countries.

Bettley (John Brown) thought the Pruteen plant could just meet its production costs when operating at near half its full capacity for the calf veal market in the post-1979 economic conditions. There was no other data collected which would back this up.

Zamgrandi (LQ) made a crude estimate of the increase in price an SCP product could command if it was sold as human food. This was about £2-3 000/t instead of £500/t for the SCP protein product. This is why the change was attractive, but of course there were many difficulties in the way of switching markets (chapter 4).

Table A8.2 gives a breakdown of the capital costs of the Pruteen process. Hacking observes that the dewatering and drying costs are greater than fermentation and compression equipment costs, (31% to 21%) and no one component exceeds 20% of the capital cost. Fermenter technology is not the major constraint on the capital costs of the process. (See table A8.3 for a breakdown of dewatering costs.)

A comparison with established methods of producing yeast biomass is instructive. This product retails for about $1000/tonne but is produced with conventional fermentation techniques. It is a non-sterile, batch fermentation from mostly antiquated equipment with the investment capital completely amortised. The Cellulose Attisholz plant was a good example of such plant. Used as a nutritional supplement or for baker's yeast a retail price of $1000/tonne is achieved. Table A8.5 gives a breakdown of costs, total costs being approximately $840/tonne. These processes are only economic because of the high value of the market. The difference between this cost and the approximately $400/tonne cost of SCP products represents the achievement of the more advanced SCP fermentation processes and their economies of scale. This difference exists but it is insufficient to bridge the price gap between the specialist yeast biomass market and the bulk animal feed market. The yeast biomass market is limited and is also saturated with established producers, (see table A8.4 for world production of yeast biomass).

There has been a substantial fall in the price of hydrocarbon substrates, especially since 1986. These changed economic conditions mean that Pruteen would almost certainly be economic once more (see Swindall, chapter 7) if it was sold as a milk replacer. The decision not to do so is probably more strategic than economic (the plant still exists, intact). These economic changes will be discussed in relation to the Bioprotein process.

Initial solids (%)	kg water to remove	kg water per kg solids	Direct drying cost (¢ at 2¢ per kg water)	Total costs ($ per te)	Centrifuge costs ($ per te solids to 30% solids)
1	99	99	198	1980	99
2	98	49	98	980	66
5	95	19	38	380	22
30	70	2.3	4.6	46	—

Drying costs calculated on 1 te steam (at \$20 te^{-1}) to remove 1 te water; centrifuge costs on electricity at 5¢ per kWh.
Adapted from Labuza (1975).

Table A8.3 De-watering costs for SCP yeasts, (reproduced from Hacking, 1986 p129)

Location	Baker's yeast	Dried yeast[a]
Europe	74000	160000
North America	73000	53000
The Orient	15000	25000
United Kingdom	15500	[b]
South America	7500	2000
Africa	2700	2500

[a] Dried yeast includes food and fodder yeasts.
[b] None reported.
Production figures for USSR not reported.
From: H. J. Peppler (1979). Production of yeasts and yeast products. In *Microbial Technology* 2nd edn, Vol. 1, p. 159. New York: Academic Press.

Table A8.4 Estimated annual yeast production 1977, dry tons (reproduced from Hacking, 1986 p106)

Component	Requirement per te feed yeast (92% dry matter)	Unit cost	Cost per te yeast ($)	Percentage of selling price ($1000/te)
Variable costs				
Molasses	4000 kg	$70/te	280	28
Water (20 °C)	500 m³	2c/m³	10	1
Steam	10 te	$20/te	200	20
Electricity	1200 kWh	5 ¢/kWh	60	60
Sulphuric acid	40 kg	$0.09 /kg	3.6	0.36
Diammonium phosphate	80 kg	$250/te	20	2.0
Urea	150 kg	$220/t	33	3.3
Magnesium sulphate	5 kg	$0.30 /kg	1.5	0.15
Antifoam oil (crude lanolin)	10 kg	$1.20/kg	12	1.2
Total variable cost			620	62
Fixed costs (plant overheads, labour)			100	
Interest and depreciation at 20% of capital cost p.a.			100	
Total manufacturing cost			820	

Plant capacity 6000 te yeast p.a.
Capital cost $3.0 million.
Data adapted from Paturau (1982).

Table A8.5 Costs of yeast biomass production
Reproduced from Hacking (1986 p 106)

Analysis of confectionery waste solids (% w/w)		Annual operating costs for effluent treatment	Yeast process	Trickle process
			(£)	(£)
Sucrose	55	Power	26000	9000
Glucose	16	Nutrients, pH etc.	15000	14500
Starch	22	Bags	500	
Gelatine	3.5	Sludge disposal	—	27000
Caramel	2	Labour (£2 per man h)	4000	1000
Organic acids	1			
Coconut	0.5	Total cost	46000	51500

COD removal from effluent	COD mg l⁻¹	% COD removal	COD/BOD
Pre-fermentation	33827±2548	74±4	1.4
Post-fermentation	7795±1353		1.7

Costs of COD removal (£)	Yeast process	Trickle process
COD produced (t p.a.) in manufacturing process	1612	1612
COD removed (t p.a.) by treatment	1198	1612
Process operating cost (£ p.a.)	46000	51500
Water Authority charge for treating residue (£ p.a.)	14500	
Total cost of treatment (£ p.a.)	60500	51500
Cost te⁻¹ COD (£)	37.5	32
Return te⁻¹ COD (£)	48	
Overall cost te⁻¹ COD profit (loss) (£)	10.5	(32)

Table A8.6 Production of SCP yeasts from confectionery effluent.
(reproduced from Hacking, 1986 p233)

A8.2 Dansk Bioprotein

Dansk Bioprotein publish the following figures in their documentation.

Bioprotein/DKr	milk powder/DKr	fish meal/DKr
4.9	12	4.12 May 88
(£417/tonne)		5.78 Oct 88

As a milk powder replacer in animal feed Bioprotein is an economic proposition, irrespective of the price of fish meal. Dansk Bioprotein estimate that the value of the replacement market for Danish piglet feed alone is 68 000 t/a. Their full scale plant is planned to have a capacity of 18 250 t/a, so its output could be taken by the piglet feed market. The recent rise in fishmeal prices create a huge potential market and Dansk Bioprotein believe both that their product is nutritionally similar to fishmeal and that fish meal prices will continue to rise.

The viability of the Dansk Bioprotein process is due to a combination of factors. The 1987 partial removal of the EEC milk powder subsidy has created a demand for alternatives to milk powder. Fish meal prices have risen by a third over the last three years. Natural gas has dropped in price from the post 1979 high, just as the other hydrocarbon substrates have dropped in price, (see tables A8.7 and A8.8). Given these major changes in costs and market value, the use of a different technology in the process is itself probably not the major reason for Dansk Bioprotein's viability viz a viz Pruteen and other methanol based SCP ventures. If this view is correct Pruteen would probably also be economic under the present economic conditions.

It is very tempting to compare the Dansk Bioprotein process with the earlier attempts to commercialise SCP, especially with Pruteen. The Dansk Biotechnology process appears to differ significantly in many repects with the Pruteen plant, yet the product is nutritionally similar and is finding similar markets. The technical differences are discussed in chapter 8, but their economic significance will be dealt with here.

Dansk Bioprotein interpret a three year rise in fish meal prices as the start of a long term shortage of supply. In chapter 4 it is shown that many similar predictions have been made and that these were part of the economic reasoning behind the earlier attempts to commercialise SCP. However, Danish Bioprotein has the larger and more secure milk replacer market, which will certainly allow an economic pricing of their product, if it is accepted.

Bioprotein has been approved by the Danish government for use in animal feed. However Dansk Bioprotein have reduced the costs of their research programme by the argument that their product is similar to Pruteen, and Pruteen is already accepted as a safe product by the EEC and in all the European countries on an individual basis. Nutrition and toxicological testing amounted to as much as a third of the total cost of research on the Pruteen process, (see chapter 8), so it not surprising that they should wish to avoid such costs.

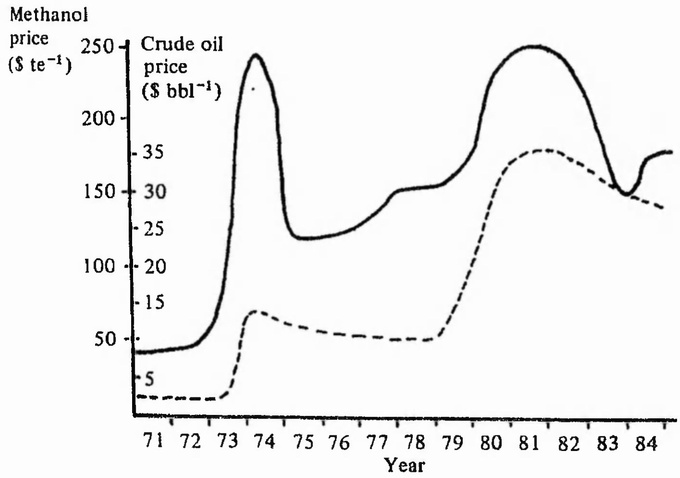


Table A8.7 Prices of Methanol and Crude Oil (US) 1971-1984
Full line, methanol, dotted line crude oil price, (reproduced from Hacking, 1986 p79)

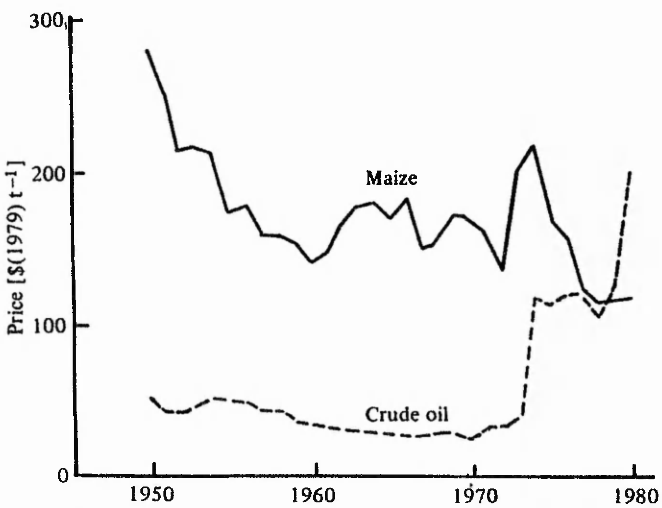


Fig. 4.1. Prices of maize and crude oil, 1950–1980. From King (1982).

Table A8.8 Prices of maize and crude oil, 1950-1980
(reproduced from Hacking, 1986 p74)

This may not be easy to achieve since ICI worked with the various regulatory authorities to ensure that new SCP products would have to pass through the same testing procedures as Pruteen, (chapter 7). ICI did not want other processes riding through toxicological barriers to market entry on the back of their work.

Pickles (ICI) remarked that the Danish pig industry is an export industry and that many pigs were exported to the UK. He doubted that the MAFF would allow the importation of pigs fed on a part Bioprotein diet if Bioprotein had been approved by the Danish governement on the above basis. It is not clear whether Dansk Bioprotein are aware of this danger to their product, or what they could do about it. Pickles observed that there was bound to be some carbohydrate leakage from the methanotrophic bacterial culture into the fermenter medium and there would always be the possibility that foreign organisms might grow on this carbohydrate, if not on the methane in the medium. This is a view with which Hacking agreed.

When Hacking had read the Bioprotein literature he raised a number of other issues. These are interesting as guides to the next stage of assessing the likelihood of success of the Bioprotein process.

1 Hacking simply did not believe that they had cut capital costs to around one tenth that of the Pruteen plant cost. In any case the claim is not quite as impressive as it sounds because Dansk

Bioprotein are comparing the capital costs of their 18 500 t/a plant to the prototype 70 000 t/a Pruteen plant. It would be fascinating to have an item by item breakdown of the Bioprotein plant costs, without this, one is left to link bits of information and wonder about the implications.

2 An example of informed guesswork is the comparison of the Pruteen and Bioprotein fermenter capacities. The projected 18 500 t/a plant consists of 24 fifty cubic metre fermenters with a total fermenter capacity of 1 200 m3. The single Pruteen fermenter also had a capacity of 1 200 m3, but an annual production capacity of 70 000 tonnes. The Bioprotein fermenters suffer from a volumetric productivity almost one quarter that of the Pruteen fermenter. This is probably due to the very low cell densities of the fermenting medium, in Bioprotein's case about 15-20g/litre. So the capital saving per unit of fermenter capacity must be very large to outweigh this productivity disadvantage. This is one of the reasons why Hacking found it dificult to believe that the capital costs were as low as claimed against the Pruteen plant.

3 However fermentation comprised only about 20% of the Pruteen plant costs. Dansk Bioprotein must have made impressive savings on the other parts of their process. This is especially true of the dewatering drying costs, which must be mainly related to the energy cost of separation. Dansk have cut out the ICI flocculating step, but again, how much of a saving does this represent? and the low cell density will incur higher separation costs (see table A8.3).

4 Dansk also refer to a discharge of "less than 20%" of the natural gas that they use. Their fermentation process achieves a relatively low mass transfer, ie conversion of mass of gas to cell mass, (see description of Shell process, chapter 8). They presumably have a transfer rate of around 80% and have decided that it is uneconomic to extract and recycle the unused fraction of natural gas. However, methane is a greenhouse gas, that is it contributes to the greenhouse effect. It is many times more potent than carbon dioxide. Hacking queried how long theywould be allowed to vent enormous quantities of natural gas into the atmosphere at a time when concern over the greenhouse effect is growing rapidly.

5 By Dansk's own figures their electricity costs must be around £100/tonne of product. So it is an energy intensive process. Since the product is priced at about £417/tonne in 1989 this implies that capital costs and other operating costs are very low indeed, less than £300/tonne. But then this is just the claim Dansk are making.

6 Hacking also queried the addition of Cu^{2+} to the fermenters to accelerate culture growth, since feed regulations were very strict about the addition of metals to feeds.

A8.3 Gas-oil

The recent (1986) decrease in the oil price has improved the economics of SCP processes based on hydrocarbons. Prices have been halved from near $30/barrel to near $15/barrel. Payne (BP consultant) believed that the Lavera gas-oil process could be economic once more. A crude estimate of costs suggest that this is so.

Gas-oil £ 94/tonne

Soya meal £150/tonne

(FT 1.7.89)

Fish meal £400/tonne approx

(Dansk Bioprotein (1988), May 1988 price and with 12 DKr to £1)

If we assume the gas-oil price represents 50% of operating costs per tonne of SCP, and a capital payback of 10%/annum with a cost of approx £100m for a 100 000 t/a plant (today's prices), the price will be,

Today's price of gas-oil SCP £338/tonne

At this price the process will be economic if sold to replace fishmeal. The capital payback assumptions are rather lax and it would be more realistic to sell the product as a milk replacer, as BP did in France for several years. The Lavera process was still able to cover costs in this market after the 1973 price rise, so it is not really surprising that it should once more be economic, with a current gas-oil price below the post-73 price (in real terms).

Similar arguments will probably apply to the n-alkane process.

Tables A8.7 and A8.8 show the evolution of crude oil, maize and methanol prices over the 1970s. The rise in maize prices in the 1972-74 period is similar to the jump in soya meal prices at the same time. The two OPEC-induced oil price rises are also visible.

A8.4 Mycoprotein and Fermented Foods

ICI and RHM have recently decided to build a new fermenter with three times the capacity of the Pruteen pilot plant fermenter (approx 18 000 t/a) to produce mycoprotein. Marlow Foods has launched an advertising campaign in the Radio Times and daily newspapers to increase awareness of their growing range of products. These include a Tesco Bombay Bhagia and Kashmiri Korma as part of the Tesco chilled dish range, the Sainsbury's Savoury Pie and a Safe way casserole.

In chapter 7 Treeby accused the food industry of being a "load of cowards." This is interesting in view of what might be considered Quorn's natural competitors, the established fermented foods. These are established in equatorial Asia, where there is a natural animal protein shortage. Various peoples in Indonesia, the Phillipines etc, have developed "crude" fermentation techniques to add protein to their food, which is abundant in fat and carbohydrate but not protein. These foods include tempeh, (soya beans fermented with a mycelial fungus), miso and tofu. Hesseltine and Wang (1980) describe many esoteric examples of such foods. The fermentations are certainly crude in the sense that they are low technology, that is they are open to the atmosphere and infection. However, as Hesseltine and Wang (1980) point out, these foods have been eaten for hundreds of years in these regions, without ill effect. The cultures are often mixed, sometimes involving partial fermentations by bacteria and fungi. They are remarkably stable ie infections are rare or non-existent when the fermentation is regulated by the associated handling traditions. There appear to groups of organisms that interact as a mixed culture and exclude other organisms. This is the same argument as Payne used to defend mixed cultures in the Lavera process, only he referred to Camembert cheese as the Western equivalent of an established mixed culture fermentation.

Heseltine and Wang (1980) conclude that effort would be well spent on attempts to diffuse the Asian fermented food practices to Africa and other protein-poor regions, (essentially the other tropical areas of the world.)

In the first world it would be interesting to know why no western food manufacturer has tried to market products such as tempeh on other than a "health food" basis. The existing approach to marketing would automatically limit the product to health food outlets. What would happen if a manufacturer took the RHM marketing approach to tempeh? Tempeh has the reputation of tasting like chicken; it has the texture of chicken (my opinion) and texture is something at which RHM have worked hard.

A8.5 Wastes

Table A8.6 reproduces a breakdown of the costs of the yeast plant that T&L installed in the Bassett confectionery plant in Sheffield. This plant is economic by comparison to a conventional aerobic digestion system, but only because of the exceptionally high concentration of carbohydrates in factory waste and because of the water authority charges for disposal of the untreated waste. The diffusion of such processes depends on the regulatory environment. This is clear from the case studies. (See Cellulose Attisholz for economics of the Pekilo sulphite liquor process.) There are probably no other such plants in the UK that would find an SCP plant economic.

A8.6 Conclusions

These crude calculations suggest that both a gas-oil and a natural gas based process would be viable under present economic conditions. Whether these conditions will continue and whether any company will want to exploit a technology with such high capital costs and long lead times is the "crunch question." The company that is doing this is, of course, Dansk Bioprotein.

The only method of increasing confidence in the future of these processes is to investigate the structure of the hydrocarbon market and its likely long term evolution. This is certainly going to lead to multiple perspectives. For example Payne was convinced that the end of the Iran-Iraq war would result in hydrocarbons flooding the world market and driving the price below $10/barrel.

However, economics has not been the only problem with the SCP processes. The accusations of carcinogen contaminants in gas-oil based products act as a deterrent to anyone considering a revival of the process and the experience of a vigorous and negative public reaction to these projects in the only countries[3] where large plant were built must poison the prospects of new ventures whatever the economics.

[3] Italy and Japan

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