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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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(R) INDUSTRIAL STUDIES AND DEVELOPMENT CENTRE—PHASE II

DP/SAU/73/004

SAUDI ARABIA.

TECHNICAL REPORT:

The potential for manufacture of single-cell protein

Prepared for the Government of Saudi Arabia by the United Nations Industrial Development Organization, executing agency for the United Nations Development Programme

United Nations Industrial Development Organization

id.76-6688

United Nations Development Programme

INDUSTRIAL STUDIES AND DEVELOPMENT CENTRE - PHASE II

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SAUDI ARABIA

Technical report: The potential for manufacture of single-cell protein

Prepared for the Government of Saudi Arabia
by the United Nations Industrial Development Organization,
executing agency for the United Nations Development Programme

Based on the work of Rashad Khalifa, petroprotein expert

United Nations Industrial Development Organisation

Vienna, 1976

Explanatory notes

A comma (,) is used to distinguish thousands and millions.

A full stop (.) is used to indicate decimals.

The term "billion" signifies a thousand million.

References to dollars ($) are to United States dollars, unless otherwise stated.

Dates are given in the Moslem calendar, designated by A.H., and followed in parentheses by the corresponding dates in the Christian era.

The following abbreviations are used in this report:

ISDC	Industrial Studies and Development Centre
LPG	Liquefied petroleum gas
SCP	Single-cell protein

ABSTRACT

The project entitled "Potential for manufacture of single-cell protein in Saudi Arabia" (DP/SAU/73/004) arose from a request by the Government of Saudi Arabia to the United Nations Development Programme (UNDP) for a petroprotein expert to study Saudi Arabia's potential for the manufacture of single-cell protein (SCP), and to provide sufficient information and guidelines to enable the responsible authorities to take a decision concerning the establishment of an SCP production plant in Saudi Arabia. The expert's one-month mission began in mid-June 1976, with the United Nations Industrial Development Organization (UNIDO) acting as executing agency and the Industrial Studies and Development Centre (ISDC) of Saudi Arabia as the counterpart agency.

The mission also had the following objectives:

1. To investigate the potential viability of the proposed petroprotein project from the technical, economic, marketing and financial points of view, with special reference to any anticipated problems of technology transfer or other possible deterrents.

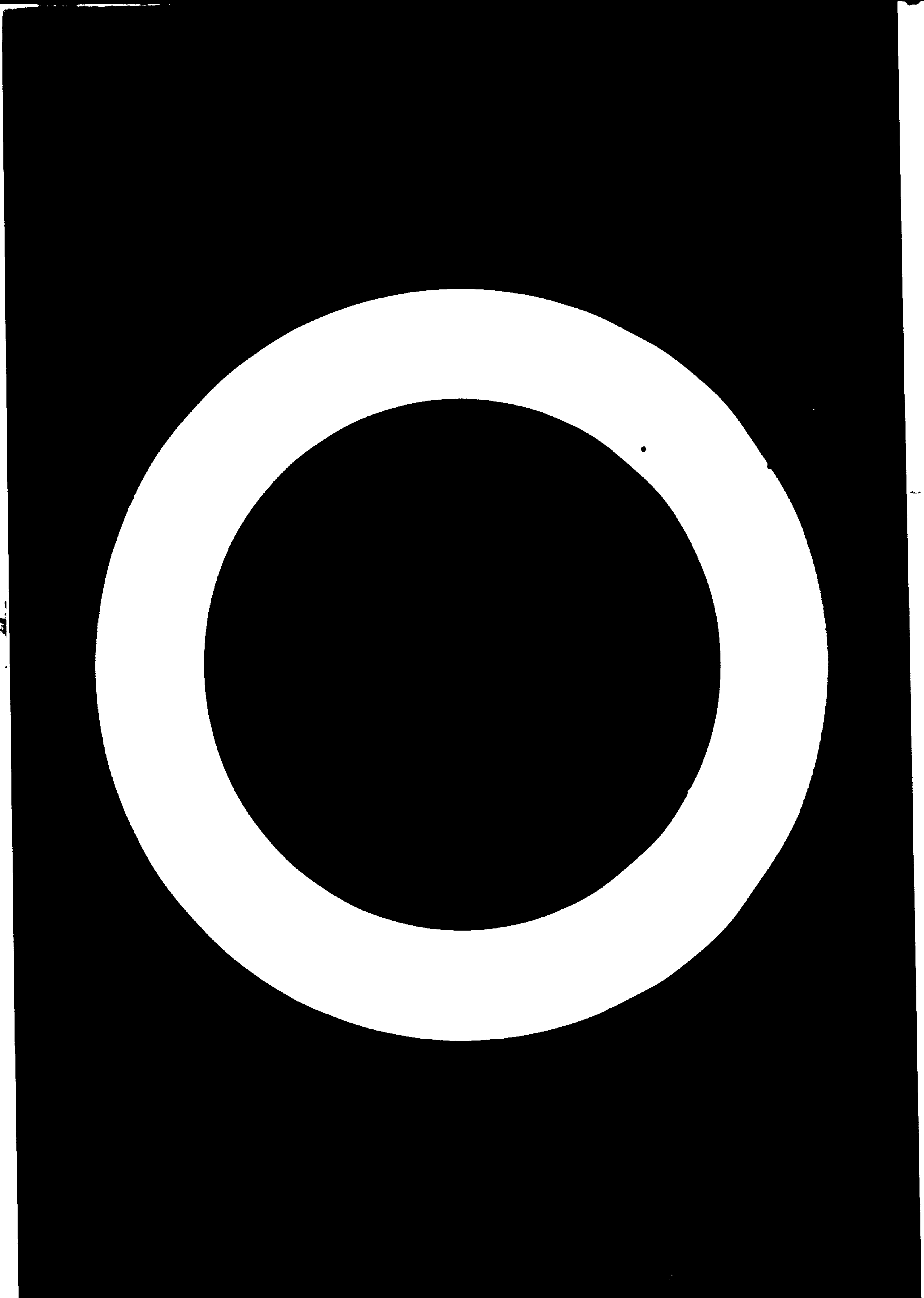
2. To assess domestic and export marketing prospects in the field of petroprotein production and the possibilities of a domestic animal agro-industrial complex as a source of animal proteins for human consumption and a stimulus to rural development.

The main conclusions and recommendations reached in the report are as follows:

1. Saudi Arabia should plan to develop an SCP manufacturing capacity of 100,000 tons per year (t/year) by 1400 A.H. (1980), to be expanded to 200,000 t/year during the following decade.

2. The most suitable process for manufacturing SCP under Saudi Arabian conditions is the n-paraffin-based process.

3. SCP should be manufactured and marketed in Saudi Arabia through either a single government-sponsored agro-industrial complex or a system of multiple agro-industrial complexes. For a single complex, the best construction site seems to be the Jaizan area. In the case of a multiple system, the SCP plant could form part of the Jiddah or Riyadh refineries, or of one of the eastern refineries.



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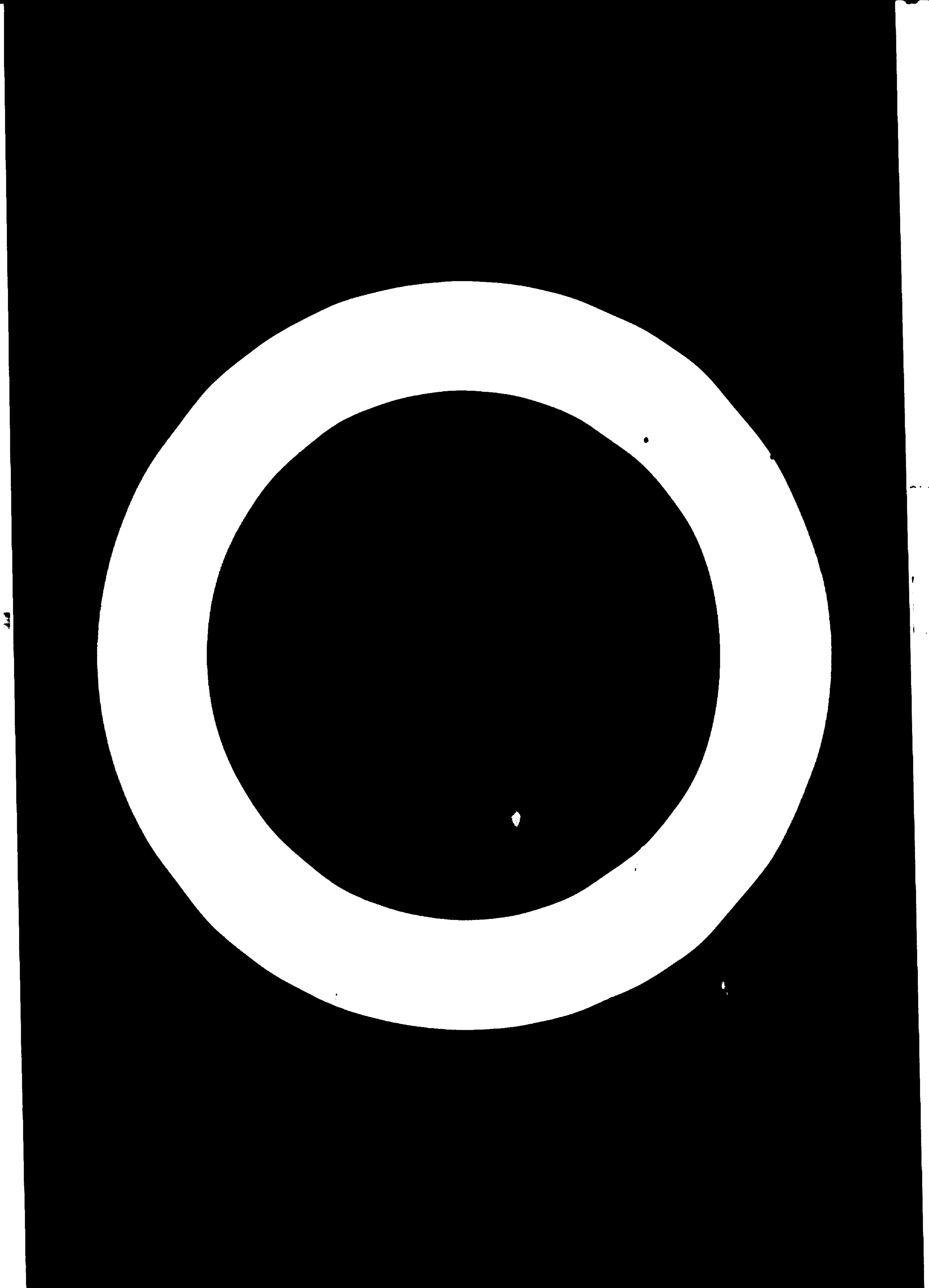

INTRODUCTION

Saudi Arabia, despite its rapidly increasing gross domestic product based primarily on oil income, is at an early stage of industrial development. It is therefore making a determined effort to develop its industry, and in particular to establish large export-oriented as well as small and medium-sized industries, mainly through the Industrial Studies and Development Centre (ISDC) of Saudi Arabia, which was established in March 1967 with the assistance of UNDP. The diversification of the national economy, the substitution of nationally-manufactured for imported goods, and the fuller utilization of existing capabilities also figure prominently among the objectives of both the ISDC and the National Development Plan. The possibility of single-cell protein (SCP) (petro-protein) production in oil-exporting countries, where the raw materials are available, has therefore aroused considerable interest in Saudi Arabia. Although a number of economic and technical problems must be overcome in order to make such a project viable, the integration of petroprotein production within an agro-industrial complex would contribute significantly to the success of the venture, and the production of milk, eggs and various meats should stimulate Saudi Arabian economic development. In order to assess the feasibility of the project, the Government of Saudi Arabia therefore requested UNDP to provide a petroprotein expert to undertake a study of Saudi Arabia's potential to manufacture SCP, and to produce sufficient information and guidelines to enable the responsible authorities to take a decision concerning the establishment of an SCP production plant. This request was granted and the expert's one-month mission began in mid-June 1976, with the United Nations Industrial Development Organization (UNIDO) acting as executing agency and the ISDC as the counterpart agency.

The objectives of the mission were defined as follows:

1. To investigate Saudi Arabia's potential for petroprotein production in the light of its present conditions and future plans.

2. To identify the market's structure, with special reference to the following aspects:

(a) The assessment of domestic and export marketing possibilities;

(b) The possibility of a domestic animal agro-industrial complex as a supplementary source of animal proteins for human consumption, as well as an expedient to rural development;

(c) The market acceptance of the product;

3. To estimate the appropriate size of petroprotein production plant in Saudi Arabia;

4. To select the type of substrate and process technology most suited to the specific circumstances of Saudi Arabia;

5. To outline any anticipated problems regarding technology transfer and any other possible deterrents;

6. To make a preliminary assessment of the potential viability of the proposed petroprotein project, from the technical, economic, marketing, and financial points of view;

7. To give concrete proposals regarding the strategy and future implementation plans.

The first week of the mission was devoted to briefing officials at the ISDC on the latest developments relating to the commercialisation of the SCP manufacturing process, and on the major engineering problems involved in scaling up from a laboratory to a pilot plant or commercial plant for petroprotein production. The second and third weeks of the assignment were spent collecting the data and information required, the sources of which included the Ministry of Agriculture and statistics published by the Ministry of Trade up to the year 1973-1974. The fourth and final week was devoted to writing the final report and discussing it with the responsible authorities at the ISDC.

I. BACKGROUND INFORMATION

A. The need for new protein sources

Only 2,000 years ago, the world population was less than 200 million. It took 1,800 years for the population to grow to 1 billion; 125 years later, it became 2 billion; only 30 years after that, the world population reached 3 billion; the present population of 4 billion was reached during the last 15 years (from 3 billion to 4 billion). This parabolic world population growth rate was not matched by growth in the rate of food production. Thus, some 30 years ago, scientists became seriously concerned that the fast increase in world population, coupled with a slow rate of growth in agricultural and food production, would inevitably lead to food shortages, and, eventually, to widespread famine. Of all the food components, protein was the most critical item, and scattered areas around the world were showing signs of acute protein shortages. Consequently, research and development has concentrated on increasing the global supply of protein. Such efforts, carried out mostly in Europe and Japan, relied on increasing the production of protein from conventional sources, while searching for novel sources of this essential nutrient.

B. Single-cell proteins: a technological breakthrough

After many years of intensive and painstaking research, scientists were able to develop a new source of protein, namely, "single-cell protein" (SCP), consisting of unicellular organisms which feed and multiply on hydrocarbons as the main nutrient. When these organisms (yeasts, bacteria etc.) are harvested and dried, they yield a powder containing 50% to 80% protein, the balance consisting of valuable vitamins, minerals, and carbohydrates. The development of the hydrocarbon fermentation process involved in SCP production required the selection of the most suitable organisms, the best hydrocarbon fractions, and a host of parameters needed to grow the organisms under optimum conditions. Scaling up the process from laboratory to pilot plant and to commercial plant required solutions to formidable engineering problems such as those of foaming, heat removal, mixing the aqueous and non-aqueous nutrients, supplying the required oxygen, and many others. However, scientists and chemical engineers of academic and governmental establishments, as well as those of private companies, succeeded in developing workable methods of inoculation, sterilisation, mixing, harvesting, drying, and packaging SCP. The developing countries can now reap the benefits of all these achievements by applying the new technology to convert non-edible hydrocarbons into edible, protein-rich material. This is a particularly welcome development for a country such as Saudi Arabia, where hydrocarbons are abundant, while agricultural growth is restricted by unfavourable water and climatic conditions and insufficent arable land.

The significance of this scientific and technological achievement can be appreciated when it is recalled that the manufacture of SCP is not subject to climatic variations, that the process requires no farm land, and that the small area required to build a 100,000 t/year plant will yield as much protein as millions of acres of the land used to produce beef. SCP production is carried out entirely indoors, and the organisms are fed on a hydrocarbon fraction, plus smaller amounts of minerals, under controlled conditions of temperature and pH, yielding material that is edible to animals or to humans.

II. PETROPROTEIN PRODUCTION

A. Various manufacturing processes

At the laboratory level, various processes have been developed for the manufacture of SCP. Several processes based on the utilization of hydrocarbon raw materials have been developed at a pilot plant level. However, only one process has been used on a commerical scale, namely, the n-paraffin-based process, and one semi-commerical process is in operation, the Amoco ethanol-based process. Large-scale industrial production of SCP, with a single plant capacity up to 250,000 t/year, exists only in the USSR. The various processes studied for manufacturing SCP are shown in table 1 below.

Table 1. Various processes for the production of single-cell protein

Substrate	Organism	Companies or states involved
N-paraffins	Yeasts and bacteria	USSR British Petroleum Kanegafuchi Dainippon Liquichimica Gulf Research and Development
Gas oil	Yeasts and bacteria	British Petroleum USSR French Institute of Petroleum Indian Institute of Petroleum
Methanol	Bacteria	Imperial Chemical Industries, Shell
Ethanol	Yeasts and bacteria	Amoco Food Company Exxon
Methane	Bacteria	Shell[a/]
N-alkanes	Bacteria	Chinese Petroleum Corporation

a/ No longer active in this field.

At this time, only the n-paraffin process can be considered for use in Saudi Arabia, since the others have not yet been developed for commercial production. The ethanol-based process is not of interest, since the Saudi Arabian authorities have ruled out the direct use of petroprotein in the human diet.

The companies holding patents or licences for the commercial production of SCP from n-paraffin include British Petroleum (United Kingdom), the Kanegafuchi

Company (Japan), the Dainippon Ink and Chemicals Company (Japan), and Liquichimica Biosintesi (Italy). However, there are major differences in the application of this process, and these are described below. Selection of a particular process should be made very carefully to suit the circumstances of the country. The factors to be considered in making a choice include the specific engineering parameters, skilled and non-skilled manpower needs, water and electricity requirements, heat generation, capital investment, the cost/benefit ratio and return on investment parameters etc.

B. Variations in the n-paraffin process

In solving the problems of scaling up from pilot to commercial plant, the various companies involved have adopted different solutions. This has resulted in major differences among the companies with regard to their method of making SCP from n-paraffin. Table 2 below outlines those differences.

The technical variations among the n-paraffin-based processes, as shown in table 2, provide the basis for making a choice as to which process should be adopted for Saudi Arabia. Some differences between the various processes are quite obvious. One example is the requirement for electric power. For example, the British Petroleum plant, with a capacity of 100,000 t/year, uses 3 huge fermenters; each of its mechanical agitators requires 11 MW. For purposes of comparison, the Kanegafuchi commercial plant, with a capacity of 100,000 t/year, uses an airlift mixing system and 10 fermenters, with each fermenter consuming 70,000 watts of electricity. This means that the requirement for electricity at the British Petroleum plant is 34,000,000 watts, compared to the 700,000 watts at the Kanegafuchi plant, at the plant owned by Liquichimica in Calabria, Italy, or at the Dainippon plant in Romania. Thus, the British Petroleum process might seem more advantageous to countries with abundant electric power supplies.

Another major difference shown in table 2 involves the sterilization requirement. The British Petroleum commerical plants are designed so that the fermentation process can take place in a sterilized medium. On the other hand, the Kanegafuchi and Dainippon processes are designed in such a way that sterilization measures are not strictly necessary. The Liquichimica plant in Calabria (which applies the Kanegafuchi process) requires emptying the fermenter completely every few days and starting a new fermentation. This eliminates the need for continuous sterilization in the fermentation process. In a country like Saudi

Table 2. N-paraffin process variations

Company or state concerned	Raw materials	Commercial plant (location and capacity)	Pilot plant (location)	Culture (organism and temperature)	Status of commercial production	Anti-foaming devices	Mixing method	No. of fermenters for a capacity of 100,000 t/year	Sterilization requirements	pH	Power required (MW/100,000 t/year)	Drying method	Washing stages	Yield (kg/kg of paraffin)	Steam required (kg/ton)
British Petroleum	n-paraffin, C_{10}-C_{23} 97.5% purity	Sarroch, Sardinia (100,000 t/year); Venezuela (same capacity)	Grangemouth, United Kingdom	Candida 30°C	The plant in Sarroch is built, but is not in operation. The plant in Venezuela is under construction		Mechanical	3	Sterilization required	4.5	34	Evaporation plus spray-drying	One stage	1.0	3,200
Kanegafuchi	n-paraffin, C_{12}-C_{18} 98% purity	Calabria, Italy (100,000 t/year)	Takasaki, Japan	Candida 30°-35°C	The plant is built, but is not in operation	Anti-foaming agent needed	Airlift	10	Sterilization not required	4-4.5	0.7	Spray dryer	Alfa-Laval separator and filtration	1.15	600
Dainippon	n-paraffin, C_{10}-C_{18} 98% purity	Jassy, Romania (100,000 t/year)	Chiba, Japan	Pichia 35°-37°C	The plant is under construction	Mechanical anti-foaming	Airlift	10	Sterilization not required	4-4.5	1.0	Film evaporation to 23%, then spray drying	3 stages by Westphalia separators	1.05	750
French Group	n-paraffin, C_{12}-C_{22} 98% purity		Solaize, France; Baroda, India	Candida trop. 30°-40°C			Airlift	10	Sterilization not required	3.5		Evaporator and dryer	Two-stage wash	1.1	800
USSR[a]	n-paraffin, C_{12}-C_{22}			Candida 30°-38°C	The commercial plants have been in operation for several years										

a/ The USSR has five big commercial plants with a total production of several hundred thousand t/year. The capacity of one of the plants is 250,000 t/year.

Arabia, it may be difficult to meet sterilisation requirements for a lengthy fermentation process. It therefore seems probable that the process chosen will not be subject to such conditions.

Another point to be considered in selecting an SCP process is the optimum temperature of growth of the organism. Since the heat generation problem is quite significant in SCP manufacture, and since Saudi Arabia is a hot country, the choice of a process may be influenced by the temperature of fermentation. It would seem that the most suitable process from this point of view is that of the French Group, in which the organism grows optimally at 38^{o}-$40^{o}C$. The next best process would be the Dainippon process (optimum temperature: 35^{o}-$37^{o}C$).

Judging from these few, but significant, differences, it would seem that the best over-all process for Saudi Arabia is the Kanegafuchi process or the Dainippon process. Both of these processes are not as technically intensive as the British Petroleum process, for example, which imposes energy and technical demands that may be too much for local manpower.

C. Safety problems

Three main concerns have been voiced against SCP with regard to its safety for human or animal consumption. These relate to its alleged toxicity and carcinogenecity, and its nucleic acid content.

Toxicity

It can safely be stated that no food or food product or animal feed material has undergone as much toxicological testing as SCP. Safety tests for the SCP have been carried out in both short-term and long-term feeding studies at higher dietary levels than would normally be used. These tests were conducted by academic, governmental, and private institutions, and they covered a variety of test animals, as well as humans (including the expert). Over 15 years of tests have shown no adverse effects on the test animals, and the conclusion was reached that SCP is not toxic to animals feeding on it directly. Five years ago, the expert ate 10 grams of SCP each day for 90 days as part of feeding tests, and no adverse effects resulted from that.

Mutagenic and teratogenic tests were also carried out to examine the possible safety hazards of SCP in connexion with reproductive processes. Successive generations of test animals were produced on diets containing up to 30% SCP. No deformities resulted from such feeding; the number and physical characteristics of the offspring were normal. When males were fed on as high as 67% SCP in their diet, their fertility was not adversely effected.

Carcenogenicity

The question of the carcenogenicity of SCP has been raised mainly by people who are not sufficiently familiar with the details of SCP manufacture. They knew that crude oil contains carcinogenic materials, namely, polycyclic hydrocarbons, and they speculated that some such materials might be carried over to the SCP, then to the animals which feed on it, and ultimately to the humans who feed on those animals. However, the critics forget that the hydrocarbons used as the source of carbon for SCP fermentation, namely the n-paraffin, is separated from the oil fractions at a boiling point which is much lower than that of the polycyclic hydrocarbons. Thus, the maximum boiling point for the n-paraffins of SCP is 320°C, while that for the polycyclic hydrocarbons is around 500°C. Consequently, the n-paraffins used in the SCP fermentation process are free from the carcinogenic materials to start with. No detectable amounts of polycyclic hydrocarbons were found in the 97%-98% n-paraffins used in manufacturing SCP. Further tests on the SCP itself and the animals feeding on it also showed no detectable traces of the polycyclic hydrocarbons.

Nucleic acids

The ingestion of excessive amounts of nucleic acids results in the appearance of symptoms of hyper uricemia (gout) in humans. Since the micro-organisms generally are known to contain relatively high concentrations of these nucleic acids, a question was raised concerning the possible side-effects of consuming SCP or animal-fed SCP.

Research on this subject (notably by biochemists at the Massachusetts Institute of Technology) has indicated that only direct feeding on SCP at abnormally high levels may lead to hyper uricemia symptoms. Since the project for Saudi Arabia deals with future indirect feeding by humans on the animals which consume low levels of SCP, the nucleic acid content should be of no concern. In any case, methods are available for the reduction of the nucleic acid level in SCP, if it is rendered necessary by direct human consumption of relatively large quantities of SCP.

D. Nutritional value of single-cell protein

SCP is comparable to other conventional protein sources, with the usual variation in amino acid composition. The general analysis of SCP is shown below in table 3.

Table 3. General analysis of SCP

Constituents	Percentage
Crude protein	55-56
Crude fat	6-12
Crude ash	6-11
Crude fiber	3-5
Nitrogen-free extract	10-17
Moisture	2-3

The crude protein in SCP is highly digestible, as shown in table 4.

Table 4. Digestibility and energy value of SCP

Animals	Protein digestibility (percentage)	Energy value (kcal/kg)
Broiler chickens	88	3,320
Growing swine	92	3,900
Pre-ruminant calves	87	3,530

In addition to the protein, SCP contains valuable vitamins, minerals, and calorie-giving carbohydrates. Table 5 shows the vitamin content of SCP, and table 6 shows the mineral content.

The essential amino acids present in SCP are shown in table 7, together with those in fish meal and soya meal for purposes of comparison.

It should be noted that in experiments carried out by the expert, it was found that replacing half the soybean meal in chicken diets with SCP (Dainippon's Viton) resulted in better weight gains than in the control experiments. It appears that SCP corrects the lysine deficiency of soybean meal, while the soybean mea corrects the methionine deficiency in SCP. Broiler chickens fed on the SCP/so ean meal mixture (10% and 20% SCP), gained significantly more weight than chickens fed the control ration (no SCP).

Table 5. SCP vitamin content

Vitamin	Amount (mg)
B 1	1.26
B 2	9.61
B 6	1.73
B 12	0.02
Pantothenic acid	30.90
Choline chloride	690.00
Nicotinic acid	100.00
Biotin	0.13
Folic acid	0.22
Inositol	580.00

Table 6. SCP mineral content

Mineral	Amount (mg)
P	1,990
K	1,630
Ca	105
Mg	249
Fe	69
Zn	22
Cu	0.5

Table 7. Amino acid composition of SCP, fish meal and soya

Amino acid	SCP	Fish meal	Soya meal
Isoleucine	5.1	4.6	5.4
Leucine	7.4	7.3	7.7
Phenylalanine	4.3	4.0	5.1
Tyrosine	3.6	2.9	2.7
Threonine	4.9	4.2	4.0
Tryptophan	1.4	1.2	1.5
Valine	5.9	5.2	5.0
Arginine	5.1	5.0	7.7
Histidine	2.1	2.3	2.4
Lysine	7.4	7.0	6.5
Cystine	1.1	1.0	1.4
Methionine	1.8	2.6	1.4

III. PETROPROTEIN MANUFACTURE IN SAUDI ARABIA

When it is considered that the agricultural potential of Saudi Arabia is restricted by unfavourable water, land, and climatic factors, it becomes clear that turning unedible oil, in which Saudi Arabia enjoys a great economic advantage, into edible protein offers tremendous opportunities. The manufacture of SCP from Saudi Arabia's abundant oil would free the country from dependence on other countries for protein supplies. This protein can in turn be used in the production of various meats with a view to achieving self-sufficiency in beef, lamb, chickens, eggs, and dairy products. Thus, it appears that Saudi Arabia's entry into the field of SCP manufacture would be most advantageous.

A. Estimated future petroprotein requirements in Saudi Arabia

The calculation of Saudi Arabia's demand for SCP is based on the estimated animal population required in the coming years to meet the demand for meats, eggs, and dairy products. The study assumes that all animals needed to meet such demand will be raised within the country, eliminating thereby the need for importing meat or live animals. The projected demand in 1400 A.H. (1980) for beef cattle, dairy cattle, lamb and goat meat, broiler chickens and layer chickens is shown in figures I through V, respectively.

Demand for beef

As shown in figure I, the demand for beef in 1400 A.H. (1980) will total approximately 500,000 head of cattle, about 85,000 head to be raised locally, about 190,000 to be imported live, and about 225,000 to be imported slaughtered. It should be noted that this is a rather conservative estimate, since a population of 7,000,000 people will, on this basis, consume about 27 kg of beef *per capita*. Considering Saudi Arabia's population increase and the influx of expatriates, the *per capita* consumption of beef may be even less. However, using this projection, the amount of SCP needed to raise the necessary beef cattle is shown below:

(a) Milk replacer for rearing calves. This represents the main usage of SCP for raising beef. The milk replacer will be needed for 500,000 head of cattle per year up to 70 days after birth (involving a weight gain of about 50 kg). Since each calf needs an average of 2.47 kg of milk replacer per kg of weight gain, the total amount of milk replacer required would be 2.47 x 50 x 500,000 = 61,750,000 kg. Since the proposed SCP content of this milk replacer is 10%, the amount of SCP required here is 6,175,000 kg = 6,175 metric tons;

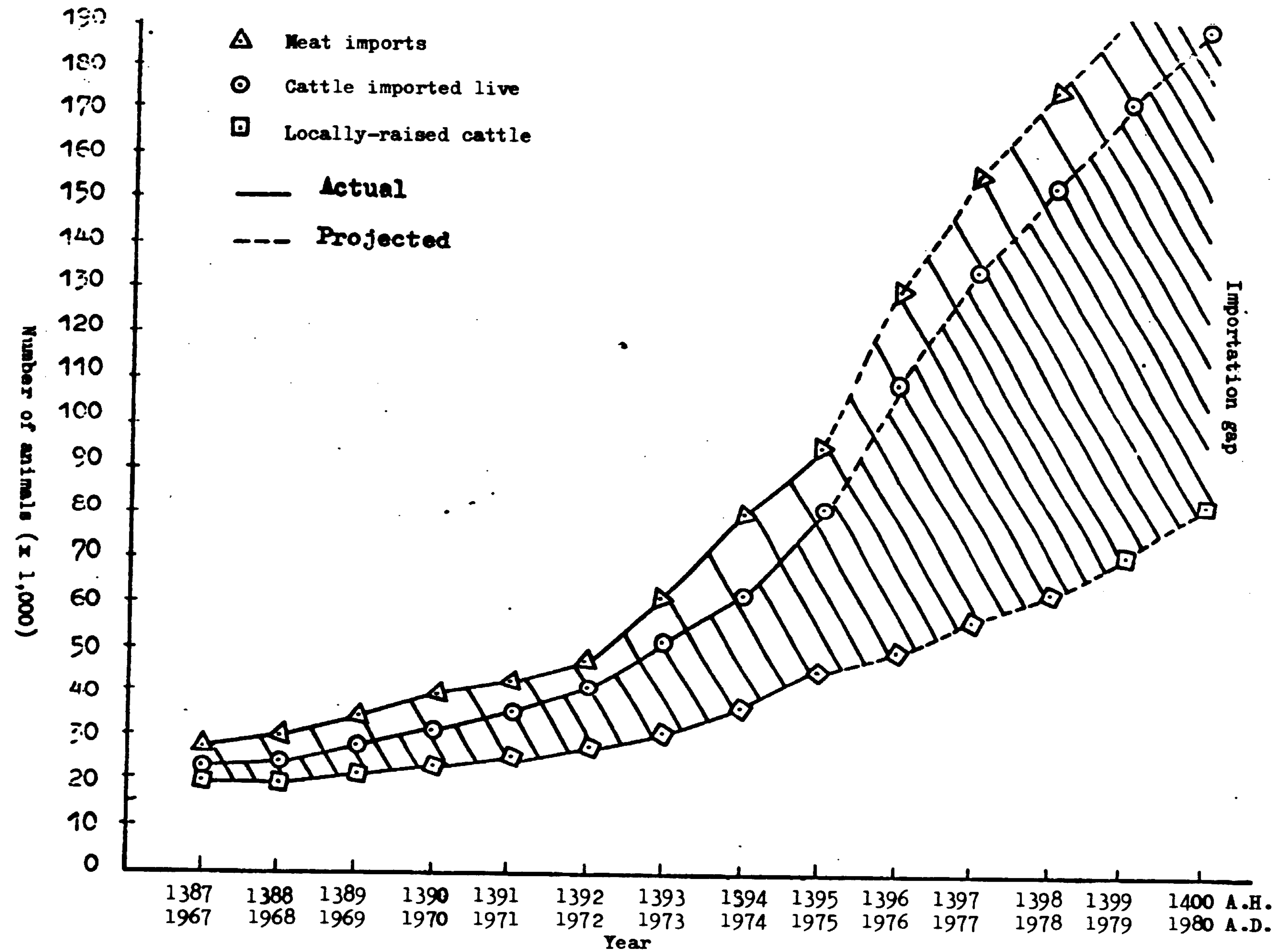

Figure I. Current and future demand for beef in Saudi Arabia

(b) Milk replacer for veal calves. Assuming that 40% of the cattle produced will be used as veal, 200,000 head of veal calves will be reared for consumption in 1400 A.H. (1980). Since veal is slaughtered after an average weight gain of about 115 kg, the total amount of milk replacer needed will be 1.6 (kg of milk replacer/kg of weight gain) x 115 (the weight gain per animal in kg) x 200,000 = 36,800,000 kg. The inclusion of 10% SCP in the milk replacer means that the total SCP requirement for veal calves will be 3,680 metric tons;

(c) SCP for ruminant cattle. For the remaining 300,000 head of cattle to be raised to 400-500 kg weight, the required proportion of protein in their feed concentrate is 22%. The conventional sources of this protein are urea and soya meal. The SCP manufactured in Saudi Arabia can replace almost half of this usually imported material, that is, up to a level of 7.0% of SCP. Assuming a feed efficiency of 6.0 kg feed concentrate per kg weight gain, the amount of SCP required for ruminant cattle would be 300,000 (head of cattle) x 2,400 (kg of feed concentrate per head) x 0.07 (the 7% SCP inclusion) = 50,400 metric tons of SCP.

Demand for milk cows

As shown in figure II, the total demand for milk and dairy products in the year 1400 A.H. (1980) will amount to roughly 120,000 tons, for which about 60,000 head of milk cows will be needed. Local production, if present trends continue, will contribute about 30,000 tons (15,000 head); 90,000 tons of milk and dairy products will have to be imported. If the total amount of milk is to be produced and processed within Saudi Arabia, 60,000 head of milk cows will have to be raised locally. The total feed concentrate required by this number of milk cows is 60,000 x 2,400 = 144,000 tons annually. With a 22% protein content in the feed concentrate, the total amount of protein required is 144,000 x 0.22 = 31,680 tons. Of these 22%, which consist of urea and soya meal, 7% SCP replacement is recommended. This means that the total SCP required by dairy cattle in Saudi Arabia during the year 1400 A.H. (1980) should be 144,000 x 0.07 = 10,080 tons.

Demand for lamb and goat meats

Figure III indicates that the total demand for lamb and goat meats during the year 1400 A.H. (1980) will require the slaughtering of 3,500,000 animals. The projected capacity for local production in that year is approximately 500,000 animals. To avoid importing 3,000,000 head in the year 1400 A.H. (1980) (more than 2,000,000 head are being imported in 1396 A.H. (1976)), the 3,500,000 head will have to be raised locally. This number os sheep and goats will need the following total amount of feed concentrate: 3,500,000 x 25 (average kg per head) x 6.0 kg (assuming a feed efficiency of 6 kg feed/kg weight)

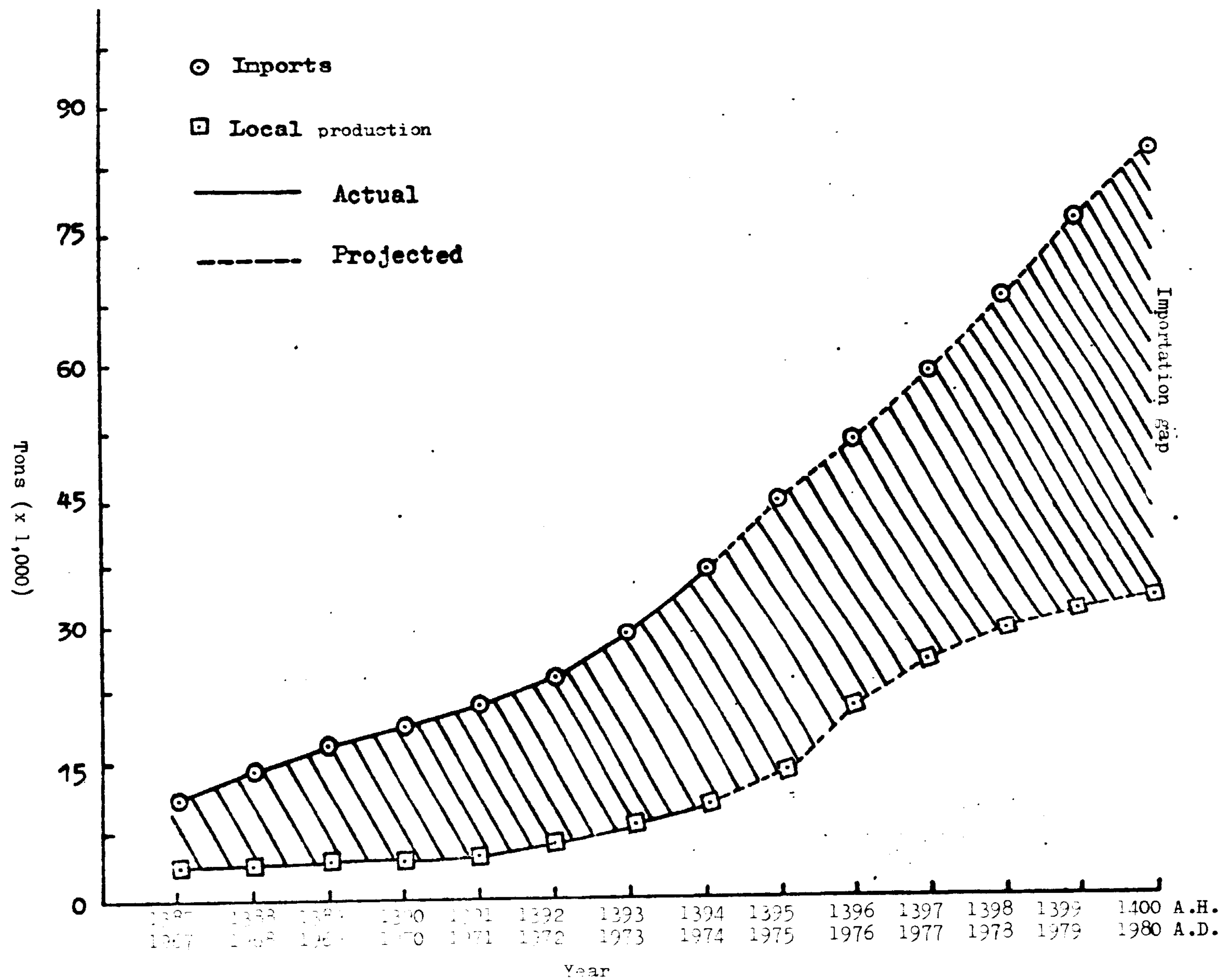

Figure II. Current and projected demand for dairy products

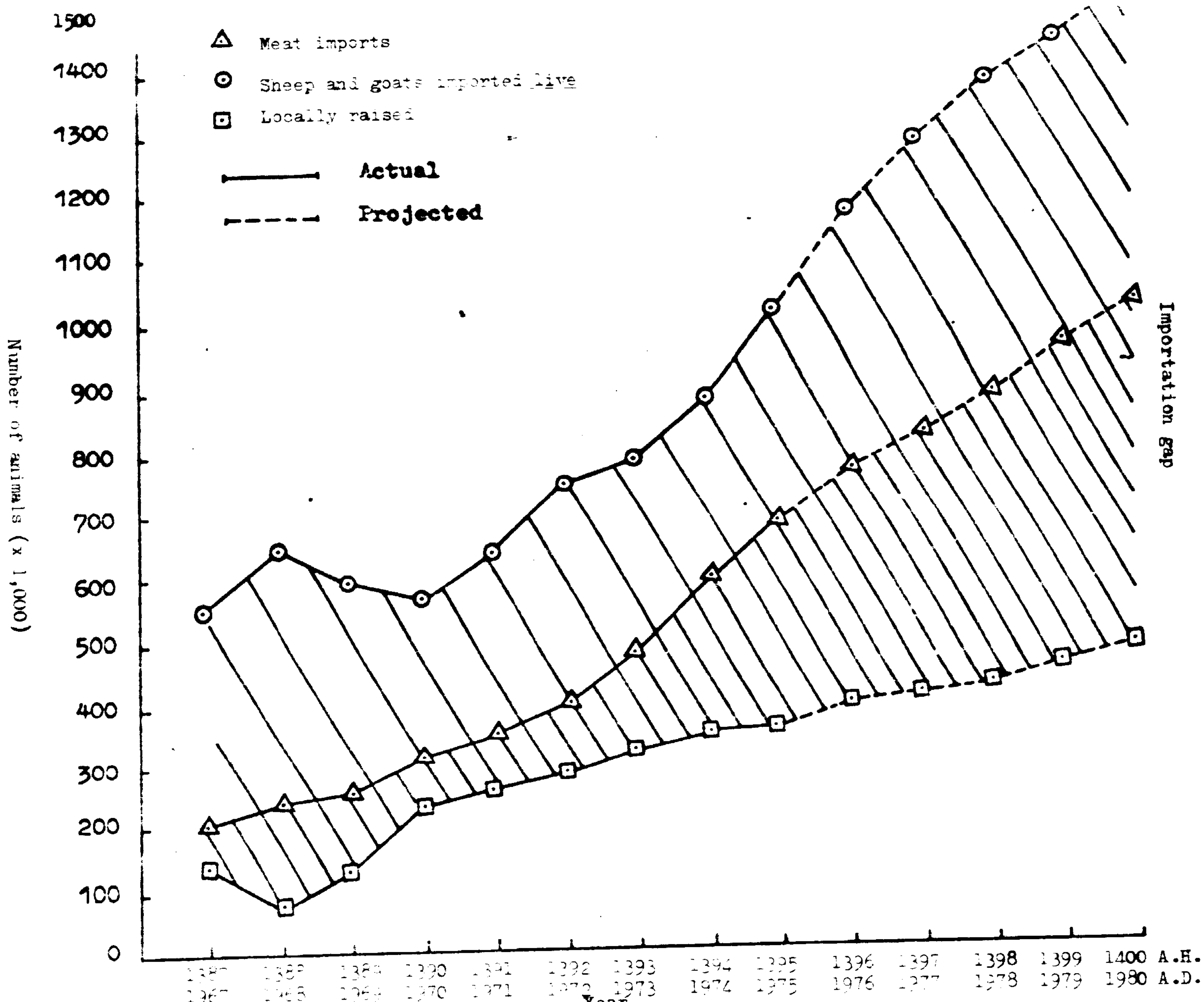

Figure III. Current and future demand for lamb and goat meat

= 525,000 metric tons. With a recommended SCP content of 5%, the total amount of SCP consumed by this sheep and goat population would be 525,000 x 0.05 = 26,250 metric tons.

Demand for broiler chickens

The accelerating rate of consumption of broiler chickens in Saudi Arabia is reflected in figure IV. By the year 1400 A.H. (1980), 90,000,000 broiler chickens will be needed, with a local production capacity of only 17,000,000. There are projects to produce broiler chickens locally in larger numbers, such as the project at Harad, with a projected production capacity of 50,000,000 chickens. In any case, feed for a total of 90,000,000 chickens will be required by Saudi Arabia in 1400 A.H. (1980) if the total demand for broilers is to be met by local production. The total amount of feed needed for this number of broilers is 180,000 tons. The recommended level of SCP contained in this feed is 15% (based on the expert's own experiments). Thus, the total amount of SCP required is 180,000 x 0.15 = 27,000 tons.

Demand for eggs

The projected number of eggs that will be needed in 1400 A.H. (1980) is 700,000,000 (see figure V). With an average production per hen of 225 eggs annually, the number of layers needed in 1400 A.H. (1980) will be 700,000,000/225 = 3,100,000. This number of laying hens would consume 127,400 tons of chicken feed during the year. With a recommended SCP inclusion level of 15%, the total amount of SCP required for the 700,000,000 laying hens would be 127,400 x 0.15 = 19,110 tons SCP.

On the basis of the above projections, the total amount of SCP required for consumption in Saudi Arabia in 1400 A.H. (1980) will be 142,695 tons (see table 8).

Table 8. Total projected demand for SCP in Saudi Arabia in 1400 A.H. (1980)

Animals	SCP required (in metric tons)
Pre-ruminant calves	6,175
Veal calves	3,680
Beef cattle	50,400
Dairy cattle	10,080
Sheep and goats	26,250
Broiler chickens	27,000
Layers	19,110
Total	142,695

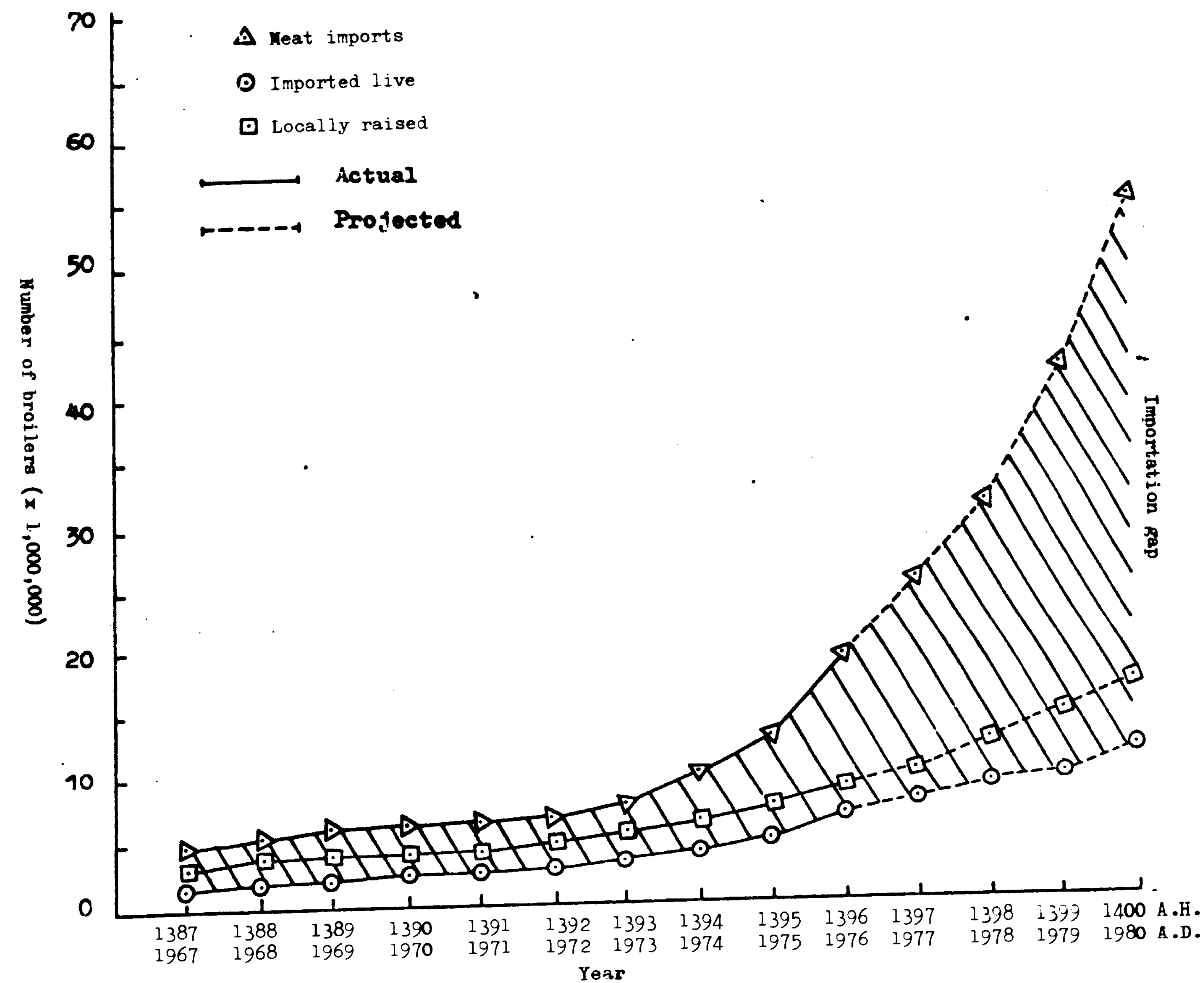

Figure IV. Current and projected demand for broilers in Saudi Arabia

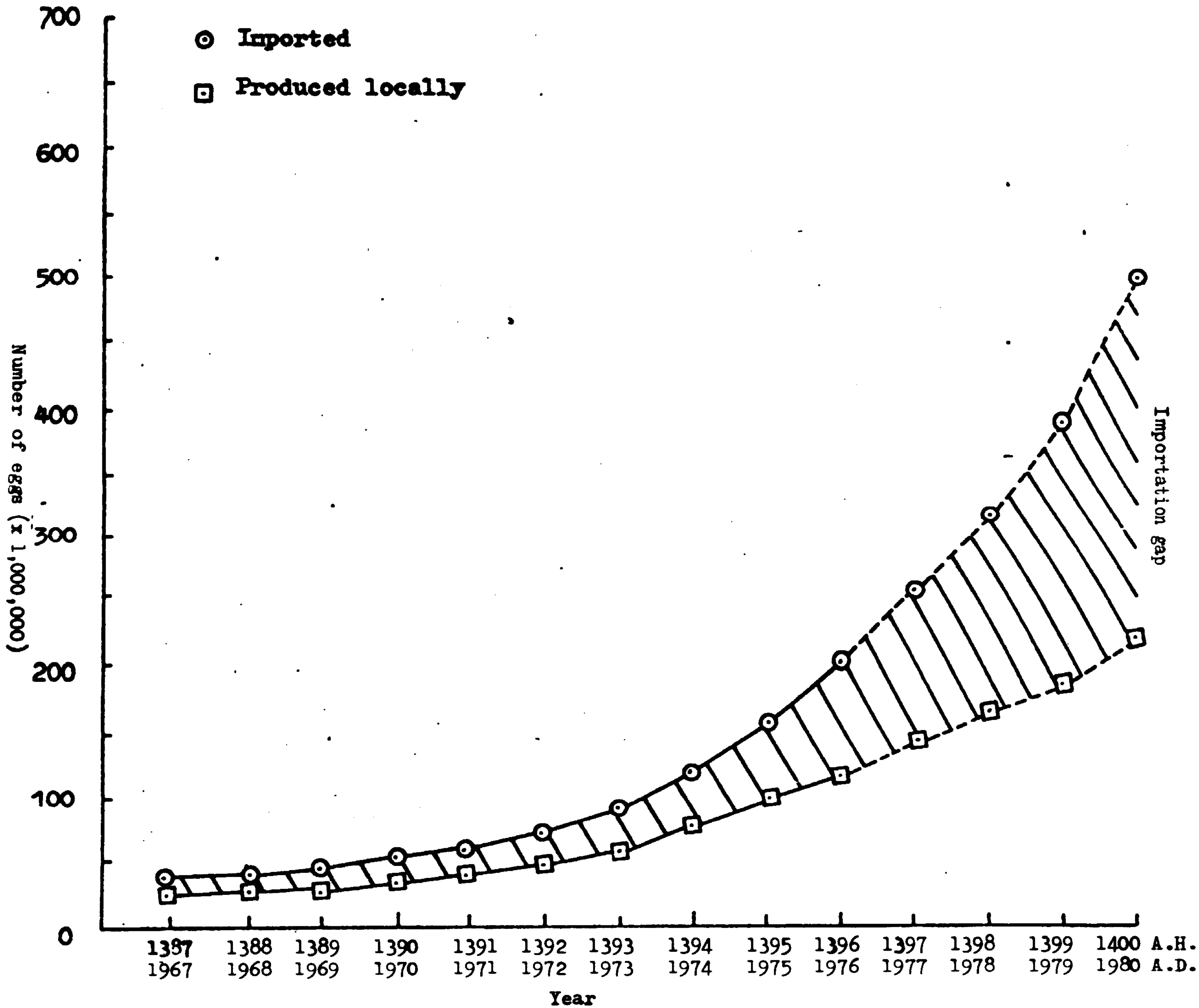

Figure V. Current and projected demand for eggs in Saudi Arabia

Recommended petroprotein production level

In view of the fact that SCP is a new feed ingredient, that the technology of SCP manufacture is quite recent, and that the demand for meats, dairy products and eggs will increase in the years after 1400 A.H. (1980), the recommended level of SCP production is 100,000 tons per year (t/year), to be doubled in five to ten years to 200,000 t/year. The SCP plant will therefore be designed for an initial capacity of 100,000 t/year, with a built-in potential for expansion on the same site to a final capacity of 200,000 t/year.

B. Saudi Arabia's petroprotein manufacturing potential

The assessment of Saudi Arabia's petroprotein manufacturing potential depends on the raw materials, technology, financing and manpower requirements of petroprotein production.

Raw materials

(a) Normal paraffins

It appears from the data collected during this study that no paraffin production is currently under way in Saudi Arabia. Nor do plans for future production of n-paraffin appear imminent, despite the fact that Saudi Arabian crude oils are rich in paraffins, as shown in table 9. Data published in The Oil and Gas Journal, 29 March 1976, also show that there should be no problem manufacturing 200,000 tons or more of normal paraffins each year from Saudi Arabia's crudes. The volume percentages of paraffins in various fractions of Saudi Arabian crude oils and, for purposes of comparison, in other world crude oils are shown in table 9 below.

Saudi Arabia clearly has an abundance of n-paraffin for use in SCP manufacture.

(b) N-paraffin specifications and processes

International specifications have not yet been established for the n-paraffin used in fermentation. However, from data provided by licensors, the following specifications seem to be generally applied:

n-paraffin content: more than 97.5%
Isoparaffins: less than 2.5%
Bensopyrene: less than 1 ppb
Carbon range: C_{10}-C_{23}

Table 9. Paraffin content of various world crude oils

Crude oil	Fraction	Paraffin content (volume %)
Arabian heavy	Light naphtha	89.6
	Heavy naphtha	70.3
	Kerosine	58.0
Arabian light (Berri)	Light naphtha	87.4
	Heavy naphtha	66.3
	Kerosine	58.9
Arabian light	Light naphtha	85.0
	Heavy naphtha	69.5
Arabian medium	Light naphtha	85.3
	Heavy naphtha	68.5
Arabian medium (Sulfur)	Light naphtha	89.7
	Heavy naphtha	67.8
	Kerosine	59.9
Iranian heavy	Light naphtha	53.0
Brass River (Nigeria)	Gasoline	42.4
Brega (Libya)	Light naphtha	72.5
	Heavy naphtha	53.0
	Kerosine	51.2
Burgan (Wafrah), Neutral zone	Light Naphtha	74.0
	Heavy naphtha	44.0
Cabinda (Angola)	Light naphtha	78.2
	Heavy naphtha	51.1
Duri (Indonesia)	Light naphtha	52.5
	Heavy naphtha	18.0

The molecular sieves processes of Union Carbide and Universal Oil Products are the most appropriate for achieving a low isoparaffin content. The Union Carbide process is a vapour phase process, while that of Universal Oil Products is a liquid phase process. Owing to the lack of data from these two licensors, no details about their processes can be given here. One of the SCP consulting firms may be able to help in this respect.

The required capacity for n-paraffin production in Saudi Arabia should match the SCP production, since one ton of n-paraffin is needed to manufacture one ton of SCP. Therefore, the recommended size of an n-paraffin plant to serve the SCP complex is 100,000 t/year, to be expanded later to 200,000 t/year. This is an economical size.

(c) Mineral requirements

Relatively small amounts of minerals and ammonia are required. The requirements for the production of one ton of SCP are as follows (kg):

$(NHO)_2HPO_4$	126
$MgSO_4 \cdot 7H_2O$	35
Liquid ammonia	129
Other salt	11

These should not present any problems, so far as Saudi Arabia's production of SCP is concerned.

Technology

(a) Cooling requirements

On the basis of the available data, the heat flux is derived from the yeild by the following equation:

$$q = (11,300/p) - 3,600$$

where q = kcal produced/kg biomass

p = yield = kg biomass/kg paraffin

The heat of combustion of n-paraffin is 11,300 kcal/kg, and that of yeast (SCP) is 3,600 kcal/kg. The amount of heat generated in various SCP production processes is given in table 10.

Table 10. **Heat generated in various SCP production processes**

Process	Fermentation temperature (in °C)	Heat generated (kcal/ton of biomass)
British Petroleum	30	7.7×10^6
Kanegafuchi	35	6.2×10^6
Dainippon	37	7.2×10^6
French Group	39	7.2×10^6

Three cooling systems can be employed.

1. Indirect cooling with sea water. This is the system applied at the Liquichimica SCP plant at Calabria, Italy (Kanegafuchi process). The fermentors are cooled with fresh water, then the hot fresh water is moved to heat exchangers away from the fermentors, where the fresh water is cooled with sea water. The cooled fresh water goes back to the fermenters to repeat the cooling process. The obvious advantage of this system is that any leakage from the cooling system will introduce harmless fresh water into the fermentors, and not yeast-killing sea water.

2. Direct cooling with sea water. In this simple exchanging system, sea water is used to cool the fermentation broth through external exchangers.

In either cooling system, the sea water temperature should be tested at various levels (depths), and the most suitable depth determined accordingly. The deeper the source of sea water, the cooler it is, but there is a technical limit as to how deep it is possible to go for this purpose. The disadvantages of the direct sea-water cooling system include the inherent danger of leaking sea water into the fermentation medium,and the corrosion that is caused by sea water.

3. Refrigeration system. Despite the relatively high investment and energy expense, a refrigeration system may be worthwhile, and may even prove less expensive when the operating cost and sea-water corrosion effects are taken into account.

(b) Process water and energy requirements

The data about underground water, rain etc., indicate that the possible project sites have no dependable sources of good-quality process water. The amount of process water required will be 20 t/t of SCP. A large quantity of this water will be recycled. For a plant with an output of 100,000 t/year, 15,000 m^3/day of fresh water will be required. For the maximum, eventual, capacity recommended here (200,000 t/year of SCP after 10 years), twice as much water will be needed. If the plant belongs to an agro-industrial complex where the consuming animals are reared, the provision of drinking water for the animals should also be considered. Thus, the maximum amount of water needed would be 50,000 m^3/day. This amount cannot be secured in any of the possible sites for the SCP plant. Therefore, it is recommended that a desalination plant be established alongside the SCP plant, with a capacity of 50,000 m^3/day.

Electric power must also be ensured for the SCP plant and the associated agro-industrial complex. It is therefore recommended that a double-purpose plant, ensuring both water desalination and power generation, should be established, with the capacity to produce 50,000 m^3/day of fresh water, and 1.5 to 2.5 million kilowatts. In the case of combined gas turbine desalination and power plants, there is a close relationship between energy and fresh water production, varying between 30 and 50 kWh/m^3.

SCP cost analysis

Table 11 below shows estimated battery limit investment costs at current European prices for the establishment of SCP plants at various capacity levels. The data are then adjusted to reflect conditions in Saudi Arabia, taking the following points into account: extra cooling requirements in Saudi Arabia, inflation, the load factor, and the European to Saudi Arabian cost ratio.

(a) Battery limit investment

European prices for a 100,000 t/year SCP plant are shown in table 11 below.

Table 11. SCP plant investment costs

Data from licensors	Capacity (in t/year)	Battery limit investment (million $US)
British Petroleum (1974)	100,000	25.0
Kanegafuchi (1974)	100,000	28.5
Dainippon (1973)	60,000	28.0
French Group (1974)	40,000	11.5

(b) Extra cooling costs and inflation

When extra cooling costs and inflation are taken into account, the adjusted battery limit investment costs are as shown in table 12 below.

Table 12. Adjusted battery limit investment costs

Licensor	Battery limit investment (million $US)
British Petroleum	32
Kanegafuchi	36
Dainippon	34
French Group	30

(c) Load factor under Saudi Arabian conditions

A maximum flow rate of 1,150 m^3/h for cooling is assumed. For a 30°C culture (British Petroleum process), the output has to be reduced by the following factors:

June	-0.55
July	-0.80
August	-1.00
September	-1.00
October	-0.75

The total reduction capacity is 2% per year for a culture with a temperature of 30°C. For higher culture temperatures, there is no need for reduction. The following final load factors are therefore obtained:

British Petroleum	0.74
Kanegafuchi	0.86
Dainippon	0.88
French Group	0.90

(d) Battery limit investment in Saudi Arabia

The preceding data on battery limits have been based on European prices and contruction conditions. In table 13 below a factor is used which takes into account both the price differences between the European and Saudi Arabian bases, and the scaling-up factor.

Taking into account the load factor, plus extra cost for building conditions in Saudi Arabia, the figures contained in table 14 are obtained.

Table 13. Comparative investment ratios

Capacity (in t/year)	European basis		Scaling-up ratio	Saudi Arabian basis	
	Scaling-up factor	Value		Absolute	Relative
100,000	0.8	1.0	1.85	1.85	1.0
60,000	0.8	0.665	2.00	1.33	0.7
40,000	0.8	0.480	2.15	1.03	0.56

Table 14. Battery limit investment

Process	Investment costs for a theoretical capacity of 100,000 t/year (in million $US)	Actual production
British Petroleum	59.2	65
Kanegafuchi	66.6	69
Dainippon	62.9	67
French Group	55.5	62

(e) Total investment for the SCP plant alone

Total investment for the SCP plant alone may be derived from the battery limit investment (B1) figures given in table 14 above.

Offsites (B2) = 0.35 B1

Engineering fees (B3) = 0.15 (B1 + B2) = 0.2025 B1

Spare parts (B4) = 0.03 B1

Royalties (B5) = 0.03 B1

Process data book (B6) = 0.08 million $US

Fixed capital = B1 + B2 + B3 + B4 + B5 + B6
= 1.622 B1 + 0.08 million $US

Start-up expenses (B7) without n-paraffins = 3 months of operating costs

Depreciable capital = Fixed capital + B1

Working capital = 6 months of operating cost without n-paraffins

It should be noted that these are only preliminary estimates. A complete investment study requires more elaborate data from licensors, taking into account Saudi Arabia's specific conditions. The services of a professional consulting group is needed to finalize these figures. A number of consulting firms specializing in petroprotein agro-industrial complexes are available for this purpose. It seems clear, however, that n-paraffin process cost differences are due mainly to special mixing, sterilization, and load factor requirements.

(f) Operating cost components

The operating costs of raw materials and utilities are given in tables 15 through 19.

Table 15. N-paraffin operating costs

Process (98% n-paraffins)	Consumption (t/t)
British Petroleum	1.0
Kanegafuchi	0.87
Dainippon	0.95
French Group	0.95

Table 16. Nutrient salts cost breakdown

Nutrient	Consumption[a] (t/ton of SCP)	Cost of salt	
		$/ton	$/ton of SCP
Phosphoric acid	0.062	570	35.4
Sulphuric acid	0.015	32	0.48
Ammonia	0.126	70	8.82
Potash	0.033	425	14.0
Mg chloride	0.043	105	4.5
Miscellaneous			0.9
Total			64.0

a/ The same consumption is assumed for all four processes.

Table 17. Electricity costs

Process	Consumption (MWh/ton of SCP)	Cost[a] ($/ton of SCP)
British Petroleum	3.0	64
Kanegafuchi	2.5	60
Dainippon	2.9	62
French Group	2.1	51

a/ Calculated at $24/MWh.

Table 18. Steam and fuel costs[a]

Process	Steam		LPG	
	Consumption (t/ton of SCP)	Cost ($/ton of SCP)	Consumption (t/ton of SCP)	Cost ($/ton of SCP)
British Petroleum	3.2	9.6	0.25	7.5
Kanegafuchi	0.6	1.8	0.50	15.0
Dainippon			0.57	17.0
French Group	0.8	2.4	0.28	8.4

a/ Steam costs are calculated at $3/ton of SCP and fuel costs (LPG) at $30/ton of SCP (1 ton = 11,000 kcal).

Table 19. Process and cooling water costs[a]

Process	Cooling water		Process water	
	Consumption (t/ton of SCP)	Cost ($/ton of SCP)	Consumption (t/t)	Cost ($/t)
British Petroleum	1,150	17	20	10
Kanegafuchi	660	10	55	28
Dainippon	650	10	20	10
French Group	580	8.7	22	11

a/ Process and cooling water costs are calculated at $0.5/ton and $0.015/ton respectively.

Manpower

Although processes involving sterilisation require more manpower, for purposes of calculation it is assumed that all four processes use the same amount of manpower. The labour requirements are given in table 20 for plants with SCP capacities of 100,000 t/year and 200,000 t/year.

Table 20. Labour costs

Manpower	Plant with a capacity of 100,000 t/year		Plant with a capacity of 200,000 t/year	
	No. of staff	Cost of staff ($)	No. of staff	Cost of staff ($)
Management				
Engineer (foreign)	1	36,000	1	36,000
Director(s) (local)	1	14,000	2	28,000
Drawing master(s)	6	60,000	10	100,000
Process operators				
Skilled workers	100	500,000	150	750,000
Handling operators				
Unskilled workers	10	30,000	20	60,000
Skilled workers	10	50,000	20	100,000
Maintenance				
Highly skilled workers	15	90,000	30	180,000
Control laboratory				
Biochemists	15	90,000	30	180,000
Administration	3	18,000	5	30,000
Total	161	888,000	268	1,464,000

Total costs

Depreciation: straight-line method over 10 years.

Capital cost: 7% per year on depreciable capital; 9% per year on working capital.

Other fixed charges:

Maintenance = 0.02 (B1 + B2) per year.
Taxes and insurance = 0.01 (B1 + B2) per year.

The above results may be used to calculate production costs as follows:

Production cost = Operating cost + utilities + labour costs + fixed charges + capital cost.

The fixed cost is about 40% of the production cost for a plant with a capacity of 100,000 t/year and 30% for a plant with a capacity of 200,000 t/year.

In general, processes which do not require sterilization measures, and which have low energy requirements and high fermentation temperatures, may result in significant cost reductions. This makes the Japanese processes of Kanegafuchi and Dainippon particularly advantageous for Saudi Arabia.

C. Petroprotein production as part of an integrated agro-industry

Among the possible markets in neighbouring countries for SCP produced in Saudi Arabia, the largest seems to be in Egypt, or perhaps the Sudan. Both these countries have very limited purchasing power, and they would be consumers for Saudi Arabia's SCP only if they received it in the form of aid. The other possible markets are North Africa and the Gulf area. Both these areas are potential producers of SCP themselves, and they may decide at any time to build their own SCP manufacturing plants. This rules them out as possible markets for Saudi Arabian SCP. This report is therefore concerned primarily with SCP consumption within Saudi Arabia. The country may, however, decide to expand the SCP industry in the future in order to become an exporter of meats, in which case the Saudi Arabian SCP would still be consumed locally. Expansion can be achieved by introducing one of the agro-industrial systems described below.

Single agro-industrial complex

Under the system of a single agro-industrial complex, the SCP plant would be established on the same site as the consuming animals (cattle, sheep, goats, and chickens). Figure VI shows an outline of this system. The complex in this case would consist of the following components:

- SCP plant (including the n-paraffins plant and the water desalination/power plant)
- Grain and hay farms (25,000-35,000 hectares)
- Animal feed plant (units for the manufacture of cattle, sheep, goat and chicken feeds)
- Breeding stations (artificial insemination for mass reproduction of cattle, sheep and goats)
- Cattle feed lots (to raise 500,000 head/year)
- Sheep feed lots (to raise 1,000,000 head/year)

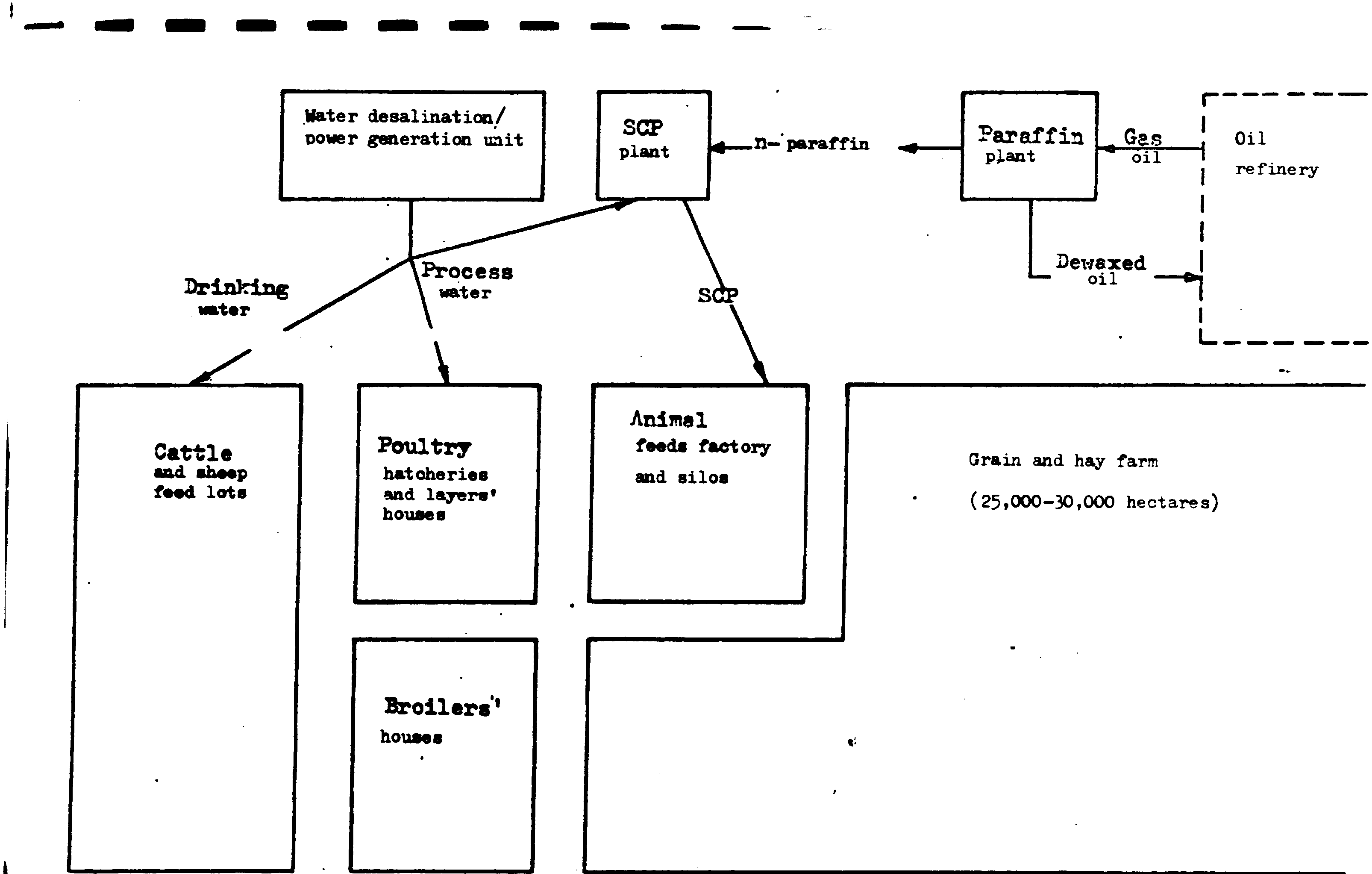

Figure VI. Single SCP agro-industrial complex

Goat feed lots (to raise 1,000,000 head/year)
Chicken hatcheries (to house broilers and layers)
Broiler houses (to raise 20,000,000 chickens/year)
Layer houses (to produce 300,000,000 eggs/year)

Multiple agro-industrial complexes

Under the system of a multiple agro-industrial complex, the SCP production facility would distribute its SCP to feed plants around the country, and the animal feeds would in turn be distributed to the various agro-industrial complexes to be established around the country. The SCP industry would make possible the establishment of several agro-industrial complexes near the country's consumer centres. The major obstacle to the expansion of animal production in Saudi Arabia is the protein shortage. Developing SCP manufacture in the country would therefore help to overcome this obstacle. Figure VII shows an outline of the multiple agro-industrial complex.

D. Possible production sites

In the case of the single-complex system, the best location appears to be the Jaizan area, in the south-western corner of the country. The reasons for recommending this particular location is that 500,000 hectares of arable land are available for growing the grain and hay that would be required for the complex. Moreover, if for any reason the area failed to produce the needed amounts of grain and hay, a good source of these materials exists just across the Red Sea from Jaizan, namely, in the Sudan. Another reason for recommending this area is that Jaizan is a port which can be used to export the products of the SCP complex. The Jaizan area has excellent roads which connect it with the rest of the country (a new superhighway has just been opened between Jaizan and Jiddah). The n-paraffin for the Jaizan SCP plant can be manufactured at the Jiddah refinery, which would benefit significantly by the possibility of dewaxing its naphtha and gas oil products as part of the n-paraffin manufacturing process.

In the case of the multiple agro-industrial complex, the best location for the SCP plant would be Jiddah. The SCP plant would then be attached to the Jiddah refinery, in view of the refinery's role as manufacturer and supplier of n-paraffin. The SCP produced would then be distributed to the agro-industrial complexes and to the private animal and chicken growers around the country.

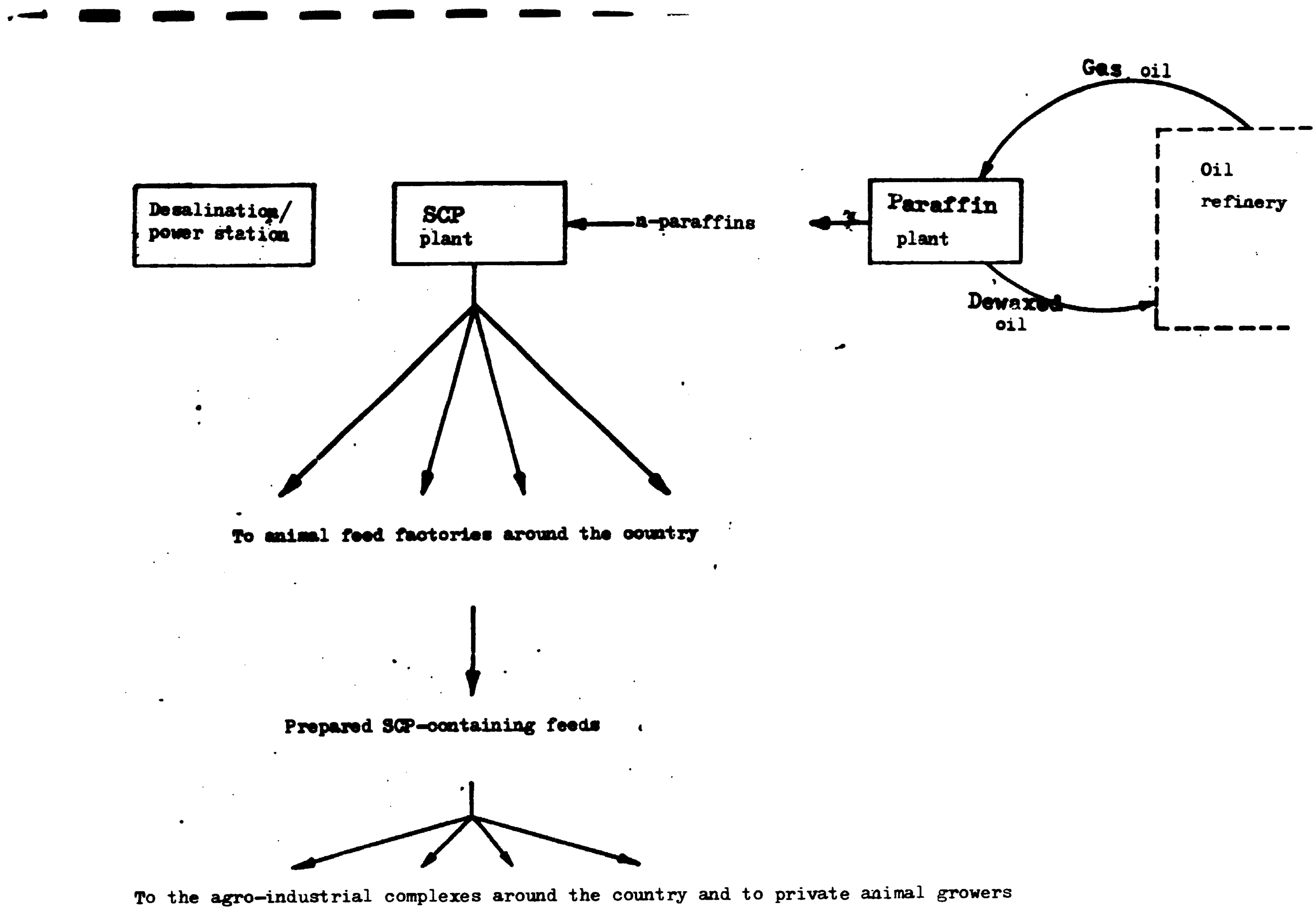

Figure VII. The multiple agro-industrial complex

It should be noted that despite all the above-mentioned factors, there may be others, unknown to the expert, which make it appear to the authorities just as advantageous to link the paraffin/SCP complex to the Riyadh refinery, or to any of the refineries in the eastern part of the country. Moreover, detailed information concerning the exact number of on-site animals, rations, grain and hay requirements, animal breeds, methods of reproduction and rearing, feeding systems etc., can only be determined by specialized firms. Comprehensive pre-project studies by such firms can provide full details on all aspects of a project from the design stage to the initiation of plant operations.

CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

1. The importance of SCP is that it makes possible the establishment of a single agro-industrial complex, or a multiple agro-industrial system, by overcoming the protein shortage which, since protein is the main ingredient in feed concentrates, prevents the expansion of animal production. Other problems such as the provision of grain and hay can be solved through the vast potential of the Abha/Jaizan area for producing fodders and hay, or by importing grains and hay from the Sudan.

2. The data contained in figures 1 through 5 of this report show that if the need for SCP in Saudi Arabia is based only on the locally raised animal population, it would amount to only about 20% of the total estimates calculated in the report. This amount would not justify the establishment of an SCP industry in Saudi Arabia. Such an industry would only be justified if all the required meats, dairy products, and eggs are produced in the necessary amounts within Saudi Arabia, thus eliminating all imports of meat or live animals, and if the entire SCP output could be consumed locally, since Saudi Arabian SCP export possibilities are virtually non-existent.

3. According to Ministry of Agriculture data, the Saudi Arabian private feed industry will produce less than 150,000 tons of animal feeds by 1400 A.H. (1980). A 10% inclusion of SCP in this projected total amounts to 15,000 tons of SCP per year. Due to the lack of expansion possibilities and private feed producers' apprehensions about future demand, the establishment of an SCP industry in Saudi Arabia cannot therefore be based on the current and projected output of private feed factories.

4. The most suitable process for manufacturing SCP under Saudi Arabian conditions is the n-paraffin-based process, as developed commercially by Kanegafuchi or Dainippon Ink and Chemicals, both Japanese companies.

5. A decision cannot be taken on the feasibility of establishing a large agro-industrial complex producing all of Saudi Arabia's meat, dairy, and egg requirements until a professional group, or a consortium of specialized companies, carries out a detailed study of the proposed complex and determines the amounts

of grain, hay and fresh water needed, the suitability of novel methods of turning corn stalks and agricultural crop wastes into feed etc. Some significant patents relating to these subjects have appeared in recent years.

B. Recommendations

1. Saudi Arabia should plan to develop an SCP manufacturing capacity of 100,000 t/year by 1400 A.H. (1980), to be expanded to 200,000 t/year during the following decade. Its n-paraffin production should expand at the same rate and to the same levels as the SCP output.

2. SCP should be manufactured and marketed in Saudi Arabia through either a single Government-sponsored agro-industrial complex or a system of multiple agro-industrial complexes. For a single complex, the best construction site seems to be the Jaizan area, where more than 500,000 hectares of arable land is available, and the products can be exported through the Jaizan port. In the case of a multiple system, the SCP plant could form part of the Jiddah or Riyadh refineries, or of one of the eastern refineries.

3. To ensure the provision of the necessary water and electric power supplies, a double-purpose plant ensuring both water desalination and power generation should be established alongside the proposed SCP plant, with the capacity to produce 50,000 m^3/day of fresh water and 1.5 to 2.5 million kilowatts.

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