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The Soviet Hydrocarbon-Based Single Cell Protein Program

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The Soviet Hydrocarbon-Based Single Cell Protein Program

PRÉCIS

One of the major obstacles to expansion of the Soviet livestock industry is a shortage of high protein feed supplements. In an attempt to correct this deficiency, the USSR has made a commitment to the development and production of synthetic protein supplements, especially yeast single cell protein (SCP). Soviet animal feeding trials indicate that yeast single cell protein can replace other high protein feedstuffs, including soybean meal and fish meal in livestock rations, particularly those for swine and poultry. The Soviet effort probably will have a significant impact by 1980.

While the Soviets have grown yeast SCP on many different substrates, readily available Soviet petroleum resources offer the best substrate for rapid expansion of this protein technology. The Soviets have six high capacity petroleum-based SCP production plants in various stages of construction and operation, and two additional plants reportedly are being built. They appear to be having technical difficulties with the production process, especially in continuous flow fermentation technology, but all of the facilities under construction are expected to be completed and operating by 1980. The estimated capacity of the completed plants is in excess of 860,000 metric tons, possibly one million metric tons annually. As a livestock feedstuff, one million tons of single cell protein, on a protein equivalent basis, is equal to about 30% of the oil seed meal that could be derived from Soviet harvests of sunflower seed and cottonseed, the major oil seed meal crops grown in the USSR.

The Soviets have large reserves of high n-paraffin petroleum, and they probably could double single cell protein production from this source over the next 10 years. Future expansion would depend on how successful they are in producing high protein feedstuffs from other sources and on the demand for n-paraffins for other purposes.

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THE SOVIET HYDROCARBON-BASED SINGLE CELL PROTEIN PROGRAM

Project Officer

Contributor

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CENTRAL INTELLIGENCE AGENCY
DIRECTORATE OF INTELLIGENCE
OFFICE OF SCIENTIFIC INTELLIGENCE

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PREFACE

Single cell protein (SCP) is a term used to identify feed and food protein concentrates derived from microorganisms grown on various organic substances, including n-paraffins from petroleum, waste materials (primarily cellulose), and ethanol. Some types of SCP, such as yeasts grown on cellulose hydrolysates and byproducts of alcohol fermentations, have been used for many years, primarily as a vitamin supplement in human and livestock diets. More recently, SCP has gained worldwide attention as a possible major source of protein from nonagriculture resources. The protein content varies with organism and substrate. Yeast SCP, the most likely kind to gain wide prominence as a livestock feed, contains 50% to 65% crude protein.

A major deficiency in Soviet efforts to upgrade their livestock industry is an inadequate supply of high protein supplements for inclusion in mixed feeds. The currently planned expansion in conventional agricultural practices is unlikely to correct this deficiency. In lieu of increasing dependence on imported high protein feedstuffs, the Soviets are developing and building facilities for synthetic production of protein supplements. The Soviets emphasize the use of SCP primarily as a high protein livestock feedstuff within the USSR, but they also are considering it as a possible human food supplement for protein-deficient underdeveloped countries.

This report evaluates Soviet progress in the exploitation of SCP from petroleum hydrocarbons and the potential role of SCP in Soviet livestock production. This report was prepared by the Office of Scientific Intelligence and coordinated within the CIA. The cutoff for information is January 1977.

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THE SOVIET HYDROCARBON-BASED SINGLE CELL PROTEIN PROGRAM

PROBLEM

To evaluate the Soviet hydrocarbon-based single cell protein program and its impact on Soviet livestock production.

SUMMARY AND CONCLUSIONS

The Soviets suffer chronic shortages in high protein feed supplements for their livestock. Increased production of SCP derived from petroleum hydrocarbons, to which a large resource commitment has been made, is important to their plans to eliminate these deficiencies and to increase livestock production. They have established research and development facilities dedicated to the growing of yeasts on hydrocarbons and have built or have plans to build two pilot plants and eight large-scale production plants for cultivating yeast SCP on petroleum hydrocarbon.

Increased quantities of SCP are important to the Soviet plan to increase their supply of meat and to the conservation of their grain supply through increased feed conversion efficiencies of their livestock rations. While SCP will permit the Soviets to be more self-reliant in protein feedstuffs, it will not completely eliminate the need to import soybeans during poor harvest years of cottonseed and sunflower seed, as occurred in 1972 and 1975, because of the feed demands for increased livestock production.

To develop and produce petroleum hydrocarbon SCP that meets prescribed quality standards, either a highly purified n-paraffin (99% pure) must be used as the growth substrate or, if a gas oil substrate is used, a biomass purification step must be included in the final stages of processing. The Soviets are having difficulties in both areas—in producing 99% pure n-paraffin and in purifying the SCP product—as evidenced by their acknowledged need for Western process technology and initiation of negotiations for this technology.

The Soviet SCP plants are designed to produce yeast on an n-paraffin substrate in a multistage, continuous fermentation process. The major processing steps are fermentation, separation of yeast from substrate, and drying. Technical difficulties in the fermentation process and problems in separation and purification technology make it unlikely that their present process is operating at anticipated efficiencies. Many of these difficulties are expected to be resolved through purchase and exploitation of Western technology.

Six Soviet SCP production plants are in various stages of construction and operation. [redacted] It is estimated that the facilities now under construction at these plants will be completed and in production by 1980 with a combined annual capacity in excess of 860,000 metric tons and a possible capacity of 1 million metric tons annually. There may be further increases in capacity after 1980. Some Soviets claim to have a current annual production capability of 300,000 metric tons of SCP from petroleum hydrocarbons in four partially operational plants. A number of fermenters have been [redacted] in operation [redacted], although [redacted] the fermenters are operating at well below rated capacity.

Approximately 1 million metric tons of n-paraffin substrate will be consumed in the production of 1 million metric tons of SCP. This amount of paraffin represents a small fraction (estimated 1 to 2%) of the total paraffins available to the Soviets from their petroleum production. In 1975, the USSR produced about 500 million metric tons of petroleum, much of which had a high concentration, up to 20%, of n-paraffin. The n-paraffin must be removed to improve the physical properties of petroleum for other uses.

Yeast SCP is expected to be of significant benefit to the Soviet livestock industry, particularly swine and poultry. The production of SCP will provide the Soviets with a reliable supply of high quality protein without taxing agricultural resources, such as land, fertilizer and equipment. One million metric tons of SCP represents on a protein equivalent basis about 30% of the Soviet production (5-year average 1970-74) of oil seed meals, 95% of which are sunflower seed and cottonseed meal. In terms of land-use savings, this quantity of SCP would be comparable to the amount of sunflower meal and cottonseed meal that could be obtained from approximately 2 million hectares of sunflowers or 1.26 million hectares of cotton (average yields 1970-74).

An estimated 3 million metric tons per year of SCP could meet the demands of the Soviet livestock industry. SCP from petroleum hydrocarbons, along with expanded production of cellulose hydrolysate SCP, probably will permit them to achieve a total SCP capacity of about 2 million tons per year by 1980, or about two-thirds of their requirement. The Soviets have large reserves of high n-paraffin petroleum and, if current ventures are successful, they could probably double the amount of SCP grown on this petroleum substrate over the next 10 years. Future expansion probably will be dependent upon the demand for n-paraffins for other purposes, on improvements in technology for producing yeast on cellulose hydrolysates, on Soviet success in developing technology for efficiently producing other types of SCP (e.g., bacteria on natural gas or yeast on methanol), and on the cost effectiveness of producing SCP versus other sources of protein feedstuffs.

DISCUSSION

INTRODUCTION

One of the prime obstacles confronting Soviet livestock production plans has been a general shortage of all types of feed. The most acute shortages are concentrated feeds—both high energy and high protein.[1 2 4 5 7 12] Soviet feed rations contain a large proportion of poor quality roughages with relatively low protein and energy content. The addition of more high protein feeds would increase the efficiency of both roughages and feed concentrates.[13 16] Therefore, intensification of the Soviet livestock industry depends upon availability of high protein feed.

Soviet investigators have attempted four general approaches to nonagricultural high protein feed production—aquaculture (water plants), pisciculture (marine and freshwater fish culture), microbiological synthesis (single cell protein), and direct chemical synthesis. Of these various alternatives, the Soviets felt that the most viable for them was the growth of protein rich microorganisms, mainly yeasts, on substrates such as wood wastes and petroleum fractions.[3] Since the late 1960s, the Soviets have been emphasizing SCP derived from the n-paraffin hydrocarbons in petroleum.[4] Their reasoning is based on the large reserves of high n-paraffin petroleum in the USSR; petroleum refineries which provide a reliable, concentrated source of substrate; and the smaller capital investment per unit of production for n-paraffin SCP plants than for wood hydrolysate plants. Using a hydrocarbon substrate, the Soviets believe they can produce enough yeast SCP to help overcome their shortages of high protein feed. They now claim to be the first country to organize large-scale production of yeast SCP from petroleum derivatives and currently are building large plants for production.[14 15 18]

SCP FOOD VALUE

Livestock Feedstuff

The most important indices of the biological value of a high protein feedstuff are its amino acid composition and digestibility. On this basis, Soviet and Western data on the nutritional value of petroleum grown SCP generally agree that it is a high quality protein supplement for livestock, principally swine, poultry and preruminant cattle.

The essential amino acid distribution in yeast SCP is compared with soybean meal and fish meal, which represent the best of the plant- and animal-derived high protein feed supplements, and with sunflower meal and cottonseed meal, the most abundant high protein plant feedstuffs produced in the USSR (table 1).[14, 18, 22, 23] These data indicate that the essential amino acid composition of Soviet and Western hydrocarbon grown yeast SCP products is equivalent or superior to the oil seed meals as a protein supplement. SCP is superior to the oil seed meals in total protein content and lysine, a nutritionally limiting essential amino acid in most grains. Like most oil seed meals, SCP is deficient in methionine. SCP would be a valuable complement in rations using large quantities of sunflower seed meal protein, with its relatively high methionine and low lysine content. With the addition of methionine, which is economically produced in the USSR by chemical synthesis, SCP has an amino acid distribution comparable to fish meal.[9, 18] The latter contains a highly favorable amino acid balance and is prized as a protein supplement for swine and poultry.

In addition to a highly favorable amino acid balance, yeast SCP is richer in the B-vitamins than either oil seed meals or fish meal (table 2). Fodder yeast, a torula yeast produced on carbohydrate hydrolysates, has been used in the USSR and elsewhere for many years as a vitamin supplement in livestock feeds.[18, 22] Hydrocarbon-grown yeast is comparable to hydrolysate yeast in vitamin composition.

The Soviets have conducted extensive animal feeding tests with their petroleum-based SCP product. They claim to have achieved an increase of 10 to 30% in productivity and 10 to 20% in feed conversion efficiency with the addition of 5% SCP to basic rations for swine, poultry, and preruminant cattle (table 3).[18] These and other data clearly demonstrate the value of SCP as a high protein feed for the above types of livestock.[14, 26] The large increases realized in production and feed conversion efficiencies with the addition of 5% SCP indicate that the basic control rations were severely inadequate in protein and corroborate claims that high protein livestock feedstuffs are a major need in the USSR.

Animal feeding experiments conducted by British Petroleum Company (BPC) with their SCP product confirm the fact that hydrocarbon grown yeast SCP

Table 1

Amino Acid Composition of Total Proteins of Hydrocarbon Yeast SCP and Some Conventional High Protein Feedstuffs

(In percent)

Essential amino acid	SCP[1] (USSR)	SCP[2] (BPC)	SCP[3] (Japan)	Fodder yeast[4] SCP	Fish[5] meal	Soybean[6] meal	Sunflower[7] meal	Cottonseed[8] meal
Lysine	7.2	7.6	8.0	7.9	7.0	6.3	3.6	4.1
Methionine	1.2	1.5	1.1	1.6	2.6	1.3	3.2	1.6
Cystine	1.0	0.9	1.2	1.2	1.0	1.5	1.5	2.1
Threonine	5.1	4.7	6.0	5.4	4.2	3.7	3.2	3.5
Valine	5.4	5.1	5.5	6.0	5.2	5.2	4.9	4.9
Leucine	7.8	8.5	7.7	7.2	7.3	7.4	5.5	6.0
Isoleucine	4.9	6.7	5.2	6.0	4.6	5.5	4.5	3.8
Phenylalanine	4.4	4.7	4.9	6.2	4.0	4.8	2.1	5.6
Tyrosine	3.3	2.8	3.5	4.4	2.9	3.1	—	—
Histidine	2.9	1.9	2.2	2.9	2.3	2.4	2.1	2.6
Tryptophan	0.9	0.9	1.1	1.0	1.2	1.3	1.1	1.6
Arginine	3.9	4.3	4.8	5.4	5.0	6.9	7.5	10.1
Crude Protein (N x 6.25)	50 to 65	65.0	56.4	48.3	65.0	45.8	46.8	41.9

[1] Average value—5 samples—analysis by Soviet Institute of Nutrition.
[2] British Petroleum Co—analysis by Soviet Institute of Nutrition.
[3] Average of three samples—Dainippon Ink & Chemical Co—analysis by Soviet Institute of Nutrition.
[4] Torula dried yeast.
[5] Fish meal—average values—fish meals can vary widely.
[6] Soybean oil meal—solvent extracted—44%.
[7] Sunflower oil seed meal—solvent extracted—without hulls.
[8] Cottonseed oil meal—solvent extracted—41%.

Table 2

Vitamin Content in Various High Protein Livestock Feedstuffs
(mg/kg)

Vitamin	Yeast SCP (USSR)	Yeast SCP (BPC)	Fodder yeast	Fish meal	Soybean meal	Sunflower meal	Cottonseed meal
Thiamin (B-1)	17	3	4	0.7	7	—	7
Riboflavin (B-2)	70	117	55	4.8	3	3	5
Pantothenic acid	160	160	145	9	15	10	14
Choline	2600	7000	2100	3080	2743	2900	2780
Nicotinic acid	600	400	350	60	27	220	40
Pyridoxine	30	10	35	—	8	16	5
Biotin	3	—	—	.26	0.32	—	—
Folic acid	3.4	5	16	0.2	0.7	—	2.3
B-12	.08	.05	—	.09	—	—	—

has a high value as a protein source for swine and poultry.[19, 20] In contrast to Soviet tests, BPC used a quality control ration containing adequate soybean meal, fish meal, and methionine supplements. In test rations, SCP replaced either soybean meal, fish meal or a combination of the two on a protein equivalent basis at levels of 5 to 15% of the diet for swine and 7.5 to 20% of the diet for broilers and laying hens. These experiments indicated that there were no significant differences between control and test (SCP) rations in promoting growth of broilers and pigs, egg production and fertility, litter size and growth rate of pigs farrowed by sows on test rations, and feed conversion efficiency. BPC tests clearly show that SCP can replace large portions (5 to 20% protein equivalent) of conventional animal and plant protein supplements in animal feeds. The lack of a negative (protein inadequate) control ration in these tests prevented demonstration of the true value of SCP as a protein supplement in protein deficient diets.

The Institute of Nutrition, USSR Academy of Medical Sciences, Moscow, conducted biological assays on the Soviet SCP product, using rats as the experimental animal. These tests indicated that the protein efficiency ratio (PER) of Soviet produced SCP is approximately 50 to 60% that of casein, a standard reference protein. The value of the SCP product increases to that of the control (casein) when its amino acid composition is improved by combining SCP with other sources of animal and vegetable protein with a high methionine content.[14] Rat assay procedures on BPC's SCP product gave similar results by the addition of methionine to the SCP.[20]

Determination of protein digestibility and energy content of the BPC yeast product on chicks and pigs

Table 3

Efficiency of SCP in Livestock Feeding[1]

Type of animal	Increase in productivity	Reduction in fodder input per unit of production	Other benefits
Fattening pigs	Weight gain increase 15-30%	10-20%	Fattening period reduced by 20-30 days
Poultry (broilers)	Weight gain increase 25-30%	10-15%	Reduced fattening period and death losses
Laying hens	Egg-laying increased 20-30%	10-15%	Higher egg fertility
Suckling calves	Weight gain increase 10-25%	10-20%	Growth accelerated. Replaces 20-30% whole milk

[1] SCP was added at a level of 5% by weight of total feed.

Table 4

Protein Digestibility and Energy Content of SCP

	SCP	Soybean meal*
Protein digestion rate—%		
poultry	86	92
pigs	90	91
Metabolizable—cal/gm		
chicks	2.55	2.25
Digestible energy—cal/gm		
pigs	4.1	3.3

*Soybean meal solvent extracted—44%.

gave results as shown in table 4. SCP made up 15 and 30% of the ration in these tests. Results again show that SCP is comparable to soybean meal in poultry and swine nutrition.[20 24]

Soviet claims for the value of SCP in terms of increased production of livestock varies, but all estimates indicate that adequate amounts of SCP would substantially increase total livestock production in the USSR. Various estimates as to the contribution that a metric ton of SCP added to mixed feeds would make on livestock production range from 400 to 600 kg of swine (liveweight), 1.5 to 2.0 tons of poultry (liveweight), 10,000 to 35,000 eggs, or a savings of 8 to 9 tons of whole milk by feeding SCP to calves.[9 10 18 25 26]

Based on the smaller of the above estimates, a million metric tons of SCP would increase the production of livestock, milk or eggs in the USSR, as shown in table 5. These values are based on 1975 production figures [8 82] and assume adequate mixed feed production, feedstuffs distribution, and livestock raising facilities.

In addition to increased output of livestock products, the Soviets claim that supplemental SCP in mixed feeds would benefit Soviet agriculture by substantially reducing time and labor required per unit of production and by increasing the feed efficiency of both roughage and concentrated feeds. In view of the results the Soviets have reported on their feeding trials with SCP, the claimed added benefits are realistic. The estimated value of SCP to Soviet livestock production coupled with Soviet oil resources and production costs, apparently justifies the emphasis they place on yeast SCP as a protein feedstuff.

Hydrocarbon Yeast Safety

The Institute of Nutrition, USSR Academy of Medical Sciences, under the direction of Academician A. A. Pokrovskiy, conducted extensive studies on the biological safety of hydrocarbon grown SCP.[14] The purpose of the evaluation was to determine toxicity and tolerance levels in animals and to assess the quality of livestock products produced on rations containing SCP.

This study, which extended over a 6-year period, was carried out in both medical and agricultural institutions with the feeding of many different hydrocarbon grown yeasts to thousands of agricultural and experimental animals, including rats, dogs, monkeys, rabbits, swine, cattle, and poultry. The studies resulted in the establishment of preliminary quality standards (table 6) by the USSR Ministry of Health for hydrocarbon grown SCP for use in animal feeding. Methods of using hydrocarbon SCP as a livestock feed were recommended also.

Table 5

Contribution of One Million Metric Tons of SCP to Soviet Production of Swine, Poultry, Milk or Eggs

	1975 Production (thousand mt)	Increase in production from SCP supplement (thousand mt)	Percent increase over 1975 production attributable to SCP
Swine*	8,428	400	4.7%
Poultry*	2,083	1,500	72.0%
Milk**	90,800	8,000	8.8%
Eggs***	57.7	10	17.3%

*Liveweight—Based on reported slaughter weights of 5.9 and 1.5 million mt for swine and poultry, respectively, and dressing yield of 70% and 72%.

**Savings in milk by feeding SCP to calves.

***Number of eggs in billions.

Table 6

Soviet Quality Standards for Hydrocarbon SCP

	Content
Moisture	Not over 10%
Total nitrogen	Not less than 8%
Protein (N x 6.25)	Not less than 48%
Nucleic acid	Not over 8%
Lipids	Not over 5%
Residual hydrocarbons	Not over 0.1%
Polycyclic hydrocarbons	0.000
Lead	Not over 5 mg/kg
Arsenic	Not over 5 mg/kg
Aflatoxins	0.000
Microorganisms	
Pathogenic	00
Live yeast cells	00
Nonpathogenic	100,000 per 1 g

The principal SCP components having possible deleterious effects on its use as an animal feedstuff are listed below. As indicated, none of these would appear to be a maior problem provided the prescribed quality standards are met.

a. Residual hydrocarbons, particularly polycyclic hydrocarbons, which may accumulate in animal fat: The alkane hydrocarbons in SCP, at the low levels specified by the USSR Ministry of Health, are metabolized by the animal and do not accumulate to a significant extent. Polycyclic aromatic hydrocarbons, many of which are carcinogenic in man, are not allowed in SCP products meeting Soviet safety standards.[14 29]

b. Nucleic acid was present in various yeast samples at levels of 6 to 18%: High dietary levels of nucleic acids produce an accumulation of uric acid in primates and is a major detriment to the extensive use of yeasts by humans. The Soviets claim that the accumulation of uric acid does not occur to a significant degree in livestock when SCP containing 8% nucleic acid is fed at levels up to 15% of the diet.[14]

c. Possible presence of fungi which produce toxins having possible hepatotropic, carcinogenic, or other toxic properties. No toxic substances of this nature were found in any of the hydrocarbon yeast samples analyzed according to the Soviets. Substances of this nature are not allowed under the standards established by the USSR Ministry of Health.[14]

d. Hydrocarbon grown SCP has a relatively high content of fatty acids with odd numbered carbons compared with the lipid content of most conventional feedstuffs. Some accumulation of these in tissues of experimental and farm animals was apparently observed with certain SCP feedstuffs. The problem was claimed by the Soviets to have been overcome by rigid specification of alkanes used as the substrate and methods of using hydrocarbon yeast in animal feeding.[14] Recent evidence indicates that odd chain fatty acids are more prevalent in nature than most people had realized. These fatty acids also are metabolized readily by the animal.

The Soviets claim that multigeneration experiments with animals have shown that hydrocarbon SCP has a relatively high biological value with complete absence of carcinogenicity, mutagenicity, and teratogenicity. Detailed investigations of hygienic, physicochemical and organoleptic properties of meats, eggs and milk from farm animals fed hydrocarbon SCP did not reveal any major deleterious change. Long term experiments were conducted in rats to evaluate the meat from hydrocarbon SCP-fed animals as a food. In several generations of rats fed this meat, no abnormalities were reported in behavior, growth and development, food metabolism, liver enzyme systems, or in hematological, morphological, and histochemical factors. Assessment of the biological value and harmlessness of dairy products and eggs from cows and hens fed with SCP rations were generally favorable. Animals fed on these products did show some increase in blood cholesterol and lipids after being on the diet for 6 to 7 months. The latter result prompted A. A. Pokrovskiy, a leading Soviet nutritionist, to recommend caution in using SCP in feeds for lactating cows and laying hens.[14]

Large-scale controlled investigations of products from animals fed on hydrocarbon yeasts were carried out on a large group of human volunteers. Taste tests did not reveal any differences between meat, dairy products, or eggs from SCP fed animals and corresponding control products. Two feeding trials with meat products from SCP fed animals were conducted, each lasting more than six months, on groups of more than 100 individuals. These studies confirmed that these products were highly nutritious and palatable and there were no unfavorable effects resulting from their consumption.[14 30]

The conclusion from these studies was that hydrocarbon yeast SCP, meeting the criteria established by the USSR Ministry of Health, was a highly satisfactory feedstuff supplement for livestock when fed at levels up to 15% of the diet.

In general, Soviet assessments of the safety of using SCP as an animal feedstuff were substantiated by BPC* and Japanese studies.[20, 24] In multiple generation studies in rats and quail with the BPC yeast SCP product, 13 generations of rats and 23 generations of quail have received SCP diets without ill effects.

Human Diets

Although the Soviets claim that they are not considering the introduction of proteins from unicellular organisms into human diets, they, as do many Western nutritionists, realize its potential as a protein source for human consumption. A. A. Pokrovskiy of the Institute of Nutrition states that the use of SCP as a significant protein source for human diets has considerable risk from the safety standpoint as well as acceptability.[14, 31] He concludes that the biomass of microorganisms must be subjected to rigid technological processing to isolate purified textured protein for human consumption. Western experts agree and some feel that SCP in the human diet to any reasonable extent as a protein food is at least 20 years away.[28]

Soviet interest in the possible employment of proteins from hydrocarbon SCP as a human food was shown during the Joint Conference on SCP of the US/USSR Working Group at the Massachusetts Institute of Technology on 24 to 26 March 1976. At this conference a paper by A. N. Grigoryan, Chief of Laboratory of the All-Union Institute of Protein Synthesis, was presented on the development of methods for obtaining purified protein substances for food from microbiological synthesis.[32] The Soviets also demonstrated synthetic foods resembling rice grains, macaroni and caviar, which were probably prepared from a purified, artificially flavored protein derived from soybean and/or SCP with reduced nucleic acid and lipid content.[33]

It is doubtful that the processing of SCP proteins for human consumption in the USSR will go beyond the laboratory stage in the near future. This is based on repeated admissions by the Soviets of the need for SCP for animal feeds, the possible reluctance of the Soviet citizens to accept petroleum based SCP as a major dietary supplement, and the relative expense of preparing a purified protein. This position could change drastically if world food supplies take a sudden downturn and prospects for using SCP protein as an aid to developing nations appear advantageous.*

*Tests devised and conducted by the Central Institute for Nutrition and Food Research at Zeist, Holland.

SCP FERMENTATION TECHNOLOGY

The major factors influencing the production of a single cell protein product consist of the growth medium or substrate, the microorganism to be cultivated, and the fermentation process. The Soviets have been involved in research and development of the production of SCP from hydrocarbons and alcohols since the early 1960s. They have investigated each of the basic approaches: (1) growth of bacteria or yeast on purified paraffin (C11-C18) separated from crude oil, (2) growth of bacteria or yeast on the gas-oil fraction of crude oil, containing 10 to 20% normal paraffins, (3) growth of bacteria and yeast on methanol, (4) growth of yeast on ethanol, and (5) growth of bacteria on natural gas. Yeast grown on purified normal paraffins and gas-oil has been emphasized.[9, 35]

Substrate

Either purified n-paraffin or gas-oil can be used for production of suitable SCP products for livestock feed. While the gas-oil process uses a less expensive starting material than the purified n-paraffin process, it is necessary to employ an additional centrifugation and a solvent extraction stage at the end of the harvest train to remove residual hydrocarbon from the protein product. The unmetabolized, dewaxed oil with improved pour point is returned to the refinery. BPC has developed two production processes, one to handle the purified n-paraffins and the other the gas-oil substrate. Products from both of these processes meet European Economic Community and Soviet quality standards for animal feed.[19, 20]

According to the Soviet press, the results of SCP research and development at the All Union Scientific Institute for Protein Synthesis in Moscow led to the

*T · future world need for protein rich foods was pointed out in a recent study conducted by the Massachusetts Institute of Technology for the National Science Foundation.[16] In this study it was stated that "given foreseeable expanding world protein requirements, it is by no means certain that conventional US Agriculture based on current and past agricultural research will be able to meet both US and foreign protein demands for an indefinite future at acceptable domestic and internationally competitive price levels. It might well be desirable to anticipate these demands by more intensive application of science and technology in order to reduce production costs of conventional protein foods and to prepare for a time when unconventional protein sources might provide acceptable price-competitive alternatives with less pressure on the nation's resources." Two of the 14 areas of research recommended by this study involved SCP, nonphotosynthetic and photosynthetic.

decision that purified normal paraffin was the best substrate for large scale production of SCP.[36] At the Protein Advisory Group of the UN Symposium, Brussels, in March 1976, E. R. Shenderel* stated that research showed the n-alkanes of the C11-C18 fraction with a purity of 99% was the best substrate for producing SCP meeting the quality standards accepted in the USSR.[9] Yeast grown on 99% pure n-paraffin (C11-C18) is said to contain less than 0.1% of residual hydrocarbons in the final feed product. This level of hydrocarbon in the SCP product meets Soviet quality standards for animal feed and the product requires no further processing to remove residual hydrocarbons.

The Soviets are apparently having difficulty in large scale separation of purified n-paraffin substrate (99% purity—C11 to C18) as evidenced by admitted needs for US process technology by the Ministry of Petroleum Refining and Petrochemical Industry of the USSR (MPRPI).[37-39] The MPRPI is negotiating with Liquichemica, an Italian firm, for construction of two separation plants (turnkey) with a combined annual capacity of 1.3 million metric tons of normal paraffin. In October 1975, it was reported that the negotiations would probably not be completed until mid-1976. It will take 3 to 4 years to put the plants in operation from the start of production.

The Soviets also have had problems apparently with purification of the SCP product. They claim that health was a major consideration in choosing normal paraffins and are very concerned with cleaning the product after growing yeast on gas-oil.[40 41] Although purified n-paraffin is the probable substrate of choice, the Soviets are interested also in utilizing the cheaper diesel fraction (gas-oil) in SCP production.[18 43 44] This process is attractive since it produces the protein concentrate as well as low paraffin diesel oil by employing organisms that selectively deparaffinize the oil.

The repeated Soviet emphasis on the use of purified n-paraffin substrate and the apparent problems in obtaining the desired 99% purity suggest that the current Soviet petroleum SCP production process is based on a purified n-paraffin substrate, considerably less than 99% pure. It is probably necessary to employ a solvent extraction stage to remove residual hydrocarbons and excess nucleic acids from the protein product.

*Shenderel, First Deputy Chief of Main Board for Microbiological Industry of the USSR Council of Ministers.

Microorganism

One of the most important factors related to SCP production from hydrocarbons is selection of suitable microorganisms. Soviet scientists have reported extensive research in this area and have investigated at least nine species and numerous strains of *Candida* yeasts, including *C. tropicalis* and *C. lipolytica*, the species used by BPC plants.[42 45 46 56 77] Soviet scientists claim that a high yield strain of *Candida guilliermondii* has proven to be the most suitable and is the principal yeast currently being used in the production of SCP in the USSR. A protein content of 65% and a yeast cell to substrate yield of 1.2 to 1 have been claimed for selected strains of this species.[29]

Process

The SCP production process consists of three major steps: fermentation, separation and purification of biomass, and drying of purified biomass. The initial research and development on fermentation processes for the production of yeast SCP from petroleum derivatives reportedly was conducted at the All Union Institute for Synthesis of Protein.[48 49] It is believed that in this experimental process, the Soviets employed a two-stage, airlift, continuous fermentation method.[9 49]

Subsequent research conducted by the Institute for Biochemistry and Physiology of Microorganisms at Puschino apparently led to new and improved methods for production of SCP from various carbon sources and resulted in construction of the first operational pilot plant for petroleum fermentation at Krasnodar.[47] An airlift system using n-paraffin with improved air distribution and ferment circulation was believed to be the primary system at Krasnodar. In 1972 the plant was considering the use of newly developed plate column fermenters.[40 50] This pilot plant and possibly one at Novo Chernikovsk (Ufa) provided the yeast used in Soviet feeding and medicobiological studies conducted by the Institute of Nutrition, USSR Academy of Medical Sciences.[51]

The development, design, and construction of production scale fermenters and ancillary scientific equipment were a joint effort of various institutes under the Main Administration of the Microbiology Industry, the Moscow Institute of Chemical Machinery, the Ministry of Machine Building, and Irkutsk Scientific Research Institute of Chemical Machinery.[49 51] According to the Soviet press, in May 1974, equipment was not yet available for use, but the principles and apparatus were suited for automated control of industrial fermentation processes. Automated SCP plants are being planned and built.[62,63]

There is reasonable evidence that the Soviets have developed a continuous flow fermentation system utilizing multiple fermenters.[18,40,48] Although the Soviets began using airlift fermenters, they were not believed to be able to do the necessary mixing on an industrial scale and the major mixing is probably by means of mechanical agitation.[54,55]

The First Deputy Chief of the Main Administration for Microbiology Industry of the USSR claims that the Soviet hydrocarbon process is simpler and better than other processes and that they were to have licensed their process by late 1976.[29] This claim is refuted by evidence that their large scale production plants, which are in various stages of production, are not producing efficiently or near design capacity. US specialists who visited the Soviet Union were turned down in their efforts to visit Soviet plants because the Soviets said they were not operating at rated production.[40,56,57] Some Soviet scientists who claimed to have been involved in the design and construction of the production facilities stated that output was only about 1/4 of rated capacity.[21]

The apparent failure to attain production goals is consistent with other indications of bioengineering difficulties associated with scaling up laboratory processes to large scale production. Major shortcomings in the field of microbiological synthesis, especially for single cell protein production, include the lack of reliable low tolerance sensors for a production scale continuous fermentation system, lack of automated systems of fermentation control, and the lack of overall product control and reproduction efficiency. The crux of the Soviet problem seems to be in applied computer technology and chemical engineering, especially in computerizing the production process.[6,41] While automation and computer support are likely to be incorporated in their design, the sophistication and quality are probably well below those of Western technology.[40,56,57,77]

[redacted] there are three basic computer control systems under study in the USSR.[40] These are: (1) the computer coupled fermentation unit purchased from a US firm, New Brunswick Scientific Instrument Company in mid-1974.[58,59] This unit is located at the Institute of Protein Synthesis and, although Soviet engineers visited the US for a three-month instruction course, the unit is still not being operated optimally. [redacted] [redacted] this system was not in operation because of inadequate air, water and electrical facilities, and the inability of the Soviet scientists and engineers to comprehend equipment operation procedures.[51] (2) An original design by the Institute of Protein Synthesis, status unknown, and (3) a system being developed by the Kazan Institute of Chemical Technology which is in the initial stages of development. Based on discussions with Soviet scientists and engineers, Western experts believe that a laboratory fermentation system at Pushchino, Institute for Microbiological Physiology and Biochemistry, has temperature and pH coupled controls which optimize yield through computer selected variables. Pushchino is reportedly the most advanced laboratory project under way.[40] It is doubtful that any large scale or pilot plant fermentation process is computer controlled.

The Soviets appear to be having problems with other areas of the continuous fermentation process and fermentation equipment. They have repeatedly admitted problems with foam control and are now attempting to control foam mechanically to avoid using antifoam chemicals which may interfere with dispersion of the mixture in the fermenter. Mechanical foam control is preferred by US fermentation experts. Soviet representatives to the US/USSR microbiological exchange meetings have shown great interest in research on fermentation environmental mensuration equipment such as amino acid analyzers, oxygen sensors, and carbon dioxide sensors. Most of this hardware is already commercially available in the US.[57] Centrifuges and spray head dryers for separation and drying of biomass have been purchased from Sweden and Denmark, reportedly because Soviet equipment was not satisfactory and did not hold up well.[50,60,61]

During 1972, the Ministry of Foreign Trade purchased approximately $200,000 of fermentation equipment from a US company. The equipment, consisting mainly of fermentation chemostats, is being used in the laboratories at Pushchino. They also ordered additional fermentation chemostats from the US company in 1973.[60] There is also evidence that the Soviets acquired solvent extraction technology for removing residual hydrocarbons from the final SCP product from an unnamed Western firm.[26,41,59,63]

Although the Soviets apparently have designed, built, and at least partially installed their own fermentation equipment in industrial SCP production plants, they have expressed an interest also in purchasing entire SCP plants and technology from Western nations.[34] It was reported that the Soviets signed a letter of intent to purchase an SCP plant from an Italian firm, *Compagnia Tecnica Industrie Petroli* (CTIP).[44, 64] This letter of intent was to be exercised only after the SCP plant being built in Italy was operating and the process for producing SCP from n-paraffin by continuous cultivation of a *Candida* species of yeast was demonstrated. This process is based on the use of 1,000 cubic-meter airlift fermenters.[64] In the fall of 1974, British Petroleum reportedly was negotiating with the Soviets to construct a 100,000 ton/year SCP plant.[64] Neither of these negotiations has reached fruition.

The present Soviet hydrocarbon SCP production is probably based on a continuous fermentation process. The yeast of choice is believed to be a high-yield strain of *Candida guilliermondi*. The culture medium contains a purified n-paraffin substrate, water and salts of phosphorous, ammonia, potassium, and other elements necessary for optimum cell growth. Separation of the final SCP product is probably by centrifugation and solvent extraction technology. After separation the yeast is concentrated and dried in spray dryers. The yeast-to-substrate (n-paraffin) yield ratio is probably 1.0-1.2 to 1.0.

In general, the Soviets seem to be scientifically strong but weak in applied chemical tech- ology and engineering. In spite of the enormous amount of Soviet activity in microbiological synthesis of protein, they are apparently encountering considerable difficulties in optimizing production scale operations. The realization of full production of their SCP plants in the near future may relate to how successful they are in attaining Western assistance and technology.

SCP PLANT DEVELOPMENT

The first experimental Soviet plant for producing SCP from petroleum is believed to have been put in operation in 1964 in Krasnodar. This plant operated on a gas-oil substrate. The Soviets encountered toxicological problems when gas-oil was used as the substrate and a second pilot plant was built at Krasnodar utilizing rectified 99% pure n-paraffin as the substrate. The Krasnodar facility, which reportedly is engaged in other microbiological production activities, e.g., alcohol from sugar, hydrolytic SCP, is believed to have produced the first hydrocarbon-based SCP meeting Soviet safety standards in the mid-1960s. The facility subsequently served as a pilot plant for testing newly designed fermentation, separa'ion, and dehydration technology.[60, 61]

The first pilot plant located at a petroleum refinery was constructed during the 1960s in Bashkirskya, ASSR, at the Ufa Petroleum Refinery Novo Chernikovsk. The pilot pla..ts at Krasnodar and Ufa provided the yeast SCP used in Soviet feeding trials and served as the models for construction of large scale production plants.

Based on Soviet press reports and open literature, and reports from Western experts engaged in exchange programs with the Soviets, eight industrial petroleum-based SCP plants are being constructed.[48, 64, 65–69, 71, 78]

According to the Soviet press, however, construction at Kremenchug was started in late 1975.

According to 1974 Soviet press releases, the Gor'kiy plant will have an annual capacity of 70,000 metric tons and three other plants under construction, presumably at Kirishi, Ufa, and Volgograd, will have capacities of 70,000, 180,000, and 240,000 mt/y, respectively.[78]

SCP INDUSTRIAL DEVELOPMENT

The Soviets have utilized cellulose derived yeasts (hydrolysate yeast) as a feedstuff for many years and SCP from this source represents over half of the total SCP produced in the USSR at present. Although some Soviets have claimed that production of 700,000 tons of hydrolysate yeasts were obtained in 1975,[9,40] other evidence indicates that the annual production is probably closer to 500,000 tons annually. Officials of the All Union Research Institute for Hydrolysis and the All Union Hydrolysis Corporation stated that there are about 50 hydrolysis SCP plants in the USSR with a typical output of 6,000 mt/y.[21,69] In March 1976, Dr. Grodova of the All Union Institute for Protein Synthesis stated that there were about 50 hydrolysis SCP plants, with a total output of 500 thousand mt/y.[42]

The Soviets are emphasizing the production of SCP from petroleum derivatives and make the reasonable claim that the n-paraffin process for SCP is much more promising and economical than the process using wood pulp or other cellulosic materials.[26,74] This claim is based on three major factors: (1) The USSR has large reserves of high n-paraffin content petroleum, the value of which is increased by dewaxing, (2) petroleum refineries provide a reliable, concentrated source of substrate that permits construction of plants with a high production capacity, and (3) construction of n-paraffin SCP plants requires only about one-half as much capital investment per unit of production as the construction of hydrolysis SCP plants.

Soviet press reports indicate that eight industrial scale petroleum hydrocarbon based SCP plants are being built.

[redacted] If the Soviets overcome their process difficulties, which they probably will do, and plant construction proceeds at the projected pace, the Soviets probably will have a hydrocarbon SCP production capability in excess of 860,000 mt/y by 1980 and a possible production capability of 1 million mt/y by that time.

Although the total production of feed yeasts in the USSR has increased steadily since 1965, reaching a level of 540,000 metric tons in 1974,[76] it is doubtful that the Soviets met their 1975 goal of 978,000 mt/y of SCP from all sources.[1] By 1980, they will probably be well on their way to achieving their goal of 2 million tons of SCP from all sources.[85] The Soviets have large reserves of high n-paraffin petroleum and, if current ventures are successful, could probably increase SCP production from this source by a factor of two over the next 10 years. Future expansion, however, would depend on demands for n-paraffin for other purposes, e.g., waxes, detergents and prices on world markets.

Yeast SCP is expected to be of significant benefit to the Soviet livestock industry. The production of SCP will not tax agricultural resources, such as land, fertilizer and equipment, while providing the Soviets with a reliable supply of high quality protein concentrate. One million tons of SCP represents about 22%, on a weight bases, of the calculated combined average production (1970-74) of cottonseed meal and sunflower seed meal.[77] Assuming an SCP product with 60% protein, one million tons of SCP would represent 30% of the major oil seed meal production on a protein equivalent basis. (Cottonseed and sunflower seed are the two major oil seed meal crops grown in the USSR and represent about 95% of total oil seed meal produced.) This quantity of SCP would be comparable to the amount of sunflower meal and cottonseed meal realizable from approximately 2 million hectares of sunflowers or 1.26 million hectares of cotton.[13 76] Values are based on the calculated quantity of meal obtainable per hectare of crop, average yields 1970-74 (table 8).[76]

Table 8

Comparative Value of One Million Metric Tons of SCP to Soviet Cottonseed Meal and Sunflower Seed Meal* Production

	Cottonseed oil meal	Sunflower seed oil meal
SCP as percent of meal production (Wt. bases)	46%	42%
SCP as percent of meal production** (protein equivalent bases)	65%	54%
SCP million hectares equivalent	1.26	1.97

*Calculated average annual production—1970 through 1974.
**Assuming SCP protein content of 60%.

GLOSSARY

Biological value—A measure of the proportion of the food protein which can be utilized by an animal for synthesizing body tissues and metabolites. The percentage of the protein nitrogen absorbed which is retained by the animal.

Carcinogenic—Producing or tending to produce cancer.

Digestible energy—Gross energy value of a food less the energy contained in the feces.

Feed conversion efficiency—Units of feed consumed per unit of product, e.g., body weight, eggs, and milk.

Hematological—Relating to or involving blood.

Hepatotropic—Relating to or involving the liver.

Histochemical—Relating to the chemical composition of living cells.

Metabolizable energy—Gross energy value of a food less the energy contained in the feces, urine, and gas (ruminants).

Morphological—Concerned with form or structure.

Mutagenic—Producing or tending to produce genetic changes.

Oil seed meal—Residues remaining after removal of the greater part of the oil from oil seeds, e.g., soybeans, cottonseed, sunflower seed, rape.

Protein digestibility—Nitrogen intake minus fecal nitrogen. A measure of the value of a protein feedstuff.

Protein efficiency ratio (PER)—Weight gain unit per unit weight of protein consumed. The PER normally uses growth of the rat as a measure of the nutritive value of dietary proteins.

Teratogenic—Producing or tending to produce malformations in the growing organism.

n-paraffin—Straight chain hydrocarbons having the general formula $C_n H_{(2n+2)}$

Crude protein—Protein content of a food as measured by multiplying the analyzed nitrogen content by 6.25.