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The subjects considered in the course of the symposium and therefore in these volumes were construction, transportation, housing, water resources and nutrition--all highly relevant to concerns of the developing countries and all subjects of current interest at MIT. The four volumes of this report contain most of the papers that were commission to formulate questions and issues. Volume 4 contains the following papers by participants in the symposium on the subject of Food Technology:

Introductory Remarks, James Levinson

Some Reflections on Conditions of Transfer of Modern Food Technologies, Aaron M. Altschul

Production of Food and Feed by Fermentation, Arthur E. Humphrey

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J. P. Ruina (ed.)

VOLUME 4: FOOD TECHNOLOGY

April 1974

Massachusetts Institute of Technology
Cambridge, Massachusetts USA

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INTRODUCTORY REMARKS

James Levinson
Director, International Nutrition Planning Program, MIT

Let me welcome you to the session of food technology. I'm Jim Levinson. We have with us on the panel Dr. Chokyun Rha, Assistant Professor of Food Science in the Department of Nutrition and Food Science at M.I.T., Dean Arthur Humphrey of the School of Engineering, University of Pennsylvania, and Dr. Aaron Altschul, Professor of Community Medicine and International Health at Georgetown University.

Our topic today is an interesting one. Food represents a major, often the major need of low-income countries, and industrialized countries have considerable expertise in the technology of food. Seemingly, this is an ideal setting for technology transfer. There are two basic categories of food-related technology one can discuss in this context. One is agriculture technology: the technologies of new seeds--new high-yielding varieties and strains with higher protein contents and better amino acid profiles; the technologies of fertilizer, water management and pest control. Certainly there have been some important technology transfers relating to agriculture--some with very dramatic results. This isn't, however, our subject matter today.

Out subject matter rather involves the second category, namely food technology: the processing, preservation and manufacture of foods. When one speaks of food technology in the context of technology transfer from industrialized countries to low-income countries one might formulate two basic objectives: The first is to increase food supply, or more accurately, the supply of certain nutrients to populations. Food is in short supply today. In many countries the amount of arable land which is not under cultivation is negligible. At the same time there is some question about increasing indefinitely the yields on existing arable lands. The green revolution has been a mixed success. Meanwhile the traditional pattern of food trade in the world has changed considerably. In the 1940's every major part of the world, with the exception of western Europe, was either exporting food or not trading in food. Today we look at this same map of the world and find that with the exception of the United States, Canada, and the Oceania region (New Zealand and Australia), every major area of the world is a net importer. Our food reserves in this country and in other industrialized countries are lower than they have been for twenty years. And all of this is happening while population continues to increase.

What are the alternatives? One of them, perhaps, is to utilize commodities that have not traditionally been used for human consumption and to apply relevant technologies to make them nutritionally adequate and acceptable as food. Examples of this might be oilseed protein, single cell protein grown on petroleum, algae or sewage, and protein from leaves. Another approach, again aimed at that objective of increasing food supply, might be to take commodities that are used for human consumption and to increase their utilization through preservation or extention. The best known example of this is the preservation of fruits and vegetables. Another example is the toning of milk with unconventional protein sources. Still another is the production of protein concentrates from fish that otherwise would not be utilized for human consumption.

A second objective of food technology transfer is the combating of malnutrition. This doesn't mean extending the food supply per se but providing that food to malnourished populations, particularly to the vulnerable groups, in ways which address their malnutrition problems. Perhaps the primary example of this would be specially designed weaning foods for young children.

If we agree that these are the primary objectives of technology transfer relating to food, then we have to examine each of the technologies we discuss in terms of these objectives. In turn, this means we have to ask some very difficult questions.

The first question we might ask is, "Is a new food form or food product going to be sufficiently inexpensive to be purchased by those in greatest need of these foods?" The poorest 30 per cent of populations in many countries often have inadequate disposable incomes to buy even the staple of the country. They often aren't able to afford the staple and accordingly have great difficulty with anything that's more expensive. The average Indian who earns roughly $5 a month purchases only about two ounces of milk a day. If that same Indian wanted to consume a pint of milk a day, it would cost him about half of his daily disposable income. And yet some of the new foods which have been developed are several times more expensive than the regional staple.

A second question one must ask is, "Are the raw materials which are used in these foods really unutilized or underutilized or are they performing some other important function?" Are they a source of export earnings or are they an important source of animal feed or fertilizer, and how would these functions be filled in their absence?

A third question is, "Do the new foods in fact meet the primary nutritional needs of individuals in low income countries?" Do they really address the vulnerable groups in greatest need--the child in his first year of his life, and the pregnant and nursing mother? Does the food get to the child or is it diverted to other members of the family or sold on the market? If it is eaten, is it digestable or does it exacerbate existing problems of diarrheal infection? Does it supplement breast feeding or does it substitute for breast feeding?

And a fourth question, a critical one: "Are the technologies in fact appropriate for low-income countries?" Can a country with limited foreign exchange afford to import sophisticated machinery and spare parts? Can a country with an unemployment rate of 15 or 20 per cent and a serious underemployment problem afford sophisticated capital intensive industries which will employ only a small number of persons? And can the technologies we know today in industrialized countries be adapted to meet these realities of low-income countries?

These are difficult questions, but I hope we can keep them in mind as we look at these interesting examples of new technologies.

SOME REFLECTIONS ON CONDITIONS OF TRANSFER OF MODERN FOOD TECHNOLOGIES

Aaron M. Altschul
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I intend to discuss three models of new food technologies that might be appropriate to improving conditions of nutrition in developing nations. And I will discuss the chances and conditions for their transfer in two kinds of societies: one that is on the verge of famine and the second that is making economic progress. Before doing this there ought to be some general discussion of the boundary conditions and the extent to which these food technologies (and I suppose other technologies) can be introduced in an accelerated fashion, and secondly, a description of the particular problem which these food technologies are intended to treat.

BOUNDARY CONDITIONS

The history of demographic transitions for the most developed nations is one in which new technologies developed alongside general economic progress, and were part of this progress. The ground was laid for the introduction of the new technologies and they came and prospered in a healthy substrate. The situation for the less developed countries is that they are developing at a time when more advanced technologies are already being utilized in the advanced countries. The temptation to transfer the advanced technologies is overwhelming. But such transfers provoke sharp demographic transitions that the state and existing structure of the particular society may not be able to contain. The uncertainties about introduction of these new technologies are first, whether or not they will be accepted by government and the people and, secondly, whether the society is capable of managing the consequences of good nutrition and the new food habits that are generated by the introduction of these new technologies. If these new technologies are energy intensive, there is the additional issue of what net gain can be promised to offset the increased energy cost.

Starvation and malnutrition are associated with poverty, and these kinds of malnutrition are diminished as income rises. The challenge to food science and nutrition is to minimize the lag time between economic development and elimination of the problems of malnutrition. For example, when in the history of a nation's development should nutrition be eliminated as a factor in prematurity, or infant mortality, or blindness?

The role of the government is critical. Governments respond to famine and to an inordinate rise in price of the major staple, for lack of response means failure of the government to survive. In developing countries, governments respond to higher income by making available foods of higher quality or higher esthetic satisfaction. Countries like Russia have the

policy of increasing the availability of meat. Governments respond less, if at all, to malnutrition as an issue. People do not riot because of vitamin A deficiency. (It will be interesting to note the effects of recent findings of wide-spread anemia in the United States and Canada on political decisions). Hence, one of the critical factors in the introduction of the new technologies is the role of government in nurturing them. These new technologies represent an increased cost over staple foods: this increase in cost must somehow be managed by government.

THE PROBLEM

The problem in nutrition which I address is that of increasing protein under a wider variety of conditions. This is not the place to enter into a thorough discussion of the issues now being debated as to whether there is or there is not a protein problem in the world. I have discussed my own position elsewhere. I would say that surely there are conditions of food intake in which an additional increment of protein would have zero or minimal input; the condition most likely to provide this kind of a response would be very low total intake of a diet containing a higher than normal percentage of protein calories. And there are conditions in which there will be a maximal response from an increment of protein intake; these would be conditions of higher than normal or normal coloric intake and very low protein intake. In between these extremes there would be a wide spectrum of conditions which respond more or less to increments in protein depending, in part, on the individual, his age, his state of health, pregnancy, etc. This is the least of the issues, however. At issue is an increase in personal and national options for providing enough calories balanced with protein. If, for example, a person wants to increase his energy intake by using non-protein sources of calories such as vegetable oil or low protein sources of calories such as roots, like cassava, then, if an adjustment is not made, the resultant effect will be a reduction in protein value of the diet. The ability to arrange for other sources of proteins increases flexibility in personal selection of energy sources. And so proteins and energy are not separate and individual problems. There is a protein energy trade-off.

On a national basis, as nations face the need to increase food supplies to feed more people and, in so doing, diminish the resources available for protein foods, be they legumes or animal protein, there is need for opportunities to balance this decrease in protein with other means that would enable a greater flexibility of choice. This is the problem we are discussing and this is the protein component of the food problem.

FOOD and NUTRITION MODELS

These models have in common that their major effect is to reduce or eliminate entirely the need for animal protein in a diet, yet achieve adequate nutrition. In one instance there is the further effect of reducing the need for lysine-rich protein to balance out the inadequacies of cereal protein. And in one instance, esthetic quality is furnished along with nutrition.

A. Protein Foods for Vulnerable Groups

It is now possible to develop protein foods that are entirely adequate to supply the needs of weanling infants, and pregnant and nursing women. These needs have been met traditionally by products such as milk. Where these are not available, the same can be achieved by mixtures of cereals and protein concentrates. Examples of these kinds of products are Incaparina, CSM, and WSB. CSM is a corn-soy-milk protein blend mixture and WSB is a wheat-soy blend; both have been distributed in large quantities as part of bilateral and multilateral aid. In each case the major ingredients are a cereal and oilseed protein concentrate to provide the proper balance of quantity and quality of protein.

While these products seem to have some value in emergency distribution programs they have not achieved any significant success as commercially viable products. It must be remembered that the human being judges foods for reasons beyond nutrition; usually the esthetic requirements override the nutritional virtues. Food products that are both desired and nutritious can now be made, but these will be more expensive than foods designed primarily to meet nutritional considerations. Nevertheless, foods on this model are significantly cheaper than products based on animal food models. Governments interested in introducing such new foods into the national food system must recognize that the cost for attractiveness prices these foods beyond mere raw material costs.

There are some who have wanted to classify these foods, if they are manufactured by commercial concerns, as "commerciogenic" foods. Such a name is generally a derogatory term, originating from a description of commercial practices which encourage bottle feeding as against breast feeding. But some have sought to generalize this term to all new protein foods produced by commercial practice. If this oversimplification obscures the fact that certain foods have the property of eliminating the need for animal protein, then it is a disservice indeed to denigrate them just because they are produced by commercial firms. The handling and social consequences of these technologies are problems that governments must solve, but the basic contribution these classes of foods can make need not be obscured by terms such as these. An interesting point is that these terms are coined and used by physicians who have had no qualms about using drugs and the most advanced medical (professional and commercial drug) technologies in underdeveloped areas without careful scrutiny as to the ability of those areas to absorb the consequences of these technologies.

B. Fortification of Cereals with Amino Acids and Appropriate Vitamins and Minerals

This is a procedure which makes it possible for cereals to become much more efficient sources of protein, almost double in value over the unfortified cereals. Lysine plus wheat is an example of such a procedure. When at the time that the amino acids are introduced, appropriate

vitamins and minerals are also introduced, this becomes a complete pattern for fortification of a staple. This same kind of procedure can be applied to specific foods rather than to the entire staples of a country, where appropriate. The major advantage of this kind of an action is that it reduces the demands on protein from the land and provides alternative materials that are made either synthetically or by fermentation. In the latter instance this is a subsection of fermentation technology to be discussed later.

C. Meat Analogs

These are textured products made from vegetable protein, now mostly soy protein, which have some of the taste and use properties ordinarily associated with meat products. They are finding their way in the most developed countries; it is estimated that by 1980, 10% to 20% of meat equivalent of the American diet will be replaced by these vegetable protein products. Another estimate puts it that by 1980 the market for these products would total one and a half billion dollars, up from three hundred million dollars estimated for 1976, and a hundred million dollars presently.

APPLICATIONS

Case 1

Country in Danger of Famine and Barely Holding Its Own in Terms of Per Capita Food Supplies

It would seem to me that the chances of transfer of new food technologies to that kind of society are low. The reason is not that the need does not exist. Actually one can argue that the more desperate the need (the more aggravated the relationship between resources and population) the more likely that only sophisticated solutions will meet the need. No one advocates, for example, backing off the "Green Revolution" even though it is energy intensive beyond the means of the underdeveloped countries: the alternative is famine or return to huge external sources of food supply. The problem is that acceptance of a new technology is less related to need than to the state of the culture—with everything that this means: industrial production, education, communications, infra structure, etc. And coupled with that is a flexibility of outlook--absolutely indispensable for the introduction of new ideas.

The need is to maintain adequate food supplies to eliminate famine. The best that can be done under these conditions is to maximize existing practices and minimize counter productive habits. This would include better storage and handling to minimize losses, most efficient utilization of legumes, and encouragement to continue longer the practice of breast feeding. I have no illusions that these kinds of activities will solve the food problem. Rather it is a strategy for the best kind of holding action, to minimize and slow down deterioration of the food situation in the hopes that new resources can be brought to bear.

The major opportunity for introducing new technologies is in the emergency foods themselves. This has been done to some extent already in the case of products such as CSM and WSB that have been distributed in large quantities all over the world. Another area in which new technologies could be helpful is in the fortification of major cereals destined for emergency relief either at the point of origin or at the country itself. Fortification of major cereals and the production of the foods designed for infants are not competing approaches. In some instances, the distribution system is such that special foods for special groups is the least costly way of providing extra calories and extra protein. There are circumstances, however, in which the systems of distribution are such that it is better to fortify the entire supply so as to reach the people who would not be reached by an inadequate distribution system directed towards specific target groups.

Even if mass fortification is not appropriate, the notion of maximizing the nutritive value of a mixture of foods by the addition of specific nutrients, amino acids, vitamins, and minerals is well established in animal feeding and makes very good sense in any kind of a feeding situation. Thus, it is possible, for example, to reduce the amount of soy or other protein concentrate in certain mixtures by appropriate addition of amino acids where that is an economically more feasible operation.

Even though the transfer of technology has a low chance of success in this kind of a situation, there ought to be a continuing probe of pilot sections of the area to determine heterogeneities in cultural development that might provide limited opportunities for introduction of these new technologies. In so doing, the developed societies can finance the testing so that there is no need for huge capital outlay in the underdeveloped society until it is proven that this particular approach has merit.

Case 2

A Truly Developing Society

In this society there is economic progress; the challenge is to diminish or eliminate the lag in improved nutrition which would occur, but slower, with improved economic status. It would seem that in this instance, there is a good chance of these technologies being applied. Certainly the development of analogs on the milk model, particularly useful to vulnerable groups, ought to be encouraged. The use of nutrient supplements particularly in fortification of staples or of particular foods makes good sense and can be attractive. Particularly, the distribution centers where food is being made available to vulnerable groups and other institutional feeding programs such as the school lunch can benefit by maximizing the quality of the food that is being distributed and by eliminating the need for the more expensive food ingredients.

Even the meat analog model may have its place. The ability to improve both nutrition and esthetics is a real asset. Ordinarily economic development required to support extensive meat consumption is achieved much later in development. The ability to produce meat analogs from oilseed protein can be achieved at an earlier stage. Since these analogs can cost less than the meat, they can be introduced at a lower level of development. Moreover, since they are new and the conditions of their introduction can be specified by government, it may be possible to put a tax on these products which would be used to subsidize fortification of foods to be distributed to vulnerable groups. Hence, the introduction of the other technologies could possibly be financed in part by taxes on the meat analog.

Even though the chances of introduction of these particular approaches are much better in truly developing societies, it still would be wise to engage in pilot tests to determine the most appropriate conditions for their introduction.

EDUCATION OF LEADERS

We come back to the statement made earlier that the role of the government in the introduction of these technologies is crucial. If the government does not feel that this is a most appropriate priority of development and is not aware of the new tools that are available, obviously this kind of an introduction will not take place. In this respect food technology and nutrition differs from other aspects of development. Governments can understand readily the introduction of new farm production technologies or new transportation or communication technologies or new medical technologies. Traditionally, though, national ambitions have been to reach the same standard of asthetic and nutritional consumption as reached by the developed societies. This means that most governments and their advisors target their goal to increase meat consumption, finally to achieve a kind of meat consumption reached by societies they would emulate. It is far more attractive to solve nutritional problems by drinking milk or making a sandwich of bread and meat than to fortify foods. Nor is it the same to make mixtures of foods that are nutritionally the equivalent of the other models but have neither the attractiveness nor the historical role signifying economic development which the animal foods have.

I believe that it is for this reason that governments have resisted new technologies because they did not wish to admit that, perhaps, they could not reach with their resources the level of meat consumption and thereby the esthetic level of food consumption that other societies have achieved. I believe that it is one of the cruel realities that certain societies will never be able to increase the consumption of status foods.

It is becoming apparent that some societies may have over-achieved this objective, that their consumption of these traditionally high class foods has been excessive and that for medical reasons they may have to pull

back. In recent years there has been a concordance of economic factors which are forcing even the most advanced societies to reconsider their pattern of food consumption and reduce the consumption of the most expensive food items. The fact that both economic and medical reasons are in the same direction is making this transition less painful. Furthermore, the availability in the developed societies of new technologies which make it possible to achieve the same level of nutrition, and perhaps even the same level of esthetics (and ultimately maybe even the same status) makes this transition even more attractive.

The problem facing the leaders of the developing societies is to face the realities of the food situation, to decide that the traditional ways of improving nutrition by increasing the animal component are not open but that there are alternate ways that can promise better nutrition as well as better esthetics. My own feeling is that all of these ideas will be adopted first by the most highly developed societies before the leaders of the underdeveloped societies will have the courage to sponsor them in their own countries.

Finally, the attitude of the government and citizens of the affluent countries may be even more important than either the position of governments of the target countries or the nature of the technologies. In a finite world transfer of technology is insufficient. In order for sufficient energy and basic supply of foodstuff to be available to the underdeveloped countries, it will be necessary for the affluent countries to adopt personal habits and national policies that conserve energy. And they will need to adopt a food pattern that is less wasteful of food supply--certainly one that has less of the animal product component. Short of that, and especially in the United States with the largest and best fed animal pet population of all time, it is difficult to conceive of the recipient country taking the donor countries' efforts and protestations seriously.

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PRODUCTION OF FOOD AND FEED BY FERMENTION

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INTRODUCTION

The world is rapidly approaching the point where man can no longer depend solely on agriculture, animal breeding and fishing for his food. He must turn to other forms of food synthesis. One of the important new sources of food and feed protein is that of single cell protein (SCP). The term SCP was coined at M.I.T. by Professor Carrol Wilson in May, 1966. He was seeking a general name plus an achronym to identify feed and food protein derived from single cell microorganisms grown on various resources and wastes. Professor Wilson felt, and rightly so, that the use of terms such as "bacterial" or "microbial" had unpleasant connotations relative to food usage. SCP, as a term, gained international acceptance when an international conference was organized at M.I.T. in October of 1967 using Single Cell Protein as the conference title.

The idea of single cell protein is not new. Torula yeast derived by aerobically fermenting wood wastes has been produced and used as food in Germany as far back as World War I. The importance of Research on SCP has been recognized in major reports by both the Panel of World Food Supply of the President's Science Advisory Committee in 1967, and by the Advisory Committee of the United Nations Economic and Social Council on the Application of Science and Technology to Development (1967). The latter states that development of large scale facilities for producing "protein from single cells offers the best hope for major new protein supplies independent of agricultural land use".

What are the advantages of SCP?

1. They do not depend on agricultural or climatic conditions: rather, the microorganisms are cultured in large fermentation vessels.

2. They have rapid mass doubling times.

3. Genetic experimentation for protein improvement can be readily undertaken.

4. Production of SCP is not surface or sunlight limited.

The rapid mass doubling time advantage is illustrated in Table I where SCP doubling times are the order of minutes compared with agricultural

TABLE I

MASS DOUBLING TIMES*

Organism	Time for one mass doubling
bacteria and yeast	10 - 120 minutes
mold and algae	2 - 6 hours
grass and some plants	1 - 2 weeks
chickens	2 - 4 weeks
pigs	4 - 6 weeks
cattle	1 - 2 months
people	0.2 - 0.5 years

* Maximum rates are being composed

TABLE II

AMINO-ACID DISTRIBUTION OF PETROLEUM DERIVED SCP

		%			
Microorganism	Substrate	Lysine	Methionine*	Threonine*	Tryptophan*
bacteria	natural gas	5.3	3.4	4.5	--
bacteria	n-paraffin	6.5	2.0	4.0	0.9
bacteria	n-paraffin	7.0	1.8	4.9	1.4
bacteria	gas oil	4.3	1.2	4.0	1.2
yeast	n-paraffin	7.0	1.2	3.9	0.5
yeast	n-paraffin	7.0	1.8	4.9	1.4
yeast	gas oil	7.8	1.6	5.4	1.3
yeast	gas oil	6.8	1.3	5.6	2.3
algae	carbon dioxide	4.6	1.4	4.6	1.4
soy meal	-------	6.6	1.1	3.9	1.2

*Amino-acids are expressed as % of crude protein

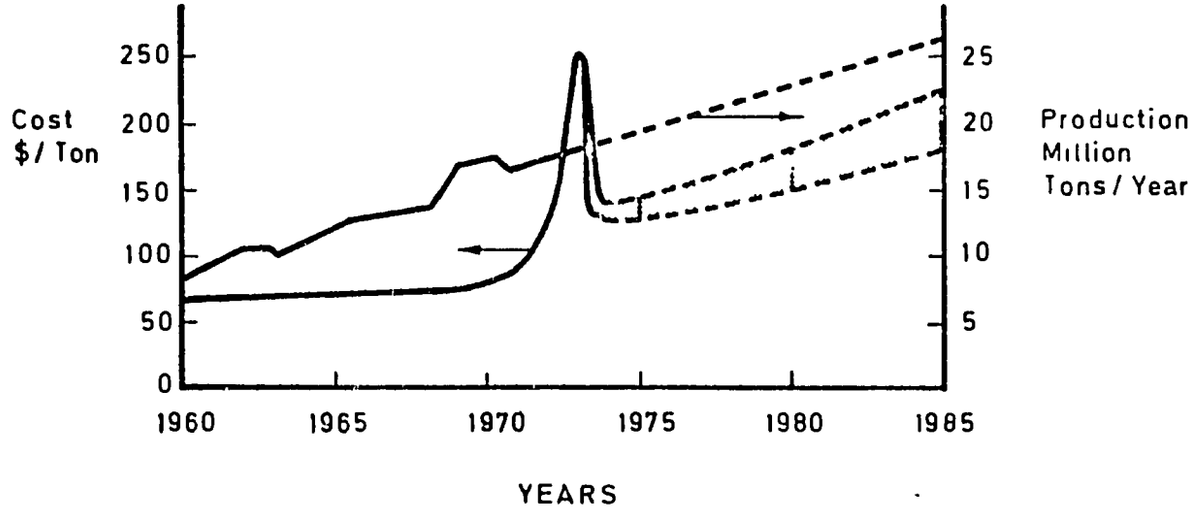
TABLE III

SCP PROCESSES CURRENTLY BEING DEVELOPED

SUBSTRATE	ORGANISM	COMPANIES INVOLVED
N-PARAFFIN	YEAST OR BACTERIA	BRITISH PETROLEUM LIQUICHIMICA GULF KANEGAFUCHI U.S.S.R. GOVERNMENT CHINESE PETROLEUM
GAS OIL	YEAST OR BACTERIA	BRITISH PETROLEUM U.S.S.R. GOVERNMENT
METHANE	BACTERIA	SHELL
METHANOL	BACTERIA OR YEAST	ICI
ETHANAL	BACTERIA YEAST	EXXON AMOCO FOOD COMPANY
SUGARS	FUNGI	TATE AND LYLE
STARCH	FUNGI	RANK, HOVIS AND MCDOUGAL
CELLULOSE	BACTERIA	GENERAL ELECTRIC COMPANY FINNISH P & P LSU - BECHTEL
CO_2	ALGAE	INST. FRANCAIS DU PETROLE

Figure 1

SOYBEAN MEAL PRICES (FOB DECATUR) PRODUCTION (US)



plants and animals where it is the order of weeks. With regard to genetic experimentation, new strains of organisms can be developed in the matter of days. It is possible to select and develop strains that have varied amino acid profiles, protein content, and cell wall digestibility. Table II illustrates some of the variety that has been achieved in the amino acid profile of petroleum derived SCP. In general bacterial SCP is comparable to fish meal, running around 60 - 75% crude protein. Yeast SCP is more comparable to soy meal running 45 - 55% crude protein. The mycelial fungi SCP is usually somewhat lower in protein content. However, it is often preferred for processing because collection can be accomplished by simple filtration rather than costly centrifugation as in the case of bacteria and yeast.

Many different carbon containing substrates can be used for SCP production. They vary from hydrocarbons derived from fossil fuel resources to sugar and starches from agricultural products to cellulosic and CO_2 wastes from agricultural and domestic wastes.

SCP can be utilized in numerous forms including food, feeds, and protein isolates. As a consequence, there is almost an infinite variety of schemes for producing and utilizing SCP.

Opinion among the experts is extremely diverse on what direction should be taken in developing SCP processes. The approach most certainly will be different in low and high technology countries. Western Europe, Russia, Japan and the U.S. have plans for 100,000 to 1,000,000 tons/year feed protein plants. (See Table III) These plants are very complicated and will utilize the latest computer control techniques. Countries in Asia, Africa and South America talk about village level technology and systems producing only 1,000 to 10,000 tons/year of feed SCP. With respect to resources utilized for producing SCP, energy rich countries, those having access to natural gas and oil, are building plants to produce SCP from gas, oil and methanol. Countries with a strong agricultural base, such as the United States, are utilizing solid wastes, such as feed lot manure, seed grass straw, and city refuse to produce SCP. Developing countries such as those in Central America look to local agricultural by-products and wastes, such as molasses, bagasse, coffee pulp, etc., as a source of material to ferment to SCP.

ECONOMETRIC CONSIDERATIONS

The long term future seems clear with an ever increasing demand for protein. The demand and prices projected in the future for soybean meal are shown in Figure 1. Some economists are projecting 1985 soybean meal prices, FOB Decatur, to be around $185 - 240/ton. This could mean $300 - 350/ton prices in Europe for soybean meal and $410 - 465/ton for fish meal. However, short term effects such as the 1970 world-wide agricultural shortfall and the 1973 Arab oil embargo, cloud the issues and make it difficult to produce sound economic advice with respect to SCP processes. If future agricultural short falls should occur and if oil embargoes are repeated,

TABLE IV

EXAMPLES OF LOW VALUE AGRICULTURAL WASTES

CROP	TYPE OF WASTE
SUGAR CANE	BAGASSE
SUGAR BEET	BEET PULP
COFFEE	PULP, WASH WATER
CAROB	HUSKS
DATES	DATE WASTES
POTATO	PEELINGS, STARCH WATER
TOMATO	PULP
GRASS SEED	STRAW

TABLE V. U.S. SOLID WASTES

WASTE TYPE	10^6 TONS/YEAR
AGRICULTURAL AND FOOD WASTES	400
MANURE	200
URBAN REFUSE	150
LOGGING AND OTHER WOOD WASTES	60
INUDSTRIAL WASTES	45
MUNICIPAL SEWAGE SOLIDS	15
MISCELLANEOUS ORGANIC WASTES	70
TOTAL	940

free world trade could be grossly restricted. This could give rise to very local decisions with respect to SCP process feasibility. Also, now that U.S. agricultural surpluses are almost extinct and crops such as wheat and soy beans have become so dominant a factor in the size of the U.S. export dollar, new decisions must be reached as to the form of U.S. aid to developing countries. Should SCP or SCP technology be a factor in this aid?

The energy and environmental crises will also affect decisions regarding the development of SCP processes. For example, SCP substrates include those derived from oil, wastes, and renewable resources. But these are also potential energy resources. By the year 2000, the energy requirement is expected to quadruple. Most of this could come from oil. Will society expend this precious resource primarily for energy, or will it be used for chemicals and SCP production? Which costs, free enterprise or societal, will dominate?

Energy considerations could also affect the kind of process. Aeration costs could become important if energy costs continue to rise. Hence, an anaerobic process in which both alcohol, as a gasoline extender, and SCP feed are produced could be the process of choice.

What will happen to the low value of agricultural wastes that are presently burned, polluting the atmosphere, or dumped, polluting the surface waters? Table IV lists some examples of low value agricultural and food wastes. From Table V, it can be seen that there is a serious problem evolving in the U.S. concerning disposal of Solid wastes, in particular, feed lot wastes and urban refuse. Pilot plant processes are being developed for converting solid waste materials into SCP feed.

These process alternatives will be considered in more detail in the discussion to follow in order to highlight their problems and advantages.

SCP FROM OIL

Large scale production of SCP from oil is a reality. Several 10,000 to 30,000 ton/year plants are "on-stream" and at least three 100,000 ton/year plants are being constructed. Five basic approaches are being utilized. These include:

1. Production of SCP by growth of bacteria on natural gas.

2. Production of SCP by growth of yeast or bacteria on methanol derived from natural gas.

3. Production of SCP by growth of yeast on ethyl alcohol derived from chemically oxidized ethylene.

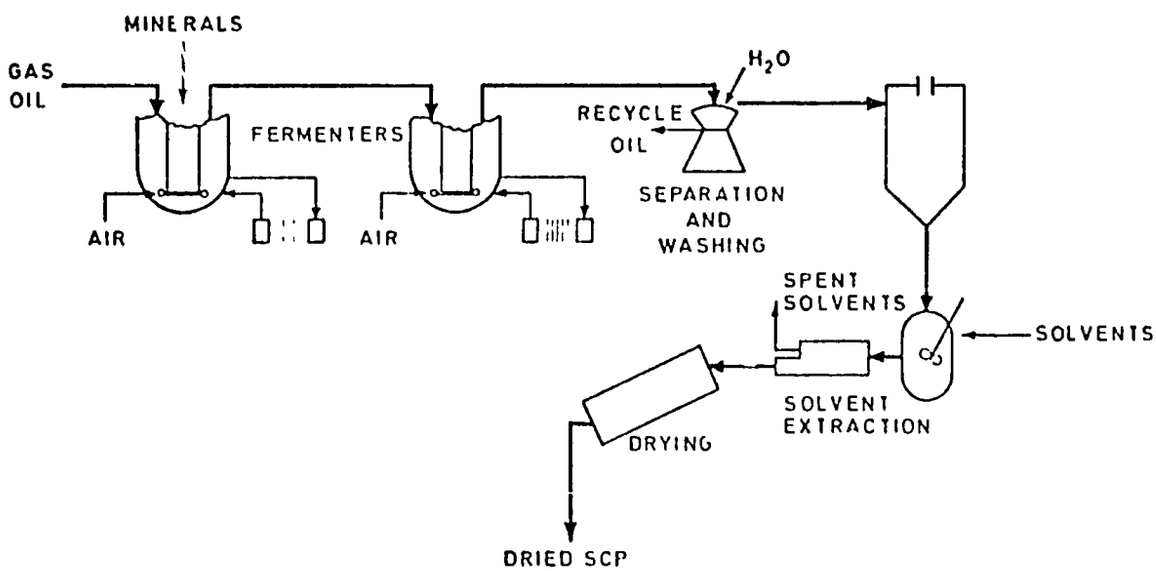


FIGURE 2. SCP FROM GAS OIL PROCESS

TABLE VI

SCP COSTS FOR 100,000 TON/YEAR PLANT

N-ALKANE SYSTEM

ITEM	DOLLARS/TON
DIRECT MANUFACTURING COSTS	227.13
SALES EXPENSES	24.00
DEPRECIATION	47.18
OVERHEAD	34.07
TOTAL PRODUCTION COSTS	332.38
BEFORE TAX PROFIT	91.38
PRICE/TON	423.76
TOTAL CAPITAL REQUIRED	$49,182,900
RETURN ON INVESTMENT =	15.8%

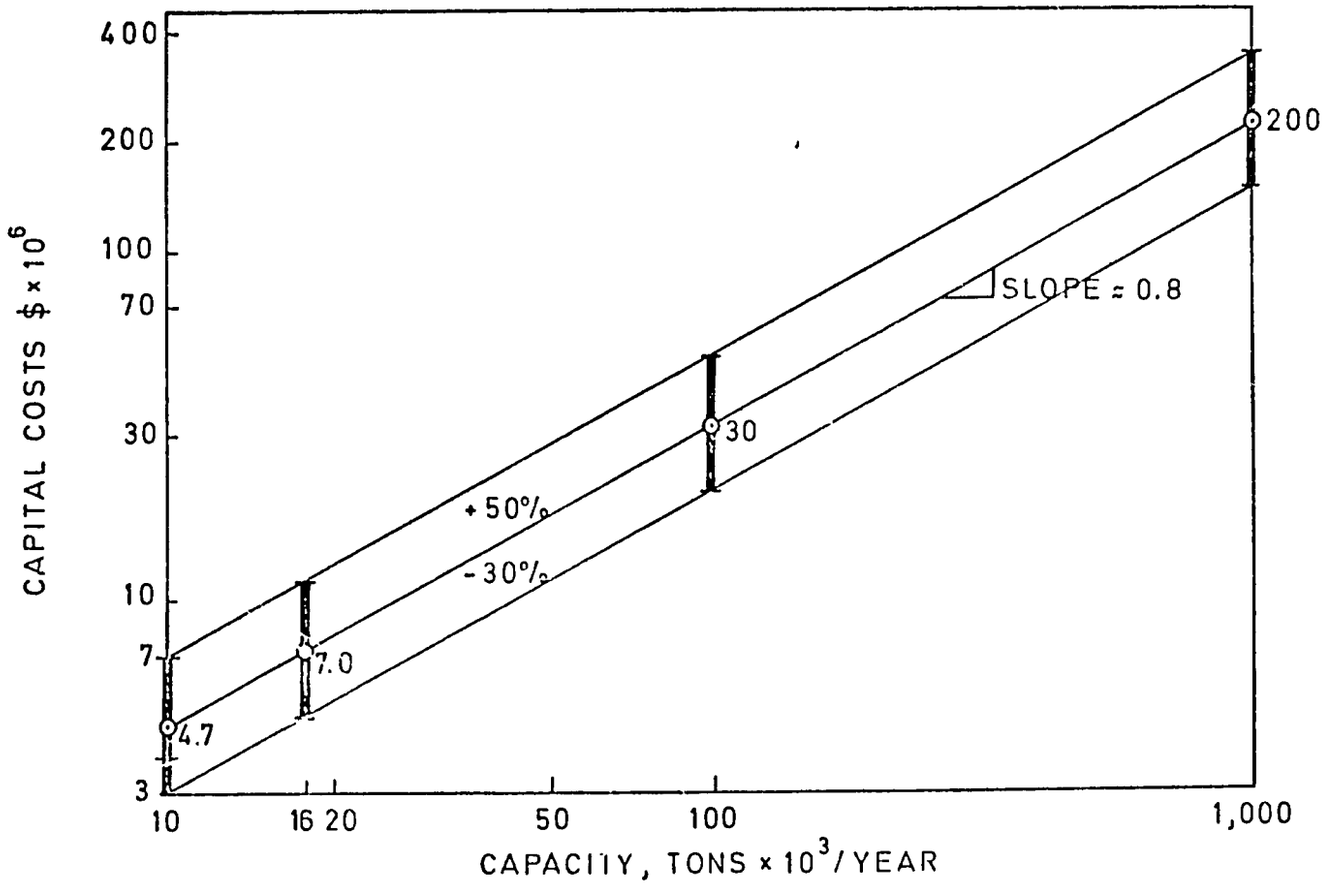


Figure 3. CAPITAL COSTS OF ASCP FROM HYDROCARBONS PLANT (1973 COSTS)

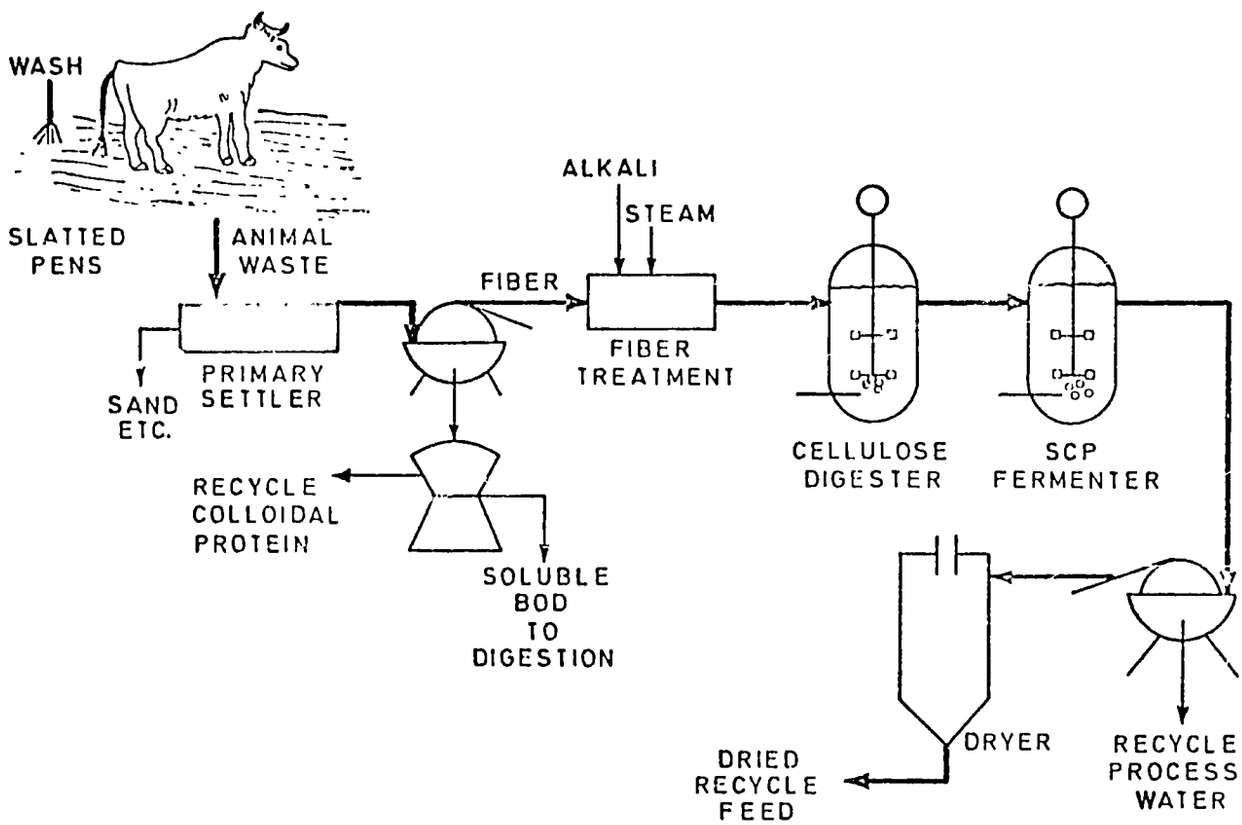


FIGURE 4. ANIMAL RECYCLE FEEDLOT WASTES SYSTEM

4. Production of SCP by growth of bacteria or yeast on the gas-oil fraction of crude oil.

5. Production of SCP by growth of bacteria or yeast on purified n-alkanes separated from crude oil.

Figure 2 illustrates a typical SCP process utilizing gas-oil. Such a process is being operated at the Societe Francaise des Petroles B.P. plant in Lavera, France. Its operating capacity is 17,000 to 20,000 ton/year. The capital cost of the unit was approximately $7,500,000. A 100,000 ton/year plant utilizing n-alkanes is being built in Calabria, Italy, by Liquichimica Biosintesi S.P.A. and is expected to be on-stream by mid-1974. This plant is projected to cost $49,000,000. (See Table VI). It is expected to yield a 15.8% return on investment for an SCP product running 63% crude protein and selling competitively with fish meal at $424/ton. British Petroleum is reportedly considering the construction of a 1,000,000 ton/year plant. On the basis of a 0.8 power scale-up factor, such a plant would cost the order of $200,000,000. (See Figure 3). Obviously, such a scheme is only possible in the highly developed and energy rich countries.

SCP FROM SOLID WASTES

In the U.S. alone, it has been estimated that there are nearly one billion tons/year of solid wastes. The bulk of this, as indicated in Table V, is agricultural, food, refuse, and feed lot wastes. The predominate component of this waste is cellulose, a material that is relatively difficult to ferment without some predigestion, by either enzymatic or alkali heat treatment.

One of the most pressing solid waste disposable problems in the U.S. is that of disposing of feed lot wastes, i.e., manure. There are consolidated feed lots that contain up to 100,000 head of cattle. Over 60 feed lots in the U.S. contain more than 25,000 head. The problem stems from the concentration of the waste. The solid wastes from a 100,000 head feed lot are roughly equivalent to the municipal sewage wastes from a city of 1,000,000 people. Several solutions for disposing of the manure have been suggested. Among those is the General Electric Company process for converting manure into recycle SCP feed. The details are illustrated in Figure 4. Manure is first collected by either mechanical or hydraulic means and the fiber recovered by filtration. The washed fiber is predigested by a combination of alkali and heat treatment. The treated fibers are then microbially digested and converted to SCP in a one or two stage continuous process. The resulting microbial cells are filtered, washed and dried prior to utilizing as recycle feed. There are a number of inherent difficulties with the process. One of the more troublesome problems is that of producing a contaminant free food.

CITY REFUSE

City refuse can be handled much the same way as manure. (See Figure 5). The fibrous material is separated by hydroclassification: then filtered

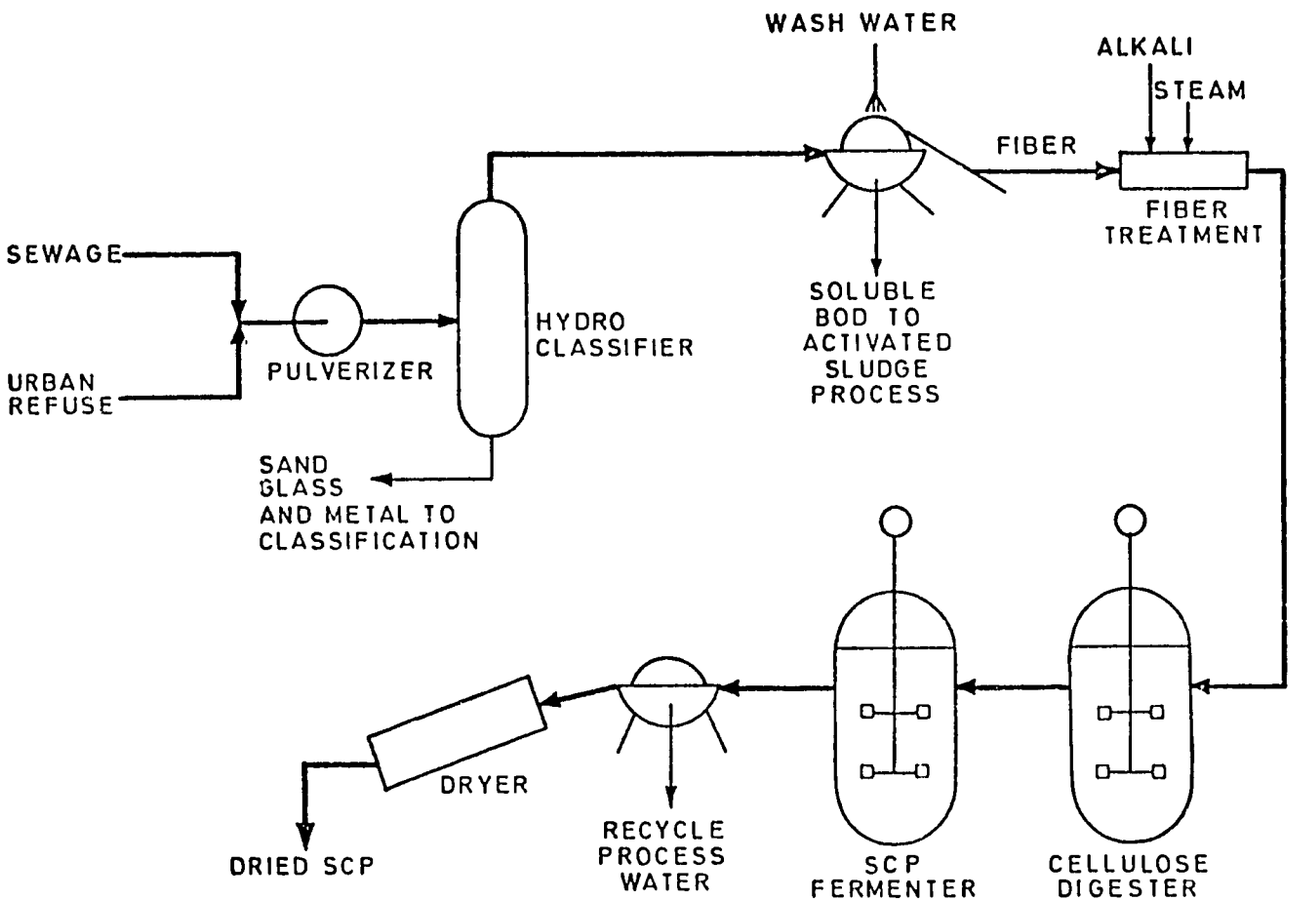


FIGURE 5. DOMESTIC WASTE RECYCLE SYSTEM

and washed, treated with hot alkali, and digested to make SCP. At the present time, many large cities are simply dewatering the refuse, separating out the glass and metals, and then burning it along with coal in the steam boilers. Because of the simplicity of this operation, plus energy recovery, it is doubtful that refuse has an immediate potential for SCP production.

AGRICULTURAL WASTES

As indicated in Table IV, numerous crops yield low value wastes. Some of these wastes are widely distributed and hence are difficult to collect in economical volumes. For the most part, such wastes occur in the developing countries with an agricultural base. Examples of such wastes are those from coffee and banana processes of Central America. A village level technology needs to be developed so that these limited availability wastes can be utilized.

Contrasted with these limited availability wastes are the large volume wastes such as those of paper, sugar and grass seed production. A specific example would be sulfite waste liquor from a wood pulping operation. In the case of sulfite waste liquors, (See Figure 6) the spent liquor is steam stripped to remove SO_2. Additions of various minerals, essentially fertilizer, to the stripped liquor makes a fermentable liquor on which single celled microorganisms can grow.

A general process for the conversion of cellulosic wastes to SCP has been developed by Louisiana State University (LSU). This process was initially developed for converting cane bagasse to SCP. However, it is applicable to most cellulosic wastes. LSU, in conjunction with the Bechtel Corporation, is attempting to market the process world-wide.

VILLAGE LEVEL TECHNOLOGY

Tate and Lyle, Ltd., a major world sugar company, is pushing the concept of village level technology SCP systems. These systems are constructed of plastic materials, operate non-aseptically, and utilize cheap labor rather than costly instrumentation for control. In contrast to high level technology which only pays in the huge economies of scale (See Table VII), village level technology can be economical on a small scale. Most people of the world do like to eat meat. Indeed, many view meat as a status food. Certainly the chicken industry has taken off in the developing countries. As a consequence, the demand for protein most certainly will continue to rise in the developing countries by at least 15-25% per year. The Tate and Lyle people believe that the idea of a cooperative SCP fermenter having roughly a 3 ton/day output is feasible as a small village plant. They have designed a non-aseptic processing unit, largely constructed from plastic materials that could be erected in the field, and that costs only $50,000.

In the hands of highly skilled technicians, such a system will operate satisfactorily. Tests under field conditions need to be performed in order to verify the true value of the village level technology scheme.

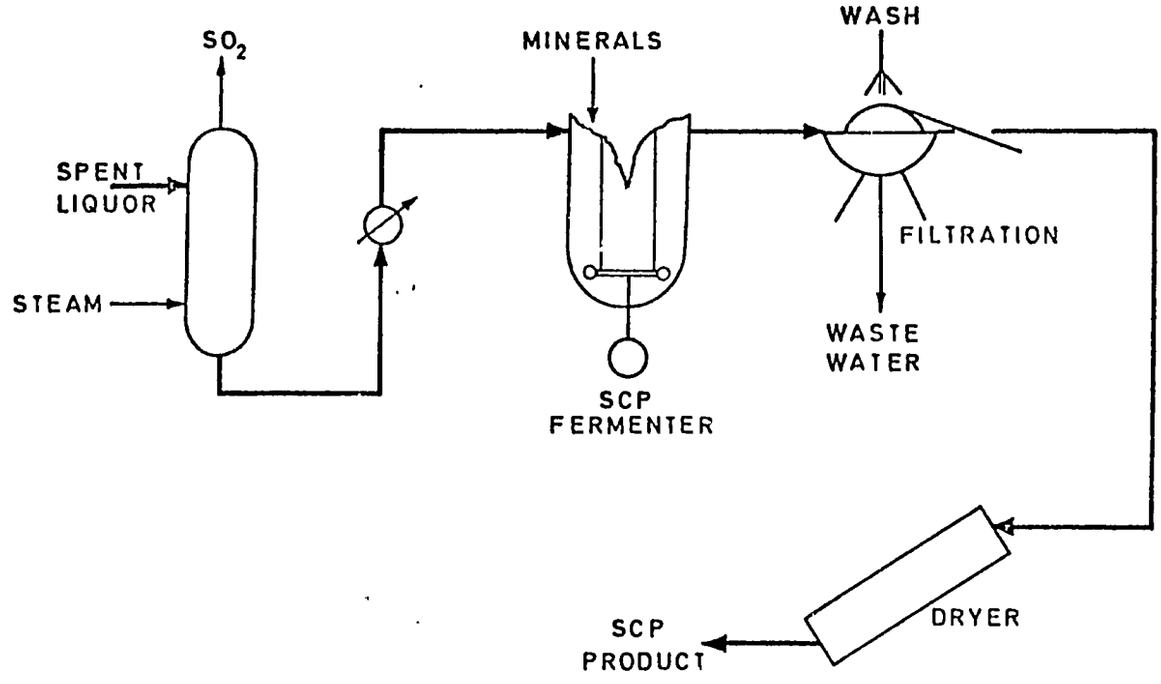


FIGURE 6. SCP FROM SULPHITE WASTE LIQUORS

FIGURE 7.
SCHEME FOR ETHYL ALCOHOL PRODUCTION AND USAGE
FROM AGRICULTURAL PRODUCTS

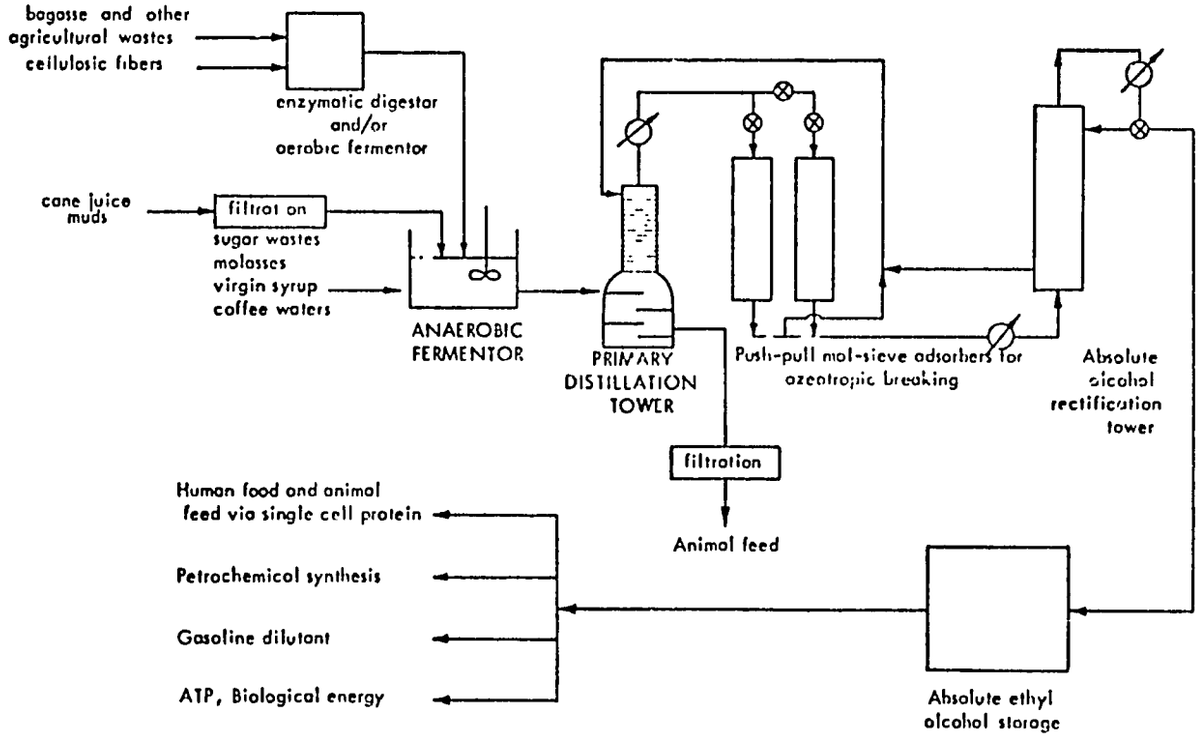


TABLE VII

SCP SELLING PRICE AND ROCE

STARCH AND AGRICULTURAL WASTE SYSTEMS

PLANT	HIGH TECHNOLOGY		LOW TECHNOLOGY	
SIZE (TONS/YEAR)	9000	1000	9000	1000
SELLING PRICE, $/TON	325	325	325	325
ROCE, %	4	LOSS	14	LOSS

TABLE VIII

VILLAGE LEVEL TECHNOLOGY SCP PROCESSES

PLANT	CASE I	CASE II	CASE III
WORKING DAYS/YEAR	100	200	300
CAPACITY TONS/DAY	84	170	250
SELLING PRICE, $/TON	325	325	325
ROCE %	9	18	25

TABLE IX

ETHANOL USES

1. SOLVENTS
2. BEVERAGES
3. FOOD AND FEED (VIA SCP)
4. PETROCHEMICAL SYNTHESIS (VIA ETHYLENE)
5. GASOLINE DILUTENT
6. BIOLOGICAL ENERGY (ATP)

ANAEROBIC PROCESSES

An interesting alternative scheme is that based on anaerobic fermentation rather than aerobic fermentation. One such process is the "Bactolac" feed developed by Dr. Hugh Henderson at Michigan State University. In this process lactose from whey wastes is anaerobically fermented to lactate. This lactate is neutralized with ammonia to give ammonium lactate which can be used to provide up to 85% of the nitrogen for rumen diet. Rather than separate out the lactate, the whole broth is dried. In this system bacterial cells that grew on the whey wastes, converting the lactose to lactate provide the needed source of organic nitrogen for the rumen. The cells plus ammonium lactate make a well balanced nitrogen source that can virtually substitute for soybean meal in the rumen diet.

Yet another viable alternative is that of converting agricultural wastes to alcohol by anaerobic fermentation. (See Figure 7) In this process the yeast cells that grow on the waste, converting the sugar and starches to alcohol, are utilized for feed and food purposes. The resulting alcohol can be used for chemical synthesis, for energy in terms of a gasoline extender, or for producing food grade SCP. (See Table IX). Such a process was recently announced by the American Oil Company.

Alcohol derived from renewable sources such as agricultural products and wastes could be a keystone to an alternate energy and chemical economy, especially in those countries with an agriculturally based economy and whose petroleum reserves are minimal or nonexistent.

In passing, note should be made that an important advantage to agriculturally derived energy and the concomitant SCP production is that many of the crops that are most efficient in terms of photosynthesis and are found in the developing countries are labor intensive crops. Examples are cane, maize, sorghum and some grasses.

GENERAL CONSIDERATIONS

Once the economic viability of an SCP process has been determined, there are many factors involved in the selection and design of the final process. In terms of organism selection, there are considerations of product safety, product end use, product handling characteristics, process productivity, which is largely dependent upon the organism growth rate, and the yield, which is affected by the organism maintenance requirement.

With respect to design considerations, the process must guarantee a continuously safe and contaminant-free product; it must match the protein demand and must utilize available raw materials. The location must minimize distributional costs and assure the availability of water, energy, labor and capital resources. It must also consider the problems of disposing of secondary and by-products.

NUTRITION PROBLEMS

One of the big problems with SCP is consumer acceptance and nutrition. For, after all, food is not food until eaten. Among the nutritional problems that have come to the fore are the amino acid content or biological value, the product digestibility, and the residual oil content, particularly with cells grown on gas oil where undesirable components may be present. Likewise, there is a problem of nucleic acid content of the SCP product if fed to monogastrics. The fat content is important because if affects shelf life of the product. Also, there are possible problems over intestinal allergic reactions when SCP is fed to humans.

All of these problems appear to have solutions. Consequently, it seems clear that SCP has arrived as a practical product.

SUMMARY

SCP processes have achieved technical feasibility. Economic feasibility will come. It is affected by political and regional considerations involving resources utilization, protein demands, energy requirements and pollution problems. Of the various operating cost factors in SCP production, substrate costs are paramount. There is process economy in large operational scale. However, small scale village level technology processes may also prove economically feasible. Various microorganisms may be considered for SCP production. Yeast have received the greatest study. They have found prior acceptance as food and fodder material. The mycelial fungi have considerable attractiveness because of their ease of filtration and ability to provide form and texture. Because of their slower growth rate relative to bacteria, they may require aseptic conditions for production. Bacteria may be used for SCP but their efficacy as a food or fodder is still largely unknown and highly suspect because of the many pathogenic bacteria. On the basis of fish and soybean meal prices during the last half of 1972, and the first part of 1973, and prices projected into the 1980's, there is every reason to be most optimistic about the future of SCP.

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