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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

THE MANUFACTURE OF PROTEINS FROM HYDROCARBONS

Report of an Expert Group Meeting
Vienna, 8–12 October 1973

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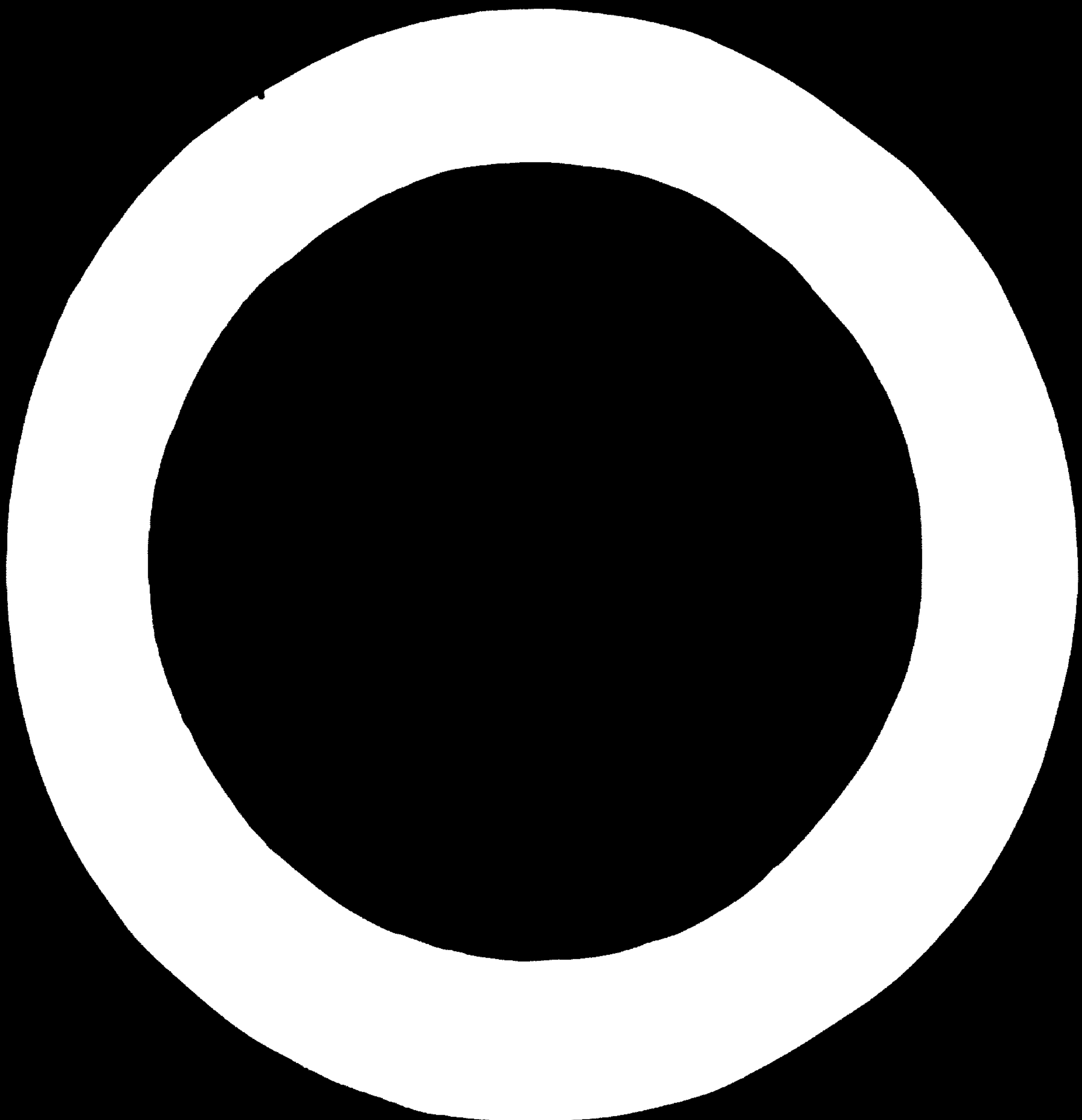

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EXPLANATORY NOTES

Reference to "dollars" ($) indicates United States dollars.

Reference to "tons" is to metric tons.

INTRODUCTION

The United Nations Industrial Development Organization (UNIDO) convened the Expert Group Meeting on the Manufacture of Proteins from Hydrocarbons in Vienna from 8 to 12 October 1973. The main purpose of the Meeting was to identify problems related to the production and utilization in developing countries of single-cell protein (SCP) - that is, protein manufactured from hydrocarbon, carbohydrate or other such feedstocks - for animal feeding and to provide guidance and recommendations for future UNIDO activities in this field. The Meeting was also intended to facilitate the transfer of SCP technology to developing countries and the promotion of new investments in it.

The Meeting was attended by representatives of the Protein Advisory Group of the United Nations System (PAG), the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO). More than 70 experts from governmental agencies and industrial firms in 20 developed and developing countries also attended.

M. C. Verghese, Chief of the Fertilizers, Pesticides and Petrochemicals Industries Section (UNIDO), was responsible for the substantive organization of the Meeting. B. Mudretsov was Officer-in-Charge. M. G. Krishna was elected Chairman and J. C. Masson Rapporteur.

The agenda covered the following topics: selection of feedstocks for SCP production, the acceptability and nutritional properties of SCP, country information and the marketing of SCP. A list of the papers presented at the Meeting is given in the annex.

CONCLUSIONS AND RECOMMENDATIONS

The Group concluded:

(a) That single-cell protein (SCP) could make a very positive and perhaps invaluable contribution towards satisfying the world's needs for protein;

(b) That the manufacturing technology for the use of normal (n-) paraffins, gas oil and several other hydrocarbon feedstocks was in existence. The owners of the technology had indicated their willingness to license it to developing countries under appropriate terms and conditions. The major deterrents to full commercialization were the uncertain market acceptability of the product and the limited availability and high cost of its raw materials;

(c) That neither n-paraffin nor straight-run gas oil presented special or insoluble safety problems in the production of SCP. Methanol, ethanol and methane would probably also prove to be safe and could also be considered as feedstocks.

The Group therefore recommended that UNIDO should encourage all countries – and particularly the developing ones, which ought to be among the principal beneficiaries of SCP technology – to work in this field wherever conditions already existed or could be created that would permit such an effort to make a positive contribution to national economies or international commerce.

The Group concluded that the countries with conditions suitable for SCP production [illegible] two groups:

(a) [illegible] SCP product [illegible] raw material [illegible] available;

(b) Countries with [illegible] markets.

The Group therefore recommended:

(a) That [illegible] whether there was a suitable [illegible] market [illegible] human food [illegible] animal feeds, the [illegible] and the [illegible] aspects. Countries [illegible] few arable [illegible] SCP, [illegible] raw materials for its production;

(b) That countries in the second group should consider establishing national programmes, which could include:

(i) Demonstration plants as instruments for the transfer of technology and the training of personnel in order to participate in the operation of industrial facility and to produce sufficient SCP for use in feed trials;

(ii) Suppliers of raw materials;

(iii) The organization that will produce the SCP;

(iv) The food technologists who will ensure the incorporation of SCP into feedstuffs in an appropriate manner;

(v) The marketing organization that will demonstrate the acceptability of the product and then be responsible for distribution and marketing;

(vi) The health authorities and their associated bodies, which would supervise and approve the testing, production transport and use of SCP.

Such national programmes would be essential, because governmental approval would be given, in each instance, for a specific product manufactured by a prescribed method from a particular feedstock. Each country would have to obtain as much agreement as possible among its own specialists on such important matters as the most appropriate technology for SCP manufacture, how the product should be used and how to fit this material into the national economy. It would also be important to reduce, as much as possible, the long delay in having a new product accepted.

The Group concluded that some developing countries might have difficulties in realising such programmes because of their lack of qualified personnel and of capital, and especially of foreign exchange.

The Group therefore recommended that UNIDO should:

(a) Attempt to identify training [illegible] and [illegible] countries [illegible];

(b) Assist, [illegible] purchase of [illegible] plant equipment by developing [illegible] those for which foreign exchange would cause difficulty;

(c) [illegible] Reconstruction and Development (IBRD) in [illegible] for the use of SCP that would be suitable [illegible] developing country with foreign exchange problems.

The Group concluded that there was a lack of basic information for the implementation of these programmes.

The Group therefore recommended that UNIDO, possibly together with the United Nations Conference on Trade and Development (UNCTAD) and the World Food Programme (WFP) should undertake an extensive study to determine:

(a) The extent of unsatisfied requirements for conventional proteins that would be probable over the next 15 years;

(b) The possibilities and problems that were likely to be encountered if such shortages were made up form other sources of proteins, and particularly by soya, or if they were not satisfied;

(c) The probable price levels for proteins considering that one price might prevail on the world market and other prices on domestic markets where foreign exchange savings might be an important consideration, as was the case with petrochemical products;

(d) The feasibility of constructing a matrix giving the approximate plant size as a function of the cost of feedstocks, location factors etc. necessary to permit the production of SCP at price levels that would be satisfactory for a representative number of cases.

The Group concluded that a clearing-house was needed for the collection of industrial information that would be useful to developing countries in furthering the development of SCP. Such a clearing-house might promote an international conference at a later and appropriate stage, collect information on possible industrial projects for the production of protein by other non-conventional means and draw up a code of practice that would facilitate the storage of SCP and its shipment across national boundaries.

The Group therefore recommended that UNIDO establish such a clearing-house.

The Group noted that certain precautions should be taken in connexion with the participation of UNIDO in the activities for the development of the production and use of SCP considered above.

The Group therefore recommended that the following needs should be considered:

(a) The need for further strengthening joint approaches of organizations in the United Nations system in this area, and particularly for concentration by UNIDO and FAO on the industrial production and marketing aspects of SCP;

This emphasis was indicated because the health and safety aspects seemed to be well enough in hand to permit the consideration, with reasonable confidence, of viable industrial and agricultural ventures;

(b) The need for developing countries, before committing themselves to any specific SCP production programme, to review the latest technological developments, perhaps with the assistance of UNIDO. Possible problems concerning the disposal of industrial wastes should be considered in this context;

(c) The need for active encouragement of collaboration between developed and developing countries and between the developing countries themselves in the development of SCP, wherever there was a transfer of technology;

(d) The need to bear in mind that, while hydrocarbons were among the most promising raw materials for SCP production, others, such as carbohydrates and agricultural wastes, should not be overlooked;

(e) The need to consider that SCP production from any and all materials was taking place within the over-all framework of a generalized and integrated policy designed to increase the availability of protein from all sources, conventional and non-conventional.

Several participants brought to the attention of the Group the fact that the guidelines issued by the Protein Advisory Group of the United Nations System (PAG) were mainly for an SCP product intended for human consumption. It was suggested that the preparation of guidelines for SCP for animal feeding might be appropriate.

The Group therefore recommended that PAG consider that suggestion favourable.

The Group concluded that, at the current stage of development of SCP technology, the raw materials most suitable for consideration were gas-oil, n-paraffins, methanol, ethanol and methane.

The Group therefore recommended that UNIDO undertake a study to determine the costs of production of these materials at various locations. The study should cover such factors as the most economic size of the production facilities and the costs of capital, production and transport. Such a study would permit comparison of the costs of producing SCP from various feedstocks.

It was brought to the attention of the Group that one of the basic elements of the work programme of UNIDO was the transfer of technology and the making available of formulae for industrial development for exchange between developing countries. Consequently, countries that had worked out appropriate technologies or that possessed the requisite facilities for research and development were requested to make such knowledge and facilities available to other developing countries that had the potentiality for the development of SCP industries. Collaboration of that kind was envisioned, particularly in the areas of training, the use of SCP samples in animal feed-lot experiments and in making available various strains of yeasts, bacteria etc.

The Group concluded that it would be desirable to establish public and governmental confidence in the quality-control procedures used in the emerging SCP industry.

The Group therefore recommended that UNIDO request an organization such as the International Union of Pure and Applied Chemistry (IUPAC) or the American Society for Testing Materials (ASTM) to set up a programme of co-operative research to standardize analytical procedures, establish the limits of precision of such procedures and recommend further analytical research and development on a co-operative basis wherever existing levels of precision were found to be too low. The following analyses should be included:

(a) Total aromatics in raw materials at the parts per million (ppm) level;

(b) Specific species of polynuclear aromatics in raw materials and products at the parts per 1,000 million (ppb) level;

(c) All carbohydrate types, by group, in SCP products at the low ppm level;

(d) Carbohydrates, lipids and nucleic acids as constituents of SCP;

(e) Amino acids and protein in SCP;

(f) Heavy metals in SCP product at the ppm level;

(g) Other analyses, particular with reference to the Codex Alimentarius.1/

The Group agreed that the marketing and acceptance of SCP products would require standardization of products and the existence of specifications for the limits of acceptability of their analytical constituents. The setting of such limits would permit the SCP industry to market standard grades of its products to the feed-mix industry.

1/ Codex Alimentarius Commission, Joint FAO/WHO Food Standards Programme, Rome.

The Group therefore recommended that UNIDO should convene a meeting of feed-mix manufacturers and potential producers of SCP to draw up agreed standards. IUPAC and competent trade and distribution associations should be invited to attend. Each country would be free to consider the proposals and to set up appropriate agencies on nutrition and public health.

The Group recognized that the cost of manufacturing SCP could be reduced if large units for the production of feedstocks were situated near sources of raw materials and of low-cost energy. It further suggested that, in some cases, the siting of SCP plants should be considered from the standpoint of regional integration rather than on a purely national basis. In some cases, such large plants might have to serve markets larger than the territories in which they were installed.

The Group therefore recommended that UNIDO and other United Nations bodies should use their good offices to promote such regional integration, without, however, sacrificing national interests.

I. BACKGROUND

Although the term SCP, in its strict sense, means a single-cell protein product also known as fermentation protein, biosynthetic protein, bioprotein, petroprotein and industrial protein, it has been used widely to refer to microbial cells, whether bacterial, fungal, yeast or algal, propagated for use as a source of protein for human or animal nutrition, and is relatively neutral in its emotional impact. The Meeting was concerned primarily with SCP arising from the propagation of yeasts or bacteria on hydrocarbon feedstooks or feedstocks such as ethanol and methanol, which are readily produced from hydrocarbons. It should be understood that, after propagation and recovery, the SCP product is composed of 50 to 80 per cent protein, the remainder being carbohydrates, lipids, nucleic acids, ash and moisture.

"SCP", as a name, may be considered as analogous to "meat"; that is, it is a very general term rather than a specific one. In discussing any particular SCP product or the process for producing it, further details may have to be supplied. Thus, any specific SCP product that is marketed may be required to show on its label the type of micro-organism and the feedstock used. It will probably also have a trade-name, as one such product already does.

SCP can be used both as a component of animal feeds and for the direct feeding of humans. The Meeting was concerned only with the first of these uses, since the problems involved in direct human nutrition are less well defined and more complex than those involved in animal feeding. It thus seemed best to consider first the relatively straightforward problems of developing an economic SCP for animal feeding before dealing with the psychological, social, political and health problems involved in its use in human foods.

The fact that some micro-organisms can be grown on hydrocarbons has long been known; research and the actual use of such micro-organisms as sources of protein began in 1957. The Meeting considered only raw materials that could be derived from petroleum or natural gas. The purpose was to select a micro-organism that could be grown rapidly on abundantly available and inexpensive raw materials. The end-product envisioned would have an amino acid content suitably balanced for use in animal feeds.

Two "first-generation" processes were based on gas oil and "normal" (n-) paraffins. Both of them have been developed by several enterprises on a pilot-plant scale and have been tested for both food value and toxicity. This work has been in progress since 1963. Some of the products have been registered for use in animal feeds. Activities related to the production, utilization or both of SCP have been carried out in many countries, among them Belgium, China, Czechoslovakia, France, the Federal Republic of Germany, India, Indonesia, Italy, Japan, the Libyan Arab Republic and some other Arab countries, Mexico, the Netherlands, Poland, the Union of Soviet Socialist Republics, the United Kingdom of Great Britain and Northern Ireland and the United States of America. Various industrial firms had planned or were planning production facilities with capacities that might exceed 100,000 tons per year by 1975. However, world production of SCP was probably less than 30,000 tons per year, although many pilot and semi-commercial plants were already in operation. Commercial production could reach 500,000 tons per year by 1980.

"Second-generation" work on the fermentation of natural gas, ethanol and methanol was in progress. Although still experimental, this work seemed promising. Other research efforts were aimed at the production of yeasts, bacteria and fungi based on the fermentation of carbohydrates, molasses, lactoserum (whey), citrus pulps, certain industrial wastes and sewage. These research programmes were not discussed.

The rising prices and limited availability of the principal animal feed sources such as fish-meal, soya beans and ground-nuts would appear to ensure a substantial demand for SCP. The technology involved is complex, however, and many technical and economic factors must be weighed. It should be noted that current technology is devoted almost exclusively to the production and marketing of SCP for use in animal feeds. This situation is likely to continue for the rest of the present decade; significant production of SCP for human food is envisaged only for the 1980s.

In many developing countries, deficiencies of protein, and especially of animal protein, are already acute. The deficiency rate could double or triple in the next 20 years. Consequently, financial considerations should not be the sole criteria for the feasibility of SCP plants in a developing country. On the other hand, in the more industrialized countries or in countries where natural protein is grown in large volume, the cost of SCP must be competitive with it or with internationally traded commodities such as soya or fish-meal.

II. SELECTION OF FEEDSTOCKS FOR SCP PRODUCTION

In SCP research programmes, the n-paraffins have been considered first, either diluted with other hydrocarbons in the middle distillate fractions of crude oil or pure, after extraction from middle distillates by molecular sieves and additional chemical treatment to obtain medicinal-grade alkanes. For example, in the United States of America such pure paraffins must pass Food and Drug Administration test 121.1146 for mineral oil used in food.

Methane has been suggested as a low-cost source of hydrocarbon SCP production, but processes that use it are still in an early stage of development. Attention is currently concentrated on methanol, which has been claimed to be particularly suitable as a feedstock for SCP production for the following reasons:

(a) It is completely miscible with water;

(b) It can be produced from a very wide range of hydrocarbon raw materials ranging from coal to naphtha and natural gas;

(c) It can be produced in virtually unlimited quantities in any part of the world where fossil fuels are available and is not limited by the output of a refinery, as is the case with normal alkanes;

(d) Its method of production, which involves catalytic degradation of the hydrocarbon substrate to CO and H_2, precludes the presence of potentially carcinogenic polycyclic hydrocarbons;

(e) If a methanol plant is built as an integral part of an SCP plant, the considerable quantities of heat liberated by methanol synthesis can be used to provide the heat required for a sterile fermentation process.

Ethanol is also being considered as a feedstock because it can be made from ethylene, which is already produced in large quantities in the petrochemical industry as well as from agricultural products. As with methanol, the method of production precludes the presence of carcinogens. Table 1 indicates the costs involved, including data on molasses, which is already widely used as feedstock for yeast. (All costs shown here and elsewhere in this report are as of October 1973.)

Table 1. Feedstock costs per ton of SCP

Feedstock	Feedstock cost (dollars/ton)	Yield of SCP per ton of feedstock (tons)	Feedstock cost (dollars per ton of SCP[a])
Molasses (50% assimilable carbohydrates)[b]	20–40	0.25	80–160
n-Paraffins	60–80	1	60–80
Gas oil	20–30	1	20–30
Methanol	40–60	0.5	80–120
Methane[c]	5–20	0.6	8.5–32
Ethanol	60–100	0.85	70–120

a/ Dried product, 50 to 80 per cent protein.

b/ The lower figure corresponds to cost in a producing country; the higher one to costs in an importing country.

c/ The range of figures for methane reflects the possible wellhead costs in a producing country of western Asia. The other feedstocks are costed at their fuel-oil value.

An economic assessment of SCP production must also take into account the oxygen requirement and heat evolved during fermentation. It is generally accepted that the fermentation of methanol, n-paraffins and methane require, respectively, 4, 4.5 and 5 times more oxygen per unit of cell than that of molasses, the amounts of heat evolved being in roughly the same ratio.

Assuming that the power required for oxygen transfer to the cells is in the same ratio, the data shown in table 2 can be derived. For this purpose the minimum and maximum figures are used in terms of kilowatt-hours (kWh) per pound of yeast produced from molasses and assuming a cost of $0.01/kWh. It must be noted that the efficiency of oxygen utilization differs from one process to another.

Table 2. Impact of the type of feedstock on the ratio of O_2 requirement and on energy cost

Feedstock	Ratio of O_2 requirement	Energy consumption (dollars/ton of SCP)
Molasses	1	5-10
n-Paraffins	2.5	12-24
Gas oil	2.5	12-24
Methanol	2	6-20
Methane	5	25-50
Ethanol	1.2	6-12

In order to make a comparative estimate of the impact of heat evolution, it is assumed that cooling water is available at 18° to 20° C, that fermentation with yeast takes place at 30° C and that, for methanol and methane, bacteria are used that grow at 40° C, thus increasing heat-transfer efficiency by a factor of 2. With these assumptions, the data presented in table 3 can be deduced.

Table 3. Impact of the type of feedstock on the cooling characteristics and costs of SCP production processes

Feedstock	Fermentation temperature (°C)	Heat evolution ratio	Relative ratio of coolant circulation	Cost (dollars/ton)
Molasses	30	1	1	5
n-Paraffins	30	2.5	2.5	12
Gas oil	30	2.5	2.5	12
Methanol	40	2	1	5
Methane	40	5	2.5	1[illegible]
Ethanol	40	1.2	1	2.5

Using the data presented in tables 1, 2 and 3, and after taking into account the loss of lipidic material during the final stage of purification by solvent extraction, the cost ranges shown in table 4 can be obtained.

Table 4. Cost ranges of SCP produced on various feedstocks

Feedstock	Cost of SCP (dollars/ton)
Molasses	90-105
_n_-Paraffins	84-116
Gas oil	54-91
Methanol	91-145
Methane	45.5-92
Ethanol	78.5-134.5

However, direct comparison of the figures given in table 4 would be misleading for several reasons. For example, yeast grown on molasses is normally separated from the spent medium by centrifuges, and the same order of efficiency can be anticipated from industrial centrifuges for yeast grown on _n_-paraffins. On the other hand, bacteria cannot be recovered by direct centrifuging; it is necessary to introduce an earlier concentration stage such as flocculation or flotation. The exhaust gas from fermentation in the methane process still contains large amounts of non-consumed methane which, if not recycled into the system in some way, would add considerably to the cost.

The cost of any prepared feedstock will depend largely upon its scale of production. For _n_-paraffins, for example, the cost varies as shown below. (These figures are only indicative, however, since the cost of crude oil varies according to such factors as its source and its content of _n_-paraffins.)

Cost (dollars/ton)	Annual capacity (tons)
120-100	50 000
100-80	100 000
80-60	200 000

The only specific limit to the size of a plant to produce _n_-paraffins is the amount of them available for separation from petroleum products. In order to benefit from the low costs made possible by truly large-scale production, a central n-paraffin unit, such as one of 100,000 to 500,000 tons/year capacity, could be built adjacent to a very large petroleum refinery and used to supply feedstock to a number of SCP plants located according to the market demand for their product.

In the case of methanol, the cost will be reduced by more than one half if very large plants (for instance, of more than 3 million tons/year capacity) were constructed. Such plants are reported to be projected for western Asia. The total cost can also include such items as the training of the labour force, commissioning expenses and working capital, some of which are related to local conditions. Since methanol can be produced from a wide range of feedstocks and is already available on the world market for other purposes, it may be expected that adequate supplies of it will always be available.

With the gas-oil process, the plant must be connected with a refinery that will supply the feedstock and receive the returned non-paraffinic fraction. Consequently, the size of the plant depends on the availability of the middle distillate from the chosen refinery; it also depends on the quantity of paraffins present in the available feedstock and on the commercial value of the raw and de-waxed middle distillate if maximum advantage of the premium for de-waxing is sought. The availability of middle distillates for SCP production, according to refinery capacity, are presented below. These data demonstrate that the production of feedstocks for SCP production would be feasible not only near large refineries such as those of western Europe but also near smaller ones of the kind that are now being erected in many parts of the world.

Middle distillates output (tons/year)		Boiling ranges of middle distillates (°C)
2 million	10 million	
	30 000	330–380
20 000	100 000	300–380
50 000	200 000	250–380

III. ACCEPTABILITY AND NUTRITIONAL PROPERTIES OF SCP

The Protein Advisory Group of the United Nations System (PAG), recognizing the importance of the development of non-conventional sources of proteins but realizing that their production involves special problems of food sanitation, safety, toxicity, processing, quality control and acceptability, has issued a series of guidelines concerning these products.

The first of these, Guideline No. 6, "Preclinical testing of novel sources of protein", was published in March 1970 and still constitutes the basic document for testing and clearance for human consumption. This was followed in [illegible] 1970 by Guideline No. [illegible], "Human testing of supplementary food mixtures", and in February [illegible] by Guideline No. [illegible], "Protein-rich mixtures for use as weaning foods".

In the meantime, the development of SCP led to the formation of the PAG ad hoc Working Group on Single Cell Protein, which prepared specific recommendations which have been adopted by the PAG and constitute Guideline No. [illegible], "Production of single-cell protein for human consumption". All of these documents are specifically designed for novel non-conventional proteins for direct human consumption. From the information and evidence available, no specific SCP [illegible] for direct human consumption has as yet been subjected to the tests recommended in Guidelines No. [illegible] and [illegible].

However, [illegible] SCP [illegible] the animal feed market has already been [illegible] to extensive animal feeding and toxicological tests in a wide [illegible], and SCP [illegible] and [illegible] produced by an established [illegible] in several European [illegible] Governments (among them Denmark, France, the Federal Republic of Germany, Italy, the Netherlands and the United Kingdom of Great Britain and Northern Ireland). Another enterprise has submitted an SCP [illegible] in Italy. Extensive tests [illegible] SCP [illegible] have recently been published.

The Group was informed by the Japanese representatives of recent pressure of public opinion that had forced some companies in their country to suspend plans to produce SCP. It would appear that this decision had resulted from political pressure and misguided public opinion.

At present, therefore, it appears that SCP can be produced that meets stringent analytical, nutritional and toxicological requirements for safety in animal feed. However, the Group considered it of utmost importance that separate guidelines should be prepared for animal feeding and toxicological testing. In this connexion, it was noted that separate guidelines that concentrated on analytical methods were being elaborated by the International Union of Pure and Applied Chemistry (IUPAC) in co-operation with PAG. It was also noted that the European Economic Community (EEC) had issued a preliminary draft [illegible] dealing with the [illegible] of [illegible] States concerning traditional and novel ingredients. PAG is co-operating with EEC in the development of these European regulations.

As part of its plan for drafting new and [illegible] of SCP for animal feed, the PAG ad hoc Working Group [illegible]. The Working Group was [illegible] in animal [illegible], animal nutrition, [illegible] and [illegible].

The important points emerged in regard to the use of SCP [illegible]:

a) Nutritional and toxicological tests are [illegible] the [illegible] product [illegible]. Any change whatever in these parameters would [illegible] product.

[illegible]

Considering the [illegible] that SCP [illegible], the Group [illegible] that, [illegible] feed [illegible] food. The Group therefore [illegible] that [illegible] be [illegible] as [illegible].

IV. PRODUCTION OF SCP

Fermentation technology for producing proteins has been known for many years, but only recently has the use of micro-organisms for extensive nutritional supplementation been considered on the scale of commercial production. This development has been possible through the selection of genetically stable micro-organisms that are not pathogenic and the recently developed scaling-up fermentation techniques. Extensive research was carried out to select micro-organisms that develop both rapidly and economically on certain substrates that are abundantly available. The scaling-up fermentation techniques have shortened the time required for process development.

The development of a fermentation industry to produce SCP involved numerous problems caused by interactions among the different branches of science involved, namely microbiology, engineering, toxicology, nutritional science, chemistry, sociology and economics. In order to develop such a technology, many critical conditions must be observed and the implications for the future that will arise from this new industry must be anticipated. Two important conditions were the long-term availability, at low cost, of raw materials and energy.

At least two medium-scale plants have been operated for several years and have achieved certification of their production as animal-feed components in many European countries. Two other major facilities using n-paraffins, with annual capacities of 100,000 tons each, were under construction in Italy. They should be completed in 1974 and 1975. Several other plants were being considered.

Economic analysis

A number of papers submitted to the Meeting presented data on the capital investment, process requirements and manufacturing costs for SCP plants erected at various locations, using different feedstocks and having various capacities.

These data are summarized in table 5. Further data were presented that showed the impact of the location of the plant on SCP process requirements and production costs. These data are summarized in tables 6 and 7. In comparing these data, it should be borne in mind that the final figures represent rather different assumptions, particularly when the estimates of different groups are concerned. Nevertheless, they are of considerable value in observing the effect of location on plant and production costs.

A sensitivity analysis model that, in general, applies to processes based on n-paraffins was discussed. The model indicates the following features:

(a) The economics of SCP manufacture is highly dependent on the price of n-paraffins. Hence, any manufacturing operation will require an adequate low-cost supply of them;

(b) The necessary SCP yield on n-paraffins involves the use of an efficient micro-organism and of n-paraffins with the proper range of numbers of carbon atoms for the specific organism;

(c) The economics of producing SCP are very sensitive to changes in the selling price. Conservative selling price assumptions are recommended when evaluating the feasibility of operations in circumstances where profitability may appear to be critical;

(d) SCP plant operation is sensitive to sales volume. Hence, market penetration should be evaluated conservatively;

(e) With the existing technologies, it appears that minimum cost of SCP would be approached at a capacity of about 100,000 tons/year. However, for optimum economic performance of a project, the local situation must be analysed carefully with respect to the immediate sales prospects, the ultimate distribution network required, the supply and costs of raw materials, and the costs and terms of financing. As a consequence, the optimum initial plant size in a developing country might be as small as 30,000 tons/year, whereas the optimum plant size in western Europe might be as large as 150,000 tons/year.

The influence of the plant site selection on the economics of producing SCP has been investigated, taking into account four different plant sites characterized by a wide range of climatic conditions, energy costs, labour costs and shipping distance from the sources of raw materials. The effect of site conditions on total utilities consumption and capital requirements has been shown, together with those on production costs, in tables 5, 6 and 7. Local energy costs and climatic conditions are the major factors in determining the utility costs for SCP production. Low energy cost counterbalances the effects of other manufacturing cost items such as refrigeration and process air-compressor horsepower. It can be a major point in fixing the plant site.

Table 5. **Estimated capital investment requirements for SCP plants erected in various locations**

Feedstock	Capacity (tons/year)	Location	Year	Direct fixed capital ISBL[a] only (million dollars)	Total capital (million dollars)
Methanol	100 000	United Kingdom	1971	30.6	40-50[b]
Gas oil	100 000	Western Europe	1973	30-40	40-50[b]
n-Paraffin	100 000	Japan	1973	20.6	
n-Paraffin	100 000	Italy	1973	30.7	41.0
n-Paraffin	100 000	Western Europe	1973	25-30	30-40[b]
n-Paraffin	45 000	Finland	1973	20.9	24.2[b]
n-Paraffin	45 000	Algeria	1973	26.1	29.4[b]
n-Paraffin	45 000	Brazil	1973	23.2	26.7[b]
n-Paraffin	45 000	India	1973	23.5	27.2[b]

a/ Inside battery limits.

b/ Including working capital.

Table 6. **Anticipated utilities consumption per ton of SCP of plants in various locations (n-paraffin process)**

	Italy	Finland	Algeria	Brazil	India	Generalised location
Steam (ton/ton)						
High pressure	-	10.0	13.3	14.2	16.3	
Medium pressure	10.9	3.6	3.6	3.6	3.6	
Low pressure	0.5	1.0	1.0	1.0	1.0	1.8
Cooling water (m^3)	1 200	1 200	1 380	1 440	1 570	775
Chilled water (m^3)	15					
Process water (m^3)	1	49	49	49	49	345
Raw water (m^3)	45					
Electric power (kWh)	500	470	470	470	470	610
Fuel gas (million kcal)	5					
Fuel oil (low sulphur, million kcal)		1.25	1.25	1.25	1.25	
Fuel (kg)						800

Table 7. Production costs[a] of n-paraffin SCP plants in various locations, 1973
(Dollars/ton)

	Japan	Italy	Finland	Algeria	Brazil	India
Raw material	66.0	130.5	132.0	127.0	148.0	165.0
Chemicals	42.0	39.1	40.8	40.0	43.0	43.0
Utilities	53.5	41.1	52.6	39.0	60.0	89.0
Packaging	3.8	2.0	-	-	-	-
Labour and overhead	5.4	6.3	13.2	6.8	8.4	5.7
Maintenance and supplies	5.7	8.9	16.5	21.0	18.6	18.8
Depreciation	26.1	47.2	29.1	36.8	32.6	33.1
Taxes and insurance	5.7	10.2	11.0	13.9	12.4	12.4
Total	208.2	285.6	295.2	284.5	323.0	367.0

a/ Excluding research and development, marketing and administrative costs.

Current technical developments

Selection of a micro-organism

The first processes for producing SCP were developed by using n-paraffins with carbon chains more than 10 atoms long and certain yeasts of the Candida species. Several experts have pointed out that these yeasts had several advantages: they were closely related to species that were widely used in the baking, brewing and fodder-yeast industries; they were genetically stable; and they were of a size that permitted the use of already established harvesting technology.

It appeared that, when other feedstocks such as methanol and methane have been considered, bacteria have generally been selected that have the inherent advantage of much faster growth rates and higher nitrogen content, although a substantial part of it might be of the nucleic-acid (non-protein) type. Contamination by bacteriophages has not been reported.

Feed-preparation technology

Two different approaches seemed to be followed: either to sterilize all of the fluids, the mineral medium, the carbon substrate and the air entering in a previously sterilized system, ensuring that accidental contamination of the fermentation system would be avoided, so that only the selected organism would multiply; or to rely on a suitable set of operating conditions to ensure that the selected organism would remain dominant, an important point being that the symbiotic flora must be sufficiently stable to guarantee a reproducible, safe biomass. It was pointed out that, in fermentation on methane, the heterotrophic part of the population acted as a scavenger for methanol, an intermediate in the oxidation of methane, which, if it accumulated in the medium, would inhibit the growth of the dominant methane-oxidizing bacterium. It was also pointed out that, in the case of hydrocarbon oxidation by a mixed population of yeasts and bacteria, a large fraction of the bacterial population would be separated from the yeast during the harvesting and be discarded with the water phase.

Fermentation technology

Most usually, the biomass was produced by a single-stage fermentation process, but two groups had developed two-stage processes, in one case to make better use of the oxygen pumped into the system as air, and in the other to make better use of the paraffins. Two principal types of fermenting equipment were in use: one with mechanically stirred baffled reactors, the other with air-lift reactors and in which the high turbulence required for good mass transfer was achieved by proper selection of the reactor geometry and air-flow rate. In the latter case, tall reactors were sometimes used to achieve better efficiency of oxygen usage by pumping air into the system under substantial pressure. It was claimed that this system had the advantage of permitting easy scaling-up by increasing the diameter of the reactor. It has been suggested that surfactants could be used to increase the mass transfer by better dispersion of the hydrocarbon phase.

The familiar problem of reactor cooling received considerable attention. Its magnitude depended upon the temperature of fermentation and the local climatic conditions. Two methods were direct cooling and a refrigeration system Sea-water or any other available cooling water could be used for direct cooling, but this system was limited by the fact that, to be economic, there must be a difference of at least 5° or 6°C between the temperature of the coolant and the broth to be cooled. Refrigeration could be by means of a closed loop where water was chilled either by evaporation (steam ejection) or with a conventional refrigeration system. Such a closed-loop system avoids the use of costly material for the coolers. Considerable information was presented on cooling and the equipment used for it.

Harvesting and finishing technology

When yeast is used, centrifugation is generally considered for the primary separation of the biomass and the spent medium. It is sometimes followed by a washing with water. The yeast cream is also sometimes subjected to a further stage of concentration before final drying. It has been suggested that attention should be paid to flocculation or flotation, but it was pointed out that the surfactants used for the latter purpose would have to be completely non-toxic.

When bacteria are used, the biomass cannot be recovered economically by direct centrifuging; it is necessary to introduce a prior concentration stage such as flocculation or flotation. Considerable information on the characteristics and performance of different types of machines was provided to the Meeting by a centrifuge manufacturer.

With the gas-oil fermentation process, the dried biomass must be solvent extracted to remove the residue of non-metabolizable hydrocarbons carried over during the harvesting. Attention was drawn to the hygienic precautions to be taken to ensure that the harvested biomass should not be contaminated by micro-organisms to an extent that would make it unacceptable to feed manufacturers.

The possible use of an undried SCP paste or slurry was mentioned. The use of such a material would permit a saving by eliminating the drying step but, since the product would be labile, it would have to be used for animal feeding promptly, without storage. Thus, its use would be limited to situations in which wet feeds or slurries were used for animal feeding.

Protection of the environment

Some processes incorporate adequate safeguards against pollution of the environment. Such protection may involve the burning of obnoxious gases produced by the fermenter, but more generally, the biological treatment of the spent water and water washings would suffice. Some experts prefer the direct recycling of the water.

Analysis and control

Organizations in such different places as China, France, Italy, Japan and the United Kingdom of Great Britain and Northern Ireland appeared to be using, for *n*-paraffin raw materials, analytical methods that had largely originated in the United States of America.[2] Some dissatisfaction with the practicability and lower limit of detection of these methods, especially for application to routine quality control was noted. That the analysis of SCP product did not appear to have been given adequate attention was indicated by the fact that the policy emerging in the feed industry was based on protein assay only; most producing firms seemed to be reporting only protein content. It appeared that standardization was badly needed if this active ingredient assay were to form the sole basis for pricing. Crude lipid content has also proved to be a source of confusion owing to the lack of standardization of the solvent and apparatus used.

Training and development of personnel

India was operating a pilot plant that uses the *n*-paraffin process under a licence from a developed country. One of the benefits of this operation was the training of personnel. The high level of technology involved in the continuous food-processing and fermentation industries indicates the wisdom of this practice for any developing country where experienced industrial technologists are usually in short supply. Towards this end, Czechoslovakia has offered the use of its experimental facilities for the education of experts in both research and production. Israel was operating a fermentation unit jointly sponsored by the Ministry of Commerce and Industry and the Hebrew University of Jerusalem, which was engaged in research and development on a variety of fermentation processes,

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2/ Total aromatics (by UV absorption), United States Food and Drug Administration test No. 121.1156 and "Individual polynuclear aromatics (by chromatography)", Journal of the Association of Official Agricultural Chemists, vol. 31, 1966, p. 548.

including SCP production from several feedstocks. These facilities may become available for training specialists from developing countries.

Licensing and technology transfer

The development of an SCP process requires a very large investment in research and development that must continue for many years before the level of commercial production is reached. This expenditure often cannot be recovered solely by the use of the technology thus acquired in the operations of the enterprise itself. It therefore usually seeks to promote the use of the process by other enterprises. This may be done in the form either of joint ventures or of licensing fees.

Four firms appeared to be willing to license their *n*-paraffin or gas-oil technologies, and at least one offered its methanol-feed process. Licences have been negotiated between a British firm and a Japanese one and between a Japanese firm and an Italian one. Joint ventures based on *n*-paraffin fermentation have been the basis for technology transfer between a British firm and an Italian one and between a Japanese firm and a Romanian organization. During the Meeting, several proposals were made for collaboration between developed and developing countries and for joint activities to be pursued directly by the parties concerned.

V. COUNTRY INFORMATION

The Group was informed that the status of development and commercialization of SCP technology in developed and developing countries varied considerably. Commercial plants (first-generation level) were operating in the United Kingdom and in France, using *n*-paraffins and gas oil, respectively. In Italy, two large-scale plants using *n*-paraffin had reached advanced stages of design and engineering, one using the technology developed in France and the United Kingdom and the other based on Japanese know-how. In Japan, two companies had developed a technology using *n*-paraffin feedstock for commercial plants. However, as noted earlier, actual commercial operation was reported to have been postponed owing to opposition from consumer groups. The Union of Soviet Socialist Republics was also reported to be operating fairly large-sized plants using gas oil and *n*-paraffins. Work was in progress in the Federal Republic of Germany to develop technology for small-scale plants. Romania was also reportedly working on such a project.

Work was progressing vigorously in many countries (Bulgaria, Czechoslovakia, Japan, the United Kingdom and the United States of America) on the use of methanol and ethanol for the production of SCP. In China, work was in progress on a pilot-plant scale using gas oil and *n*-paraffins. Continuous as well as batch (three-stage) units were being operated periodically. It was intended to use the product for animal feed. Intensive feeding and toxicity tests were in progress. Considerable work on the development of adequately sensitive analytical techniques to identify and estimate polynuclear aromatics had also been done and was continuing.

In India, work on a pilot-plant scale was in progress at two research centres using 50 kg/day units (1 m^3 fermenters). Gas oil and *n*-paraffins had been successfully used to produce SCP. Continuous and batch processes had been used. Samples have been subjected to detailed analysis, and the digestability of the samples has been studied. Animal feeding trials have been made on a limited scale. The Indian Institute of Petroleum was collaborating on this project with the Indian Oil Corporation of India and the Groupment français de protéines of France for further development. The final product was intended to be used for animal feeding in the near future, mainly with a view to increasing milk yield from dairy cattle and egg production from poultry.

In Saudi Arabia, although experimental studies on the fermentation of hydrocarbons have not yet been undertaken, detailed studies are currently under way by Petromin (General Organization of Petroleum and Minerals) to determine the feasibility of establishing an SCP plant in that country, utilizing its large hydrocarbon resources. Preferred consideration was being given to the use of alcohols produced from natural gas as feedstocks for production of SCP, and processes that use methanol and ethanol were also under study. It is expected that the price of ethanol, when produced in large-scale plants via the ethylene route in Saudi Arabia, would be very competitive with world prices, and that SCP made from such ethanol could be exported at very attractive prices.

It was reported that India and Egypt were collaborating in the development of SCP in both countries. Mexico was reported to have been operating a pilot plant (about 50 kg/day) using gas oil and n-paraffins at the Mexican Petroleum Institute. Indonesia and Iran were reported to have been doing some fundamental work on SCP derived from gas oil and n-paraffins for use as animal food materials.

In Israel, a feasibility study, sponsored by the National Council for Research and Development, on SCP production from n-paraffins, gas oil, methanol and molasses, was recently completed and has defined the specific research needs for economic SCP production in Israel. Research connected with SCP production on methanol had been under way for several years with promising results. The programme was to be expanded in the near future to provide SCP for feeding studies and to develop necessary data for construction of a plant. Research and development on gas oil and other possible substrates was also to be enlarged.

VI. MARKETING SCP

Although few of the papers presented to the Meeting dealt with the marketing of SCP, the discussion turned repeatedly to this vital subject. In the contemporary context of increasingly acute shortages of conventional proteins and rising prices for them, the prices of SCP tend to be high so as to permit profit to the producers. The discussion tended towards the position that, in these circumstances, the use of SCP could become more general, but that it was difficult to arrive at any reasonably precise predictions. It was felt that, at present, the limiting factor for the use of SCP in direct human nutrition was its lack of food appeal, but that, on the other hand, its nutritional value for conversion to human food by animals was good. Indeed, the use of SCP in some animal feeds appeared to be certain in some fields such as the replacement of milk in the feeding of calves, given the limited availability and high cost of conventional protein.

Problems of toxicity appeared to be only marginal in animal feeding with SCP. Because of the proven nutritional value of this material, the benefits from using it, when it is attractively priced, would far outweigh the risk, which was minor. Thus, the prime requirement for the use of SCP in animal feeding was that it be priced competitively with protein from existing sources and with other sources that were being developed, such as rape-seed and the reclamation of animal proteins that were being wasted.

The demand for SCP for feeding certain adult animals appeared to be doubtful, but the feeding of calves with this material or with special soya flours, even at premium prices, would be feasible because of the high selling price of the protein in skim milk powder. However, as the prices of SCP and of soya flours were related to their protein content, they were selling in a price range from $350 to $550 per ton. This market was restricted to inclusion rates of

5 to 20 per cent SCP in the feed mix, so that in Europe, for example, at an inclusion rate of 5 per cent, the potential market for SCP would have been about 80,000 tons/year.

As far as pigs and poultry were concerned, it was acknowledged that soya prices were difficult to predict, but there was a consensus that SCP would have to be competitive with soya on an iso-protein basis, although the situation might vary from one country to another. The economics in each case would have to be judged in this context.

If consumer demand proved to be insufficient to justify the production of SCP at prevailing costs, the price structure might be modified by government intervention in the form of price supports, as was done in many countries that subsidized certain agricultural products.

The animal-feed market for SCP would best be developed through the existing compound-feed industry, whose conditions for acceptance include:

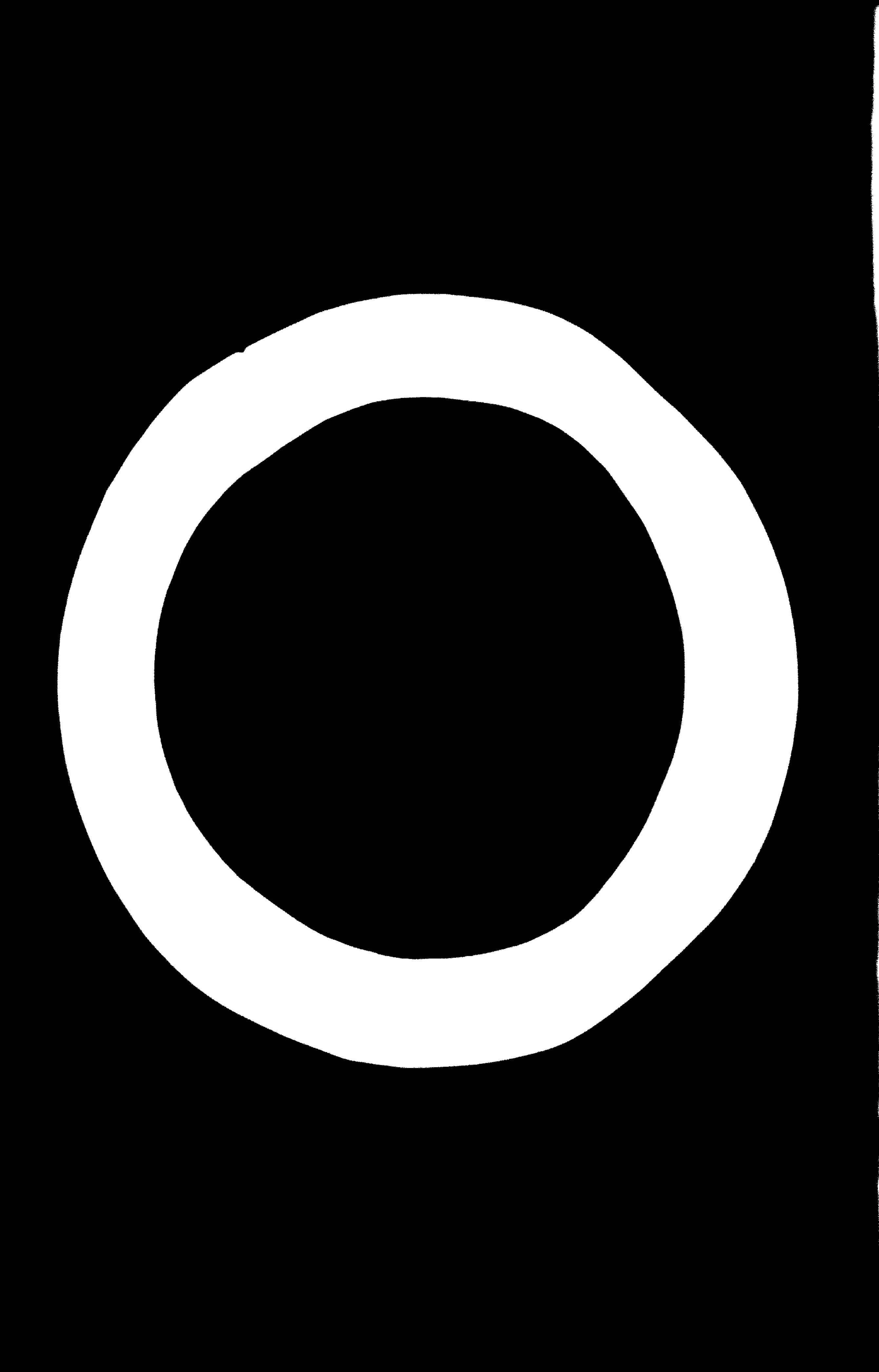
(a) Compliance with the requirements of national regulatory agencies;

(b) A conventional unit price for protein;

(c) Nutritional properties suitable for pigs, poultry and calves.

In countries without developed feed industries, livestock and poultry are usually raised by small farmers who may mix their own animal feeds. For the present, such countries should continue the orderly development of agriculture and stock-raising and also take SCP into consideration. Since conditions vary so widely from one developing country to another, marketing problems should be considered on a country-by-country basis.

There was a consensus that marketing should be given fuller consideration at future meetings and that countries that were considering the production of SCP should give careful consideration to their potential domestic and foreign markets before embarking upon a programme of capital expenditure. It was also suggested that, in the future, the market price of SCP would reflect the cost of the raw materials of which it is made unless the producers are either willing to lose money or to obtain government subsidies.



Annex

LIST OF DOCUMENTS

ID/WG.[illegible]	Agenda
ID/WG.[illegible]/Rev.[illegible]	List of participants
ID/WG.[illegible]	Provisional list of documents
ID/WG.[illegible] and Summary	[illegible] SCP production from paraffins F. P[illegible], Italy
ID/WG.[illegible] and Summary	[illegible] [illegible] A. [illegible], United Kingdom of Great Britain and Northern Ireland
ID/WG.[illegible] and Summary	[illegible] SCP [illegible] paraffins [illegible], Italy
ID/WG.[illegible] and Summary	[illegible] paraffin yeast [illegible], Japan
ID/WG.[illegible] and Summary	Protein from algae - an associated industry [illegible] Robinson and [illegible] Jarvis, United Kingdom of Great Britain and Northern Ireland
ID/WG.[illegible] and Summary	Fermentation protein from [illegible] [illegible], United Kingdom of Great Britain and Northern Ireland
ID/WG.[illegible] and Summary	The production of [illegible] [illegible], Japan
ID/WG.[illegible] and Summary	Production of SCP from [illegible] raw materials [illegible] petrochemical industry [illegible] [illegible] and [illegible]
ID/WG.[illegible] and Summary	Some specific features [illegible] bacterial food protein [illegible] normal paraffins [illegible] Kostadinov, Bulgaria
ID/WG.[illegible] and Summary	The [illegible] situation [illegible] developing countries and potentials for the production of petro-proteins [illegible] Krishna, India
ID/WG.[illegible] and Summary and Corr.[illegible]	Effect of site factors on the economics of petro-protein manufacture [illegible], [illegible] Kerns, [illegible] Cooper and [illegible] Silver, United States of America
ID/WG.[illegible] Summary only	Petro-proteins [illegible] Vienna/Chemie Linz, Austria

ID/WG.104/[illegible] and Summary	The marketing of fermentation proteins in developing countries J. Weiss, Italy
ID/WG.104/[illegible] Summary [illegible]	Development strategy of n-paraffins as raw material source for production of SCP E. Rosi, Italy
ID/WG.104/[illegible] and Summary	The economics of producing single cell protein by yeast fermentation using n-paraffins as a substrate F. Giacobbe, Italy
ID/WG.104/[illegible]	Present status and techno-economic aspects of the industrial production of petro-proteins J. C. Masson, Switzerland
ID/WG.104/[illegible]0 and Summary	Production of single cell protein from alcohols Y. Masuda and K. Yoshikawa, Japan
ID/WG.104/[illegible]	The role of developing countries in the development of the hydrocarbon fermentation process I. Al-Karawi, Saudi Arabia
ID/WG.104/[illegible] and Summary	Cell separation and fermenter cooling in protein production from hydrocarbons T. Winberg and T. Johansson, Sweden
ID/WG.[illegible]	Agro-industrial complexes and the potential use of petro-protein products UNIDO Secretariat
ID/WG.104/[illegible]4	Some problems about petro-protein as a new feedstuff Wang Yu and Fang Feng-Shan, China
ID/WG.[illegible]	The separation of n-paraffins from petroleum fractions for use as substrate in protein production W. F. Avery, Switzerland
ID/WG.104/[illegible]	BP proteins - a survey of BP's processes and production facilities with product evaluation R. M. Laine, United Kingdom of Great Britain and Northern Ireland
ID/WG.104/[illegible]	Production of SCP from hydrocarbons - economics R. M. Laine, United Kingdom of Great Britain and Northern Ireland
ID/WG.104/[illegible]	SCP production from methanol I. Nagai, Japan
ID/WG.104/[illegible]9	Design of technical petro-protein plants in Developing countries R. Knecht and U. Faust, Federal Republic of Germany
ID/WG.104/30	Nutritional and product safety considerations for food use of SCP Protein Advisory Group of the United Nations
ID/WG.104/31	Communication on the development of n-paraffin yeast R. de Baynast, France

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