NEW TECHNOLOGIES FOR THE UTILIZATION OF AGRICULTURAL BY-PRODUCTS AND WASTE MATERIALS
Proceedings of a Task Force Meeting

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PREFACE

This paper contains information on the Task Force Meeting on "New Technologies for the Utilization of Agricultural By-Products and Waste Materials" held at IIASA on September 23-24, 1980 as part of the activities of the new task (The Limits and Consequences of Food Production Technologies) of the Food and Agriculture Program.

An overview of the papers presented at the meeting, and the role of the meeting in relation to the task's overall activities is given, and the results of the review of new technologies started at the meeting are indicated. The meeting saw the beginning of further collaboration with national institutions and follow-up activities are planned within the task for 1981.

ACKNOWLEDGEMENTS

I would like to express my thanks to all those who contributed to the Task Force Meeting, whether by formal presentation, or through participation in the discussion. Special thanks are extended to Dr. Y. Khromov, Prof. G. Mikeladze, Prof. S. Münch and Dr. J.T. Worgan for their assistance in the final preparation of the meeting. I am also grateful to Julia Czekierska for her help in organizing the meeting, and for editing and typing the final manuscript. Thanks also to Gabriele Adams of Conference Services for organizational help.

Jaroslav Hirs, Task Leader, Food and Agriculture Program

CONTENTS

(Papers submitted to the organizers in written form in the sequence presented at the meeting; the names of authors who participated in the Task Force Meeting are underlined)

At the Task Force Meeting the following presentations were also made but are not included because they were not intended as written contributions to the meeting or because they are based on work published in a different form:

The Goals and Objectives of the Food and Agriculture Program
K. Parikh

The General Framework and Scope of the Meeting
J. Hirs

Economic Feasibility of Using Crop Residues to Generate Electricity in Iowa
E.O. Heady

The Utilization of Agricultural Waste for Energy Production
*J. Parikh**

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*Forthcoming as an IIASA Working Paper.

INTRODUCTION

Jaroslav Hirs

The Food and Agriculture Program at IIASA formulated its major aims as follows:

- -- to evaluate the nature and dimension of the world food problem;
- -- to identify the factors affecting this situation, and
- -- to investigate alternative ways of alleviating current food problems and preventing future ones on the national, regional and global levels.

During the first years of research activities, the Program's major focus was on the short or medium term economic problems of agricultural production and food supply on the national and global level.

In 1980 a new task was started within the Program's structure*, oriented towards long-term perspectives of agricultural development. Recognizing the increasing scarcity of some crucial resources for agricultural production (e.g. land, energy), and at the same time taking into consideration the increasing food demand in relation to the growing population, this task focuses on the problems of technological transformation in agriculture.

One of the important aspects of this investigation is the sustainability of agricultural systems in the long run which necessarily suggests the consideration and investigation of the possible environmental impacts of new technologies as well as those presently in use.

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* Technological Transformations in Agriculture: Resource Limitations and Environmental Consequences (Research Plan 1981-1985).

When beginning work on this task the complexity of the problem was recognized, being of global importance as far as future food production is concerned, but at the same time having regionally specific aspects requiring an appropriately detailed level of research. Thus, work was focused on the development of a methodology*, and the design of a system of models which could be used for the generation of alternative paths of technological development, and the application of this methodology in a number of selected areas in the form of case studies.

An important part of the task's structure is the review of technologies presently available and those that will be available during a period of the next 20 years. This review should include:

-- technologies widely used at present in food production (traditional technologies);
-- technologies likely to be available during the next 20 years, using the same kind of key inputs and giving traditional types of products (new traditional technologies);
-- non-traditional technologies, which are or will be available for the production of food, feed or bioenergy from non-traditional sources.

The ultimate goal of the task's activities in the latter field are:

-- to review present knowledge on the development and use of such technologies;
-- to assess the relative importance of these technologies and their possible impact on the food situation
  a) in particular regions, and
  b) on the global level;
-- to analyze the factors influenzing the implementation of these technologies.

In order to initiate this research work, a Task Force Meeting was held at IIASA on September 23rd-24th, 1980 as a follow-up to previous collaboration and preparatory work jointly carried out with the Department of Food Science and Technology, Tbilisi State University, U.S.S.R., and the National College of Food Technology, University of Reading, Weybridge, Surrey, U.K.

The Task Force Meeting+ was held to obtain a preliminary introduction to the field of knowledge relevant to the production of food, livestock feed and sources of bio-energy from waste materials of agricultural (or forestry) origin.

The meeting did not attempt to cover the whole range of new technologies and it was suggested that the preparation of a comprehensive list should be the first step in a systematic study of the topic by IIASA.

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* see D. Reneau, H. van Asseldonk, K. Frohberg: Limits and Consequences of Agriculture and Food Production: A General Methodology for the Case Studies. WP-81-15

\+ see Appendix for list of participants.

The majority of papers presented concerned the production of protein for livestock feed. Some papers dealt with a specific example of one new technology while others reviewed more briefly the state of the art in a number of new technologies. Other papers were mainly concerned with the type and quantities of waste materials and by-products available and illustrated how extensive quantities of waste were produced between the stages of harvesting and consumption of both plant and animal sources of food. The production of alcohol and biogas were the two sources of energy from biological materials on which presentations were given at the meeting. The economic aspects and the parameters involved in assessing the introduction of new technologies were also reviewed in separate papers.

In order to obtain the type of data required for the IIASA study, a provisional questionnaire was prepared for the Task Force Meeting and was completed by those attending in respect of a specific example of a new technology concerned with the production of food, feed or a biological source of energy. Of the eleven replies (see Table 1) to the key question on the questionnaire, namely, whether it was feasible that the technology could be applied within the next 20 years, 10 positive answers were given. On the other hand, only one suggested that the technology may have negative environmental effects.

Although the answers to the questionnaire gave useful information on the technologies listed, it was suggested during discussion that more data could be obtained from an improved version of the questionnaire. It was agreed that this improved version should be prepared and forwarded to participants to complete and return to IIASA. Participants were also asked to provide the names and addresses of other experts who would be interested in cooperating with the IIASA study and who would also be able to complete a questionnaire in respect of their knowledge of a particular technology.

Although the eleven completed questionnaires do not cover the full range of existing technologies or technologies presently being developed, a comparison of the replies proved of considerable interest and indicates the diversity of this field of study. The main questions asked and the replies are shown in Table 2 in condensed form.

The participants present at the September meeting supported the motion to continue the review. It was generally felt, that information about the various methods and locations used for the development and testing of these new technologies is rather scattered and a comprehensive review is needed.

In conclusion it was agreed that another meeting to further discuss this topic should be organized. The Food and Agriculture Program will collaborate with the Soviet National Member Organization to discuss the possibility of planning such a meeting for 1981, following a suggestion by Soviet delegates to the meeting that it might be held in Tbilisi.

Table 1. List of technologies for which the questionnaires were completed

1.	The production of submerged culture from agricultural and food processing wastes
2.	The fermentation of food by-products for example, oilseed press cake and other food processing by-products
3.	Nutritional (protein) improvement of high starch substrates
4.	Microbes for food and feed using : a) cellulose substrates, and b) edible substrates
5.	The use of ligno-cellulosic wastes for the production of mushrooms
6.	The aerobic treatment of waste water from livestock production units and the production of microbial biomasses
7.	The recovery of waste streams of the food chains
8.	Green crop fractionation
9.	The recovery of protein for animal feed or fertilizer by physico-chemical means
10.	Farm and community scale ethanol (alcohol) production system
11.	The utilization of crop residues as a fuel source in electricity generation, Iowa.

The September Task Force Meeting served as a starting point for more extensive contacts between the Food and Agriculture Program and other national institutions involved in this field of research with a view to establishing a collaborative network for the review of new technologies as mentioned earlier.

Table 2 Main questions asked and replies to the questionnaire circulated at the Task Force Meeting (condensed form)

	Production of fungal protein by submerged culture from agricul. and food processing wastes	Fermentation of food by-products (e.g. oil seed press cake &othe food processing by-products	Nutritional (protein) improvement of high standard substrates	Microbes for food and feed	
				Using Cellulose as Substrate	Using Edible Substrate
Stage of Development of the Technology					
Is the process in actual production?					
a) one or two units of production	yes			yes	
b) applied extensively	no	yes	yes		
c) on a regional basis		yes	yes (Indonesia)		
Could a feasible production unit be established from the present knowledge without further development if the capital was available?	yes	yes	yes	no	yes
Is the technology at a stage where studies on a laboratory scale suggest that a process will be feasible in the future?				yes	yes
Does the possible technology still require to be tested in practice?	no	no	no	no	yes
In how many years' time could the technology be applied on a practical scale?		imme-diately	5-10 yrs on a large scale	probably 10 years	imme-diately
Could the technology be operated					
a) as a small scale operational unit?	no	yes	yes		yes
b) on an intermediate scale?	yes	yes	yes		
c) is it necessary to apply the technology in large scale units?	no	no	no	yes	
d) is the technology flexible in scale?	yes (between b & c)	yes	yes		
Does the technology have a possible dual function?	reduction of pollution, biomass prod.			reduction of pollution production of biomass	
Inputs					
Types of raw materials					
a) wastes	yes		yes	yes	yes
b) by-products		yes		yes	yes
c) raw materials for other processes				yes	yes
Are there other uses for the wastes?		Feed			
Are the raw materials available in large quantities?					
a) on a global level	yes	yes	yes (estim)		
b) on a regional level				yes	yes
Will the raw materials always be produced a) continuously?	yes	yes	yes	yes	yes
b) in seasonal quantities?	in somecases				
Does enough raw material occur					
a) on 1 point to operate the process?	yes	yes	yes	yes	yes
b) is it distributed over a large area?	in somecases				
What is the average duration of the production cycle?	14 days/100t	2-3 days	3-7 days	30 days	2-3 days
Outputs					
Does the process produce					
a) only the main product?	yes	yes	no	yes	yes
b) also by-products?	in the future enzymes may be used		yes		
Could the end product be used as food for human consumption					
a) within the next 20 years?	yes	yes	yes	yes	yes
b) after more than 20 years?	yes	yes	yes	yes	yes

Table 2.(cont.)

The Use of Ligno-Cellulosic Wastes for the Production of Mushrooms	Aerobic Treatment of Waste Water from Livestock Production Units and the Production of Microbial Biomasses	Recovery of Waste Streams of the Food Chain	Green Crop Fractionation	The Recovery of Protein for Animal Feed or Fertilizer by Physico-Chemical Means	Farm and Community Scale Ethanol (alcohol) Production System	Utilization of Crop Residues as a Fuel Source in Electricity Generation, Iowa.
no	no		yes		yes	yes
yes	no		no		no	no
yes	no		no		no	no
yes	no	yes	yes	yes	possibly	yes
yes	yes	yes			yes	yes
no	yes	yes	no	no	no	yes
Already Applied	min. of 5 years	5-10 years		Immediately	1-5 years'	10 years'
yes	no	no	yes	no	yes	no
yes	no	no	no	no	yes	no
no	yes	no	yes	no	no	yes
yes	no	not at present	to some extent	yes	no	yes
yes	sewage purif. single cell protein prod.	yes	products with various outlets	reduction of pollution animal feed production	yes	yes
yes	yes	yes	no	yes	no	yes
yes	no	no	no	no	yes	yes
no	yes	no	yes	no	yes	yes
burnable fuel soil condit.	Biogas prod.	sometimes			Feed	Feed,erosion control,soil fertility
yes	yes	no	yes	yes	yes	yes
no	no	yes	no	no	yes	
yes	yes	yes	probably	yes	yes	yes
yes	yes	yes	yes	yes	yes	yes
yearly	continuous		6 mths in UK	12-24 hours	3 days	6 months
yes	yes	no	no	yes	no	yes
yes	no	yes	yes	no	yes	some
yes		yes	yes	yes		
yes						

THE PRODUCTION OF FUNGAL PROTEIN FROM AGRICULTURAL AND FOOD PROCESSING WASTES

J. T. Worgan

INTRODUCTION

The technology for the production of the biomass of micro-organisms has been established for more than 50 years. Although the main application of the process has been to the production of Saccharomyces cerevisiae (Baker's Yeast), produced for its baking properties, this yeast does contain 50% protein and is an example of the microbiological production of protein by an industrial process. The same process has been applied more recently to the production of Candida utilis (Food Yeast). The principle of the method is that millions of yeast cells are dispersed in a liquid growth medium. Each cell acts as an individual growing unit which is supplied directly with all the nutrients it requires and is suspended in an environment where the conditions are controlled at the optimum needed for growth. As a consequence of these favourable conditions the whole of the biomass increases at a rapid rate and from a test tube culture of yeast a mass of 100 tons is produced in 14 days.[9]

One of the main factors in determining the feasibility of producing large quantities of yeast protein is the cost and availability of the main raw materials which the yeasts are able to use for growth. These raw materials are known as substrates. Both Baker's and Food Yeast require substrates consisting of relatively simple compounds and are unable, for example, to digest starch, cellulose and many of the other compounds which occur in most of the waste products produced from agriculture and the subsequent processing of biological materials. It is for this reason that there has been recent interest in the development of fungal processes since there are many species of fungi which have a wide range of enzymes and are capable of digesting and utilising for growth the complex mixture of compounds which occur in most waste products.

The Fungal Process

Unlike the almost spherical cells of yeasts, the growing units of the filamentous fungi consist of individual strands known as hyphae which tend to intertwine forming the fungal biomass known as mycelium. However, provided that these hyphae strands are thoroughly dispersed in the growth medium fungal biomass can be produced by the same process as that used for yeast production. From laboratory and pilot plant studies and from processes for the fungal production of antibiotics sufficient data has been accumulated to predict that fungal mycelium can be grown on a large scale as rapidly as yeast and will produce the same yield of protein from the raw materials supplied. Confirmation of this prediction has recently been obtained from the Pekilo process[6] for the production of fungal protein from a paper industry waste, which is now in operation in Finland and will be referred to in more detail later in this paper.

By analogy with the process for producing yeast the batch process for the production of fungal protein is initiated by a laboratory culture. After incubation for 24 - 48 hours, this culture is used to inoculate approximately twenty times its volume of growth medium which is also incubated. This procedure is repeated through several stages of increasing size until a sufficient volume of culture is produced to inoculate the final growth vessel of 45,000 - 225,000 litres capacity. In this final stage the culture is vigorously aerated for 24 - 48 hours and the temperature and pH value are controlled. For most of the fungal species studied the growth conditions are similar to those for yeast, namely, a temperature range of 25 - 30°C and a pH range between 4.5 and 5.5. After 24 - 48 hours in the final growth stage it is advisable to pasteurise the mycelium by heating for 10 minutes at 80°C. The mycelium is then filtered off, washed and dried. The yield based on the weight of substrate supplied is approximately 50% and the mycelium may contain 45 - 55% protein.[10]

Both yeasts and fungi can be grown in a continuous culture system. The nutrient solution is introduced into the culture vessel at a constant flow rate and growth medium withdrawn at the same rate of flow to maintain a constant volume. This method has the advantage that it eliminates the stages of building up the inoculum and the output of product is greater from the same size of vessel. In order to maintain the system in equilibrium more rigorous control of the growth conditions and more elaborate precautions against infection are necessary than those required for the batch process. It may also be necessary to standardise the composition of the growth medium and where waste products are used as the substrate this can be a problem. Waste liquor from the paper making process used in Finland does have a sufficiently constant composition for the Pekilo process to be operated continuously.

Surface Culture

In addition to production in a liquid medium by a similar process to that used for yeasts fungal mycelium can also be grown on solid substrates. A substrate such as cereal straw for example is moistened with a solution containing additional nutrients such as ammonium salts to provide the nitrogen for protein synthesis. The moistened substrate is sterilised and loosely packed into trays. After inoculation with the fungal culture the trays are incubated in a temperature controlled environment protected from infecting micro-organisms. Air is circulated through the substrate to provide a supply of oxygen.

The growth conditions are much less favourable and the incubation periods quoted in the literature are much greater than those required for liquid culture. Because of the slower rate of growth and the difficulty of supplying sufficient nitrogen compounds as nutrients in the small volume of liquid the protein content of the product is only about half that of mycelium produced in liquid culture.[13] On a large scale the handling of large quantities of inoculated substrate is also a problem and the process is more labour intensive. However, it does have the advantage that it requires simpler equipment and could be operated with a less skilled labour force than the liquid culture process. It would probably be more appropriately applied to small scale production units established near the site of the raw material supply. Although the method has been frequently suggested in the literature and laboratory studies have been reported it does appear that a satisfactory process has not been developed to date. It is probable, however, that the method could be in operation within the next ten to fifteen years.

Raw Material Requirements

The chemical elements and their relative quantities are similar for the growth of all micro-organisms including the fungi (Table 1). By far the greatest requirement is for carbon in the form of organic compounds which are needed to supply the biological energy for synthesis and to provide the chemical units for conversion into the components of the microbial biomass. For cell mass with a high protein content nitrogen is required in about one-tenth the amount of the carbon supplied and for all fungal species investigated can be provided from readily available sources of nitrogen such as ammonium salts or urea. The remaining chemical elements are needed in much smaller quantities and are nearly always present in wastes from plant or animal sources, although some

Table 1. Chemical elements required for the synthesis of microbial biomass

Chemical Element	Quantity
C	8.0
N	1.7
S	0.06
P	0.25
Mg	0.04
K	0.15
Ca, Zn, Fe, Mn	< 0.03

Reference 12

supplementation may be needed to provide the optimum amounts for maximum growth.

The provision of adequate quantities of the carbon source is therefore the main factor in determining whether fungal mycelium could make a significant contribution to food or animal feed supplies in the future. Large quantities of materials which contain carbon compounds are discarded from agricultural production or from subsequent food processing. Some examples of the annual production of these wastes are given in Table 2. A considerable proportion consist of ligno cellulosic material which is resistant to microbial digestion. Wood waste, cereal straws and sugar cane bagasse are examples.

Some of the fungi particularly wood rotting species are capable of digesting ligno cellulose and in laboratory trials have been grown in liquid culture in a suspension of these types of materials. However, the rate of growth and yield of product reported to date are not sufficient to justify the development of a practical process. Further research may improve the method. Chemical or mechanical treatments of fibrous substrates can make them more susceptible to fungal digestion (Table 3). The most extensive chemical treatment consists of an acid hydrolysis of the carbohydrate polymers of the fibrous wastes to sugars. Less extensive treatments are however sufficient to enable some substrates to be used for the fungal process. Fibrous ligno cellulosic wastes do vary in their resistance to microbial digestion. Cereal husks and the residual heads of sunflower after removal of the seed are examples which are more susceptible to fungal digestion than wood. Sunflower heads have been converted by fungal growth from an unsuitable product for non-ruminant feed containing 4.5% protein and 24% fibre to a protein concentrate containing 34% protein and 11.7% fibre.[13] Total world production of sunflower seed is estimated at 12.3 x 10^6 tons and this will result in approximately twice the quantity of waste sunflower heads.

Solid non-fibrous waste materials which do not contain appreciable amounts of ligno cellulose are much more readily digested by fungi. The residual citrus pulp remaining after juice extraction and the bananas discarded from the harvested crop are two examples of wastes which in laboratory trials have been tested for fungal protein production.[13] Approximately 20% of the banana crop is estimated to be discarded.

From food processing and the production of other biological products such as starch and cellulose pulp large volumes of liquid wastes are produced. Due to the high concentration of dissolved or finely suspended organic matter in these wastes they have a high pollution strength as measured by the Biological Oxygen Demand (BOD) or the Chemical Oxygen Demand (COD) the removal of which is becoming essential in many countries due to more stringent environmental regulations. The "Activated Sludge" process is the established method of reducing the BOD of liquid wastes and yields a product which

Table 2. Annual production of some agricultural and processing wastes

Source	Annual World Output ($x 10^{-3}$, tons) Agricultural by-products	Annual World Output ($x 10^{-3}$, tons) Processing by-products
Wheat straw	286 580	
Wheat bran		57 320
Maize stover	120 040	
Maize cobs		30 070
Barley straw	52 920	
Sugar cane bagasse		83 000
Molasses		9 300
	Annual USA Output (million gallons)	
Sulphite liquor		12 000
Whey		1530

Reference 8

Table 3. Summary of the action of chemical reagents on lignocellulosic wastes.

Type of treatment	Main effects
Heat with dilute acid at temperature below 100°C	Sterilizes Separates and partially hydrolyzes hemicelluloses Hydrolyzes some cellulose to glucose Converts cellulose to hydrocellulose
Steep in alkali solution	Dissolves hemicellulose, hydrocellulose and lignin Strong solutions disrupt crystalline cellulose structure
Steep in urea solution	Breaks H-bonds disrupting cellulose structure
Oxidation in air:	
In acid conditions	Degradation of cellulose; hydrocellulose more readily degraded Products soluble in alkali
In alkali conditions	Cellulose, hemicellulose and lignine oxidized; hydrocellulose more readily degraded than cellulose Products soluble in alkali

Reference 12.

is unsuitable as livestock feed and has a low commercial value. During the fungal process the BOD is almost completely removed at the same time as a high quality protein concentrate in the form of mycelium is produced. Supplementation of most wastes with ammonium compounds is however required to give maximum yields of protein. Laboratory and pilot plant studies of this dual application of the fungal process have been applied to olive and palm oil waste liquors[13], citrus molasses,[13] rum and alcohol distillation residues, coffee waste water,[5] effluents from the manufacture of maize, wheat and potato starches[1] and deproteinised leaf liquors[11]. Some examples are given in Table 4.

SAFETY ASPECTS AND NUTRITIONAL QUALITY OF FUNGAL PRODUCTS

The mycelium of fungi has been consumed as a food for centuries in some parts of the world particularly in S.E. Asia. In Japan for example, nearly one million tons of Miso produced by the growth of <u>Aspergillus</u> <u>Oryzae</u> on rice are consumed each year. Tempeh is also a popular fungal food product in S.E. Asia. The safety and acceptability of some fungal products are therefore well established. Nevertheless, an extensive programme of testing is necessary to establish the safety of any new product. The mycelium of <u>Fusarium</u> <u>semitectum</u> has been fed as the sole source of protein over a 2 year period to 3 successive generations of rats without any adverse symptoms and feeding trials with pigs and poultry have shown no ill effects.[10] Feeding trials which have not shown any evidence of toxic effects have also been made with the mycelium of several other fungal species. The product from the Pekilo process has been extensively tested and is accepted in Finland as a safe feed for livestock.[6] At the British Association meeting in September of this year (1980) a U.K. company announced that their product, termed Mycoprotein, produced by fungal growth on waste starch had undergone sufficient testing to meet the requirements of the UK Food Regulations and the product is to be test marketed as a food for human consumption.

Chemical analysis and nutritional feeding tests with several fungal species have shown that the proteins contain all the essential amino acids required in the diet of human beings or farm livestock and the nutritional value of the proteins is at least equivalent to that of soya.[7] It is probable that fungal mycelium is also a significant source of vitamins although only a few analyses are reported in the literature. The Pekilo product contains quantities of thiamine riboflavin, niacin and biotin comparable to those in Food Yeast which is considered to be a good source of these vitamins.[6]

Table 4. Fungal protein production and simultaneous reduction of the chemical oxygen demand of effluents.

Effluent	Cod reduction %	Protein yields g/l
Lucerne deproteinized juice	68	12.0
Palm waste	90	11.0
Soya whey	75	7.0

RESOURCE REQUIREMENTS AND ECONOMICS OF FUNGAL PROCESSES

Whatever the benefits to the environment and to the food supply of the adoption of a process for the fungal conversion of wastes to protein feeds it is still important to make an assessment of the resources required to operate the process. Monetary cost in relation to the commercial value of the product is the main method in Western economies of making such an assessment. However without detailed data from processes in operation it is difficult to make an accurate assessment of cost. An indication of the cost of the Pekilo process can be estimated from data presented by Romantschuk.[6] The investment cost of a plant producing 10,000 tons of protein per year from a 100 m^3/hour effluent containing carbohydrate is given as 8 million US Dollars at 1975 prices. The protein content of the product is 55 - 60% on a dry weight basis. Assuming a period of 10 years for the life of the plant and a protein content of 57.5% the investment costs are therefore 80 Dollars per ton of protein or 46 Dollars per ton of product. Soya meal is the commodity with which the commercial value can be compared. In 1975 the approximate value of soya meal containing 40% protein was 180 Dollars per ton. The value of the protein was therefore 450 Dollars per ton. There is, therefore, a margin of 370 Dollars to allow for the costs of producing and marketing one ton of mycelial protein. The Pekilo process also has the economic advantage that the BOD of the sulphite waste liquor which is used as the substrate will be substantially reduced during production of the mycelium. The cost of reducing the BOD by alternative methods can therefore be offset against the Pekilo process costs. The process will be less labour intensive than agriculture and as estimated below, will have an energy input of a similar order of magnitude to the agricultural production of protein. If all of these factors are taken into account it is feasible that fungal protein could be produced at a cost which would be competitive with that of soya meal.

For processes which could operate with waste products which occur in substantial amounts at one site and therefore do not involve collection and transport costs, the economic advantage of using wastes as substrates can be assessed from a comparison with the ICI process for the production of bacterial protein from methanol. This process is now in commercial operation in the UK and will have similar capital and operating costs to those of the fungal process. In an estimate made of the operating costs of the bacterial process the cost of the methanol substrate is given as 41% of the total process costs.[2]

ENERGY CONSUMPTION OF FUNGAL PROCESSES

The energy input to processes has become an important assessment to make since both energy supply difficulties and price increases are liable to occur in the future. From data given by Romantschuk[6] an estimate of the energy requirements of the Pekilo process is given in Table 5. The E values referred to in the Table give an indication of the relative energy inputs involved in different systems of production. The E value of 2 for the production of fungal mycelium compares with that of 0.5 for the average value for the production of cereal crops in England and Wales during 1970-71.[3] Due to the lower protein content of cereals the comparison is more favourable when protein production is taken as the criterion. The differences between the values given in Table 6 for the energy inputs to processes for producing yeast, fungal, cereal or soya proteins are not considered to be significant. An important conclusion, however, which can be drawn is that the production of fungal protein is not liable to be more energy intensive than methods which are currently in use for the agricultural production of protein.

SUMMARY AND CONCLUSIONS

The technology is available for establishing processes for the production of fungal mycelial products containing 40 - 60% protein of a nutritional quality at least equivalent to that of soya. Several products have been shown to be safe to use as livestock feed and one product has undergone sufficient tests to be accepted for use as a food for human consumption.

Large quantities of waste materials occur from agriculture, forestry and the processing of biological materials. Further research is required to develop the technology for using the more fibrous of these waste products. However, considerable quantities of wastes occur which are suitable to use in processes for fungal protein production.

An economic assessment of the fungal process suggests that the product could be competitve with soybean meal. The energy input for the production of fungal protein is estimated to be of the same order of magnitude as that for the production of feed grain proteins and this indicates that future increases in the price of energy should not increase the relative price of the fungal product. The production of fungal protein from effluents which cause pollution problems has the advantage that the effluent is purified during the process. The saving in the cost of effluent treatment can therefore be offset against the cost of the fungal process. It is this application which is the most likely to be applied extensively in the next 10 to 15 years and a production unit which applies this principle is currently being operated in Finland.

Table 5. Energy requirements of the Pekilo process for the production of fungal protein

	Input per ton of product[2]	Energy input equivalents	
		MJ/ton	MJ/kg
Electricity	1300 - 1600 kwh assume 1450 kwh	5220	
Steam	5.5 Gcal	23028	
Cooling water	600 m^3 (Energy factor 9.1 MJ/m^3)*	5460	
	Total	33708	33.7

Energy value of product

Protein	57.5%	$\frac{575 \times 17}{1000}$	=	9.8
Remainder of product calculated as carbohydrate	42.5%	$\frac{42.5 \times 16}{1000}$	=	6.8
Total				16.6

Energy input

			MJ/kg protein
Input per kg. of mycelium containing 57.5% protein	33.7 MJ		
∴ input to produce 1 kg protein	$\frac{33.7}{57.5} \times 100$	=	58.6
Average energy input for cereal crops UK 1970 **		=	64

E value

$$\text{E value} = \frac{\text{Energy input}}{\text{Energy value of product}} = \frac{33.7}{16.6} = 2$$

E value for cereal crops UK 1970** = 0.5

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* Reference 4

** Reference 3

Table 6. Energy inputs for the production of protein

Process for protein production	Energy Input MJ/kg protein
Yeast from carbohydrates *	60
Fungal from carbohydrates **	59
Cereal grains **	64
Soya *	79

* Reference 12. ** See Table 5.

Although it is feasible that quantities of fungal mycelium may be produced in the immediate future which will be marketed for human consumption the most extensive application of the process will probably be for the production of protein concentrates for use as livestock feed.

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NEW ASPECTS OF MICROBIAL PROTEIN PRODUCTION USING VEGETABLE WASTES FROM THE FOOD INDUSTRY

Givi Mikeladze

At present the world is faced with an acute problem: that of supplying its population with adequate nourishing food products, especially those containing protein.

Under the existing conditions of "demographic explosion" and inadequate energy resources, factors which cause a prolongation of the present protein deficiency situation, traditional methods of obtaining feed or food proteins are no longer effective. It has therefore become necessary to improve these traditional methods and also to look for new ways of obtaining protein. There are many contradictory opinions on the rational use of the various protein-containing raw materials.

One of the most promising ways of eliminating protein deficiency is microbial protein production: microorganisms have a short development cycle and they surpass animals and plants a thousandfold in productivity. Moreover, microorganisms consume a variety of substrates during their lifespan.

Nowadays, yeast protein production from the wastes of the oil-processing industry is also possible. But oil and gas resources are limited and therefore research into new prospective substrates is being undertaken in order to find new sources of microbial protein. Scientists from many countries are of the opinion that the most promising raw materials for this purpose are hydrocarbons, mainly starch and cellulose which are constantly supplied by photosynthesis. The wastes from various industries for the recycling of vegetable raw materials, may provide new carbohydrate sources.

Various microorganisms such as microscopic fungi, yeasts and bacteria are used in microbial protein production. Each of the suitable microorganisms has its peculiarities as far as the specifications of the raw material required, the effectiveness of protein synthesis, the accumulation of harmful compounds and the energy input required for industrial protein production are concerned. The same applies to the technological alternatives and choice of equipment for use in microbial protein production.

The choice of nontraditional raw materials depends upon a number of factors including the scientific and technical level of development, the technical potential of the country concerned, energy and raw material resources, how well the population's food needs are met, its national traditions, etc.

In order to select the most efficient methods of protein production by nontraditional means in each country or region, we must build detailed optimal models which take into consideration all the above mentioned factors. Such an approach requires serious consideration of how best to apply modern technology in view of the problem.

This article deals with a methodical approach and an optimal decision policy for obtaining microbial protein for food and feed from the wastes of the food industry (using agricultural and vegetable raw materials). The aim of this article is to aid IIASA in the solution of the problems raised at the Task Force Meeting so that national and regional models for protein production from nonconventional sources can be established.

The Wastes and By-Products of the Food Processing Industry

Wastes and by-products of the food processing industry are important as bio-resources for food and feed production especially when used as substrates for microbiological synthesis. One advantage is their comparative stability with respect to their chemical composition, quantity, to season, their accumulation, the fact that they are not harmful to food, and other factors, which allow us to consider them as a lasting source of raw materials for industrial protein production.

All sorts of vegetable raw materials should be taken into consideration when establishing optimal models for microbial protein production from vegetable wastes and by-products of the food industry. Each group should be divided according to purpose into sub-groups according to the nature of the waste. Such an approach enables us to discuss possible optimal technologies for the winning of microbial protein. In Figure 1, wastes from the production of food from agricultural raw materials are split up into groups. This classification makes it possible to build an optimal model for their application, but more detail is required.

The Classification and Selection of Wastes and By-Products for Protein Production

In order to have large-scale microbial protein production, raw materials which have as many of the necessary criteria as possible need to be processed. Wastes and by-products can be considered as harmless raw materials if they meet the above-mentioned factors. In our opinion it is firstly necessary to specify indexes to determine their ultimate usage and weight. The main criteria for the selection and classification of wastes are: 1) the availability of a certain raw material and its qualitative stability; 2) the chemical and physico-mechanical properties of the wastes; and 3) the economic and environmental aspects of waste and by-product usage. These factors are related to the ecology, technology, technical potential, technical level, energy requirements, etc.

The decisive factors to be considered in the ultimate usage of wastes are closely interrelated with each other as well as with some lesser factors. When considering wastes separately, it is important not to forget this interrelationship. In the classification of wastes, those which meet the above factors should be grouped separately and considered as basic. Wastes that partially meet requirements are usually known as additional raw materials. One should also bear in mind similar raw materials which could be substituted for the basic ones.

The Availability and Stability of Raw Materials

If we can substitute a given agricultural crop then we should decide whether to use the real crop or the substitute in the working out of a model. This is equally applicable to the usage of raw materials in the case when a waste is estimated according to raw material stability for management in production. The technology chosen for [illegible] application would presumeably not change over a period of 10-15 years in a given region. The technology used for the same raw material in different countries varies according to national peculiarities, technological level and other factors. This is why a differential approach is essential when drawing up a national model. These factors are determining in the definition of the stability of waste resources with constant properties.

Chemical Composition and Physico-Mechanical Properties

The chemical composition and physico-mechanical properties are important in the consideration of possible waste usage directly in feed or microbial protein production, and the selection of a technology depends on the data of these properties.

When speaking about the chemical composition of waste we mean the presence of chemical components which are digestible and of use to microorganisms, as well as the presence of toxic and anti-food components, and the correlation of digestible and indigestible substances by animals. This shows the harmlessness and effectiveness of the usage of waste for feed and indicates their possible usage for microbial protein synthesis.

The wastes are divided into solid, fibrous, solid non-fibrous and liquid according to their physico-mechanical properties. Subsequently an appropriate technology is selected and they are recycled.

When dealing with protein-containing wastes, we must first of all deal with the question of obtaining protein for food. Application as protein feed is second in importance.

Wastes from food and feed protein production serve mainly as raw material for the synthesis of microbial protein.

Economic and Environmental Aspects

Economic aspects become important when finally deciding which wastes or by-products are to be used as raw materials for protein production. Similarly, when we consider these wastes as probable food for humans and animals in the ecology system as a whole, economic aspects are significant.

There are two sides to the problem which must be studied: on the one hand, we must have a clear picture of the current usage of the given waste, i.e. what products are manufactured from it and what the profits are. In the case of waste usage, we should clarify what role it plays in the overall ecology system, especially in connection with effects on the environment.

On the other hand, we must have access to complete data on available technology for microbial protein production in the different directions suggested. Technological production with minimum waste should be given primary concern in order to reduce environmental pollution. Knowledge of microbial protein application and the role of the products obtained in human and animal feeding is also an asset.

It therefore seems inappropriate to consider wastes and by-products as potential raw materials for the food industry by their properties alone (as we intend to use raw materials for the synthesis of microbial protein). It becomes more and more apparent that these questions are greatly interconnected with the environment itself, the general ecology system, energy resources and a number of other aspects of human life.

In addition to the above-mentioned recommendations, the selection and classification of wastes and by-products from the processing of vegetable raw materials for the production of microbial protein can only be considered valid if the raw materials and technology used for microbial protein synthesis are properly understood. Obviously, all possible methods of obtaining microbial protein must be thoroughly studied in order to enable the building of a model for its production.

Criteria for the Selection of an Optimal Technology for Microbial Protein Production

All methods of microbial protein production are based on the cultivation of certain microorganisms on corresponding substrates.

Dried substrates together with microorganisms are used in feed for animals. In order to enrich food products and feed, protein isolates obtained from biomass are added. Wastes left over from protein isolate extraction are applied in feed.

Microorganisms such as yeast, high forms of fungi, microscopic fungi, bacteria and anaerobic bacteria are used in microbial protein production. Each requires specific substrates for its cultivation, and special growing conditions, for it to also be able to synthesize organic compounds and enzymes, some of which may be harmful to the organism. Different methods of cultivation for the various microorganisms (submerged growth) are accordingly chosen, such as the mixed cultivation of different microorganisms (symbomethod) and others.

In the selection of production technologies preference has usually been given to methods which do not require the use of complicated equipment and a large energy input. It is possible to build an optimal model for microbial protein production from the wastes and by-products of vegetable raw materials if we apply the basic data which we have collected on decisive factors. Up-to-date data is most important when selecting the optimal variant. When considering the advantages and disadvantages of the given factors, matters become complicated because each factor cannot be considered independently of other factors.

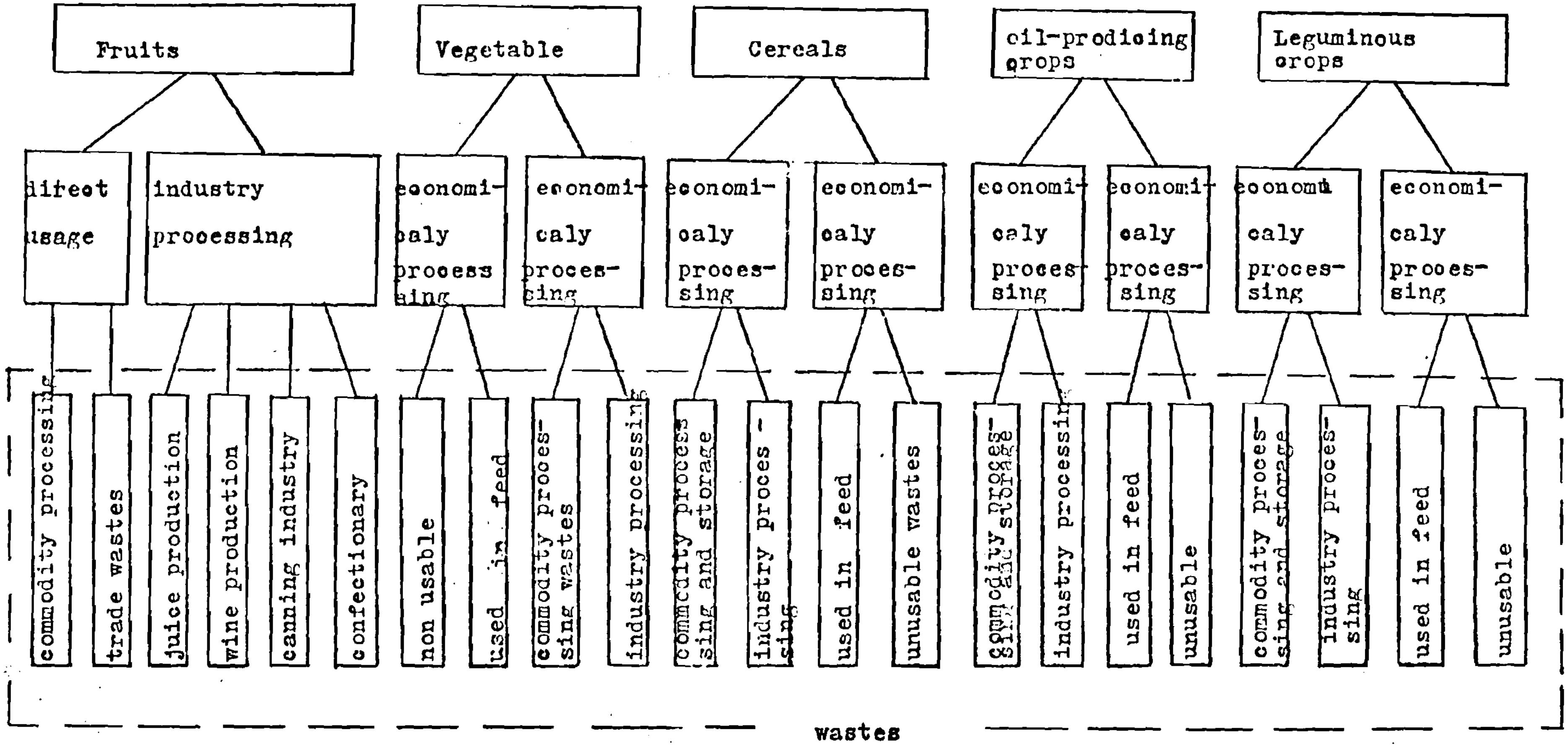

Figure 1. Vegetable Raw Materials.

PARAMETERS DESCRIBING THE NONAGRICULTURAL TECHNOLOGIES OF ANIMAL FEED PROTEIN SUPPLEMENT PRODUCTION

V.N. Iakimets*

The general purpose of Task 2 "Limits and Consequences of Food Production Technologies" is to examine the relationships between production technologies, resources and the environment over a long period. Initial investigations and modeling efforts indicated that the best way of developing this task was by means of a series of case studies at the national or regional level.

Animal feed production is one of the main aspects to be considered within the framework of Task 2. Animal products are an important part of human food. Furthermore, the amount of arable land used for the production of animal feeds exceeds that used for the production of food for direct human consumption. In the United States, for example, about 30 million hectares of land are used for the production of food for direct human consumption (13 million ha. for domestic consumption, 15 million ha for export commodities) at the same time that livestock can consume the feed from about 75 million ha. (65 million inside the USA and 10 million ha. for export) (Byerly, 1978). Therefore, it would seem important that an analysis of the limits and consequences of technological innovations in the animal feed production should be considered within the framework of Task 2.

Publications written in connection with the construction of a Task 2 model are for the most part devoted to descriptions of conventional agricultural technologies for animal feed production. However, nonagricultural technologies have recently become an important element of this production since they provide the high-protein and vitamin supplements required by animals. The simulation of the effects of the development of these technologies with the solution of the general problem of human food production ought to be possible.

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*A more extensive version of this paper is also available within the Food and Agriculture Program.

The structure and lists of parameters for the description of these technologies in the Task 2 model are suggested in this paper.

First of all let us consider a general description of animal feed production. There are three main branches of animal feed production at the regional level:

1. field feed production
2. pastures and meadows
3. industrial feed production

The general structure of these branches and their products is shown in Figure 1. In accordance with this structure animal feed production can be divided into two main types:

1. Agricultural technologies
2. Nonagricultural technologies

Field feed production and pastures and meadows are connected with the use of traditional agricultural technologies. Industrial feed production includes nonagricultural technologies for the production of different kinds of animal feed supplements, and industrial technologies for mixed feed production.

Field feed production now provides approximately 75% of animal feed such as concentrates, succulent feed, roughage, etc. Pastures and meadows provide approximately 25% of animal feed, such as green grass, hay, etc.

The structure of feed consumption in the Soviet Union is shown in Table 1. An analysis of this data shows that the basic amount of animal feed is provided by field feed production as well as by pastures and meadows. However, the efficiency of the utilization of these feeds depends to a significant extent on the protein availability. The fact is that many agricultural plants have a low content of digestible protein and an unbalanced content of essential amino acids in this protein. The utilization of feeds with an unbalanced content of essential amino acids leads to an overexpenditure on feed, to the decrease of animal productivity and finally to the low production of livestock commodities for human nutrition. According to Polovenko, 1980, 75%-80% of protein availability in feed, and the insufficient level of feeding led to a decrease in livestock commodity production (1.8-2 million tons per annum recount in meat.) The efficiency of feed utilization can be improved if the industrial methods used in the production of protein supplements are further developed. Nonagricultural technologies can have the following positive consequences on feed production, namely:

-- a decrease in the amount of land required for forage production;
-- more effective utilization of conventional animal feed due to increased possibilities of balancing animal rations;
-- improved recycling of agricultural wastes and by-products and the more efficient utilization of nonagricultural wastes;
-- improved utilization of non-renewable resources;
-- the fact that feed production is not dependant on seasonal and climatic conditions.

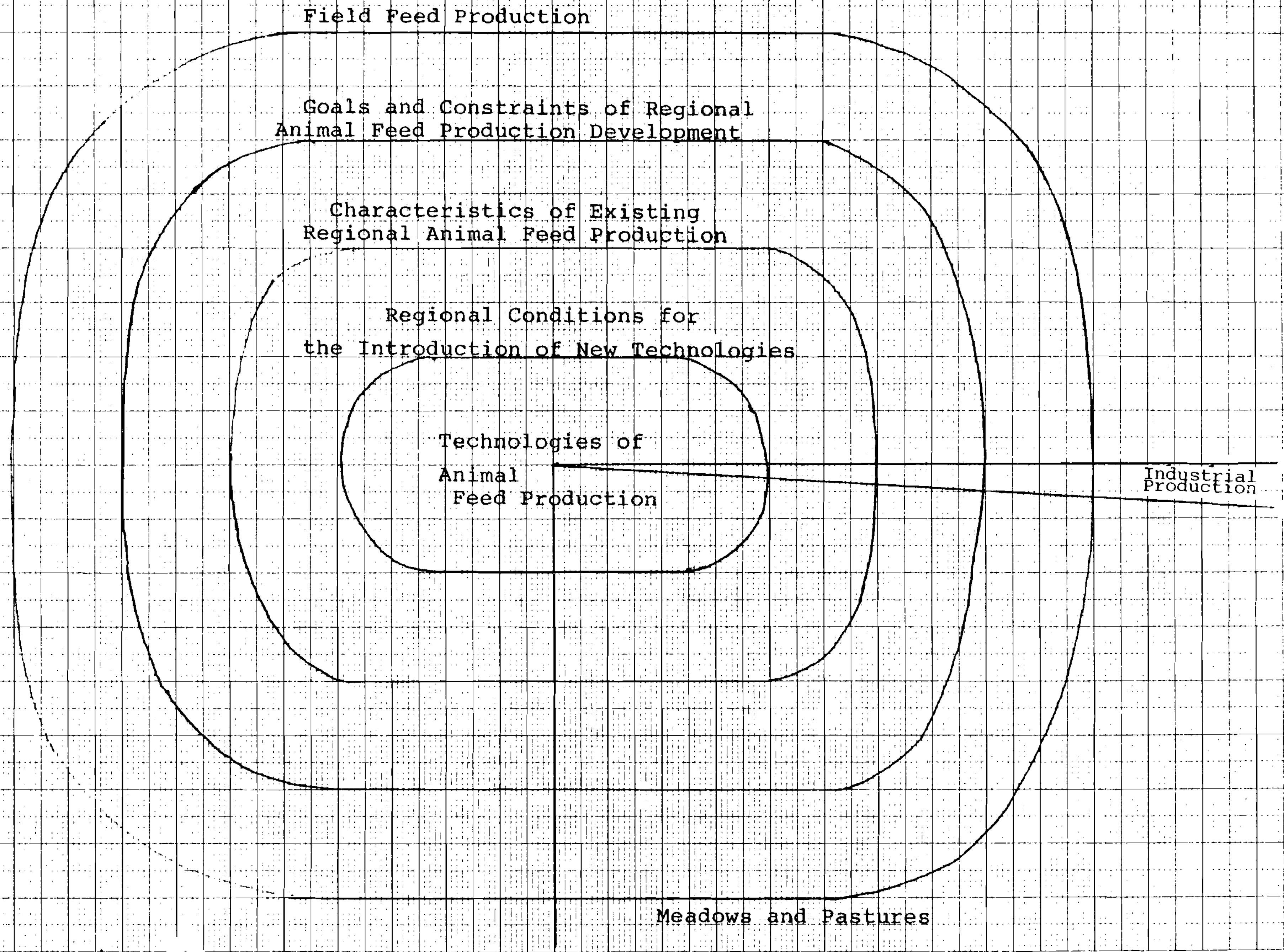

Figure 1. The General Structure of Parameters

Table 1. The Structure of Feed Consumption in the Soviet Union (millions tons)

TYPES OF FEED	YEAR			
	1965	1975	1977	1978
1. Concentrated	65.3	118.9	143.0	145.9
2. Succulent Fodder	416.6	501.6	600.1	610.8
Including Silage	166.7	171.1	205.4	200.8
3. Roughage Including Hay	164.0	237.6	235.1	240.8
4. Pastures and Meadows	373.4	386.7	380.0	379.6
5. Total Feed Consumption in Feed Units	278.	368.5	403.0	409.6

Source: Polovenko, 1980, p.37

Some nonagricultural technologies for the production of animal feed protein exist which are industrially developed. According to Milner et al, 1978, these are classified under the following four groups:

1. photosynthetic single-cell protein production (algae);
2. nonphotosynthetic single-cell protein production (yeasts, fungi, bacteria).
3. leaf protein production.
4. the chemical synthesis of nutrients such as proteins, amino acids, etc.

A detailed description of these technologies is beyond the scope of this paper and will not be attempted. Information can be found in a number of books, for example, Milner et al. 1978; Pirie, 1971; Pirie, 1975; Kotovo et al, 1979; Altschul, Wilcke, 1978; Tannenbaum and Wang, 1975. Variants of the technological cycle, raw materials and the nutritional value of the end product, the economic and toxicological aspects, status of development of the technology, and many other factors are analyzed in the above mentioned publications.

The general purpose of research efforts connected with the modeling of animal feed production in the region under study is to determine the preferred paths of technological change, while at the same time considering the environmental aspects, regional demands and conditions, the availability of different resources and raw materials, etc. This analysis must be conducted bearing in mind that dynamic changes in all these factors over a chosen time horizon might occur.

One important problem relating to the Task 2 model design is the determination and classification of parameters related to the nonagricultural technologies of animal feed production which would allow the implementation of adequate simulation of this kind of production in the region under study over the given time horizon.

Three key factors (characteristics) have to be taken into account in the description and evaluation of industrial technologies for regional animal feed production:

1. The general direction of Task 2 - an analysis of the limits and consequences of technological change with regard to the environment and resources.
2. The characteristics of the region under study and animal feed production in the region.
3. The goals of regional development in general, and the aims of the regional development of animal feed production.

The first mentioned factor is the main one. It determines the structure of proper technological parameters and requires the introduction of all factors which allow one to take into account the dynamic interdependencies among the most important components of Task 2, namely: technology - resources - and the environment. However, it will be impossible to implement an efficient applied systems analysis of all the limits and consequences of technological change without taking into account regional conditions and the goals of regional development. Therefore the second and third mentioned factors are important additional conditions which have to be considered when determining the structure of the model parameters.

Taking into account all the above mentioned factors, the following four groups of parameters can be determined:

1. technological parameters;
2. the characteristics of regional conditions;
3. parameters of existing regional animal feed production;
4. parameters of the development of the region.

Each of these groups of parameters reflects the economic, resource, environmental and physical aspects of each of the characteristics of the system under consideration (in our case, the system of animal feed production).

The main group of parameters is the technological one. We shall therefore firstly consider this group. One must differentiate between the two main ways of describing any nonagricultural technology:

1. The description of technological functions, stages and processes with a view to searching for paths of technology improvement.
2. The description of the technology and its intermediate and end products with a view to choosing a suitable technology which meets regional demands.

The first approach (internal description) is useful for engineers and technologists who are interested in the development and optimization of the technology under consideration.

The second approach (external description) is helpful for those interested in the application of a certain technology and its intermediate and end products, and those who wish to know the input of a technology (energy, raw materials, labor, etc.) and its effects on the environment.

Schematically these ways of description can be represented as in Figures 2 and 3.

The first way requires an analysis of the detailed characteristics of the technology under consideration, including the parameters of processes, the stages of a technological cycle, control parameters, etc. It will be hardly appropriate to use this kind of description within the scope of the Task 2 model. In the first place the goal of the problem under study is more extensive than the goal of the technology optimization. Secondly, the introduction of detailed characterisitics of the technology under consideration in the model data will lead to even greater complications. Therefore, the external description of a technology is preferable as far as the solution of our problem is concerned. It should be noted, however, that some elements of the internal description can also be used.

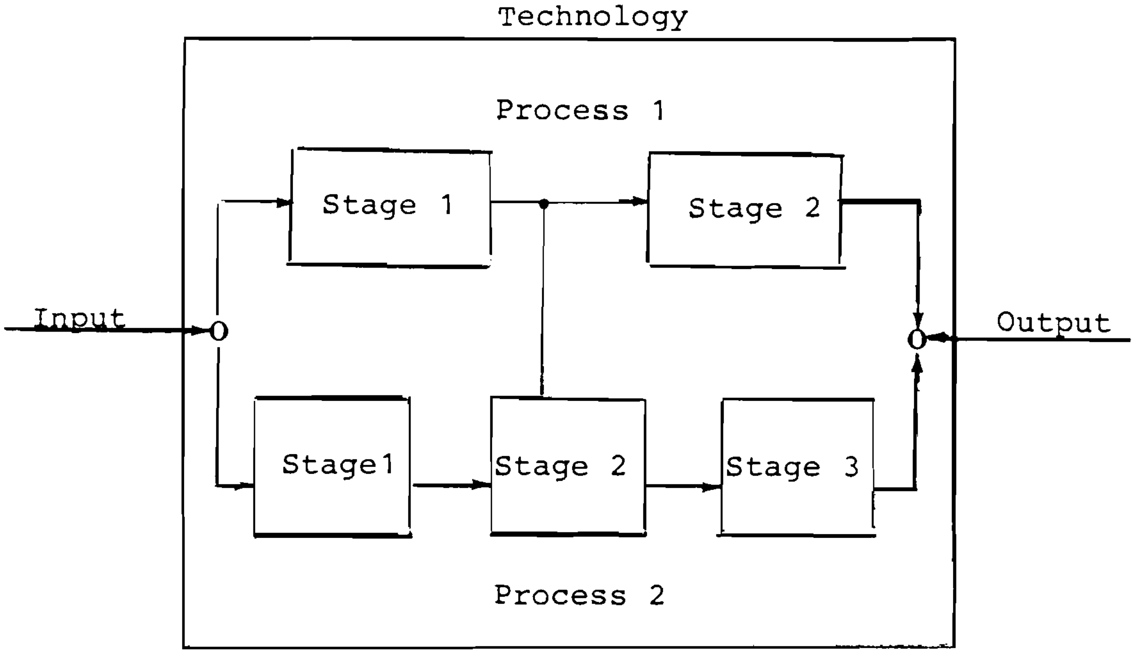

Figure 2: The Internal Description of a Technology

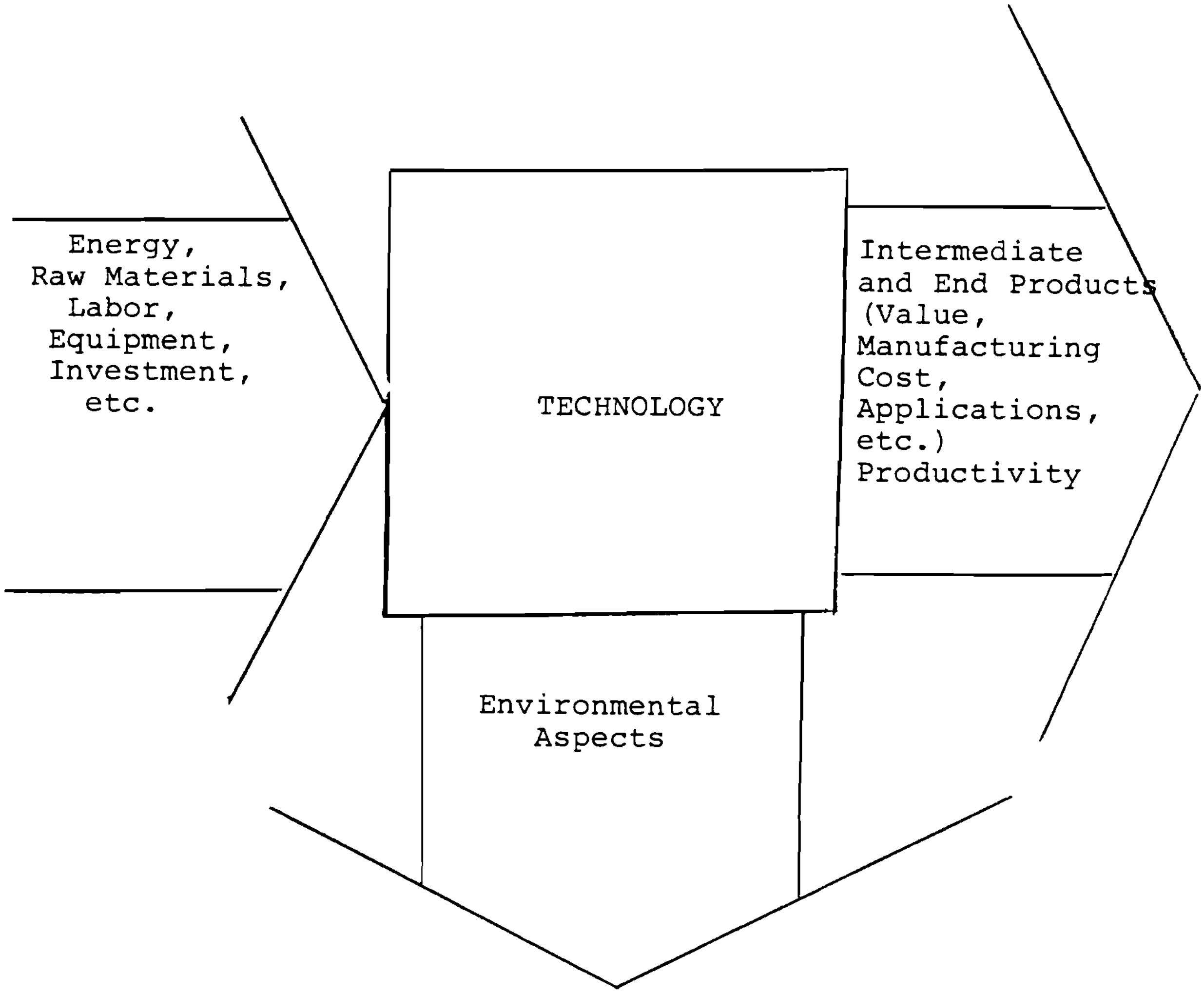

Figure 3: The External Description of a Technology

On the basis of the analysis of different variants of technologies (Iakimets, 1980) and the above mentioned aspects, we can determine the following technological parameters which can be used in the modeling process:

I Inputs

1. The demand for raw materials for the production of one unit of the end product;
2. the demand for energy for the production of one unit of the end product;
3 the demand for labor for the production of one unit of the end product;
4. the demand for capital investment for the production of one unit of the end product;
5. the demand for water for the production of one unit of the end product;
6. the demand for equipment for the production of one unit of the end product.
7. The average productivity rate of the producent.
8. The average time for the construction of a technological plant.
9. The average duration of the production cycle.

II. Output

1. The average output of the end product in one unit of time.
2. The content of animal-feed component in one unit of the end product. (protein, amino acids, vitamins, trace elements)
3. The average output of positive by-products in one unit of time.
4. The average output of negative by-products in one unit of time.
5. The content of toxicological components per one unit of the end product.
6. The manufacturing cost of one unit of the end product.
7. The average output of the end product from one unit of raw material.

However, the parameters given in the first group are not sufficient to evaluate the limits and consequences of technologies in the long run in the region under study.

We really also need a dynamic analysis of regional demands or technological products, and the interactions of various technologies must be taken into account, and the regional possibilities for the development of the technology under consideration must be known, and the effects that the technology can have on the environment of the region. Moreover, we need to know the strategic plans for the development of regional production since the region under study is included in a more complex socio-economical system and it is economically connected to other regions.

The characteristics of regional conditions include the following parameters:

1. The maximum (minimum) amount of raw materials available in the region.
2. The maximum (minimum) amount of energy available in the region for the production of technological end products per unit of time.
3. The maximum (minimum) amount of labor available in the region for the production of a technological end product per unit of time.
4. The total capital investment available in the region for the use of nonagricultural technologies in feed production.
5. The total amount of water available in the region for the use of nonagricultural production.

The third group of parameters includes those which characterize the existing regional animal feed production.

1. The total area of land for regional field feed production.
2. The total area of regional pastures and meadows.
3. The average yield of forage crops.
4. The content of animal feed components in one unit of forage crop.
5. The content of animal feed component in one unit of forage from pastures and meadows.
6. The total amount of nonagricultural supplements available in the region.
7. The total volume of the regional mixed-feed production.
8. The capacity of the mixed-feed plants.
9. The number of mixed-feed plants.
10. The expenditure on feed units per head.
11. The price per unit of domestically produced feed.
12. The price per unit of externally purchased animal feed.
13. The price per unit of externally sold animal feed.

The last group includes the parameters, characterized goals and targets of the development of regional feed production:

1. The planned increment of the volume of animal commodity production.
2. The total amount of capital investment in the production of animal feed.
3. The planned increment of the volume of production of field feed.
4. The planned average gain in weight per head per annum.
5. The demand for animal feed components per head.
6. The levels (maximum and minimum) of consumption of feed in the region.
7. The planned volume of external purchases of feed (sales of feed) for animal.
8. The planned volume of external purchases of animal commodities (sale of animal commodities) for human consumption.

The initial variant of the general structure and the lists of parameters of nonagricultural technologies which can be used in the process of modeling the regional animal feed production will be determined in this paper. It should be noted that the list of parameters for each group will need to be more precise for each case study. The parameters described in this paper are suggested for the determination of lists of coefficients, control variables and constraints in the linear programming model, which is now being developed within the framework of Task 2.

It should be noted also that a number of qualitative parameters such as types of raw materials, types of energy required, feed components, types of technology, scale of technological plants, types of animals and others have to be taken into consideration. Those parameters are usually used as indices in the linear programming models.

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ASIAN APPROACHES TO THE PRODUCTION OF FOOD AND FEED FROM LIGNOCELLULOSIC AND FOOD PROCESSING WASTES

Keith H. Steinkraus

INTRODUCTION

The Green Revolution has resulted in a vast increase in world-wide productivity of rice and wheat. This has enabled mankind to continue to feed a burgeoning population, but it has not relieved the millions of hungry and malnourished in the developing world. The basic problem remains essentially one of economics. The food is generally available if the people have the money to buy it; and farmers the world over will produce more food if they can sell it for a profit. However, we have no way at present of improving the economic status of millions of malnourished people, unless the world should unexpectedly decide to use the 350 billion dollars spent each year on armaments (100 billion of which is spent by Third World countries) on improving the economic and nutritional status of the poor (Jones 1978).

Thus, we must look for the alternate ways of increasing the food supply or modifying the distribution of cereals and legumes between animals and man.

Increased Utilization of Cereals for Feeding Humans

On a world-wide basis, about 400 pounds of cereal grains are available per person per year (Brown and Eckholm 1974) In the developing world, cereal grains are generally consumed by humans. In the United States, about 2000 pounds of cereal grains are available per person per year. Of this, about 200 pounds are consumed directly in foods such as bread, cereals, etc. The rest is used for animal feeds and alcoholic beverage production. If Americans alone became vegetarians, releasing the grain now fed to animals, we could feed approximately another 800 million people a basic cereal diet.

Development of Protein-Rich Vegetarian Meat Substitutes in the Western World -- Spun Soy Protein Analogues

Americans and other Westerners are not likely to become vegetarian _en masse_ at this point, but there have been some interesting trends in the Western world that will eventually favor our becoming more vegetarian. These have included the development of meat analogues, principally from soybean and wheat gluten (Smith and Circle 1972). Meat analogue is an industrial term for meat substitutes or synthetic meats made principally from plant proteins. The basic technique is to extract soybean protein and concentrate it to above 90% purity. The protein is then extruded through platinum dies and chemical baths to form very fine filaments similar to hair, which are then combined to form a fibrous meat-like texture. Meat flavors and fats are added. Synthetic bacon bits have been on the market for some time. Synthetic hamburger used widely in chili and other meat dishes is also on the market, and synthetic roast beef, ham, chicken, etc., have been developed.

Extruded Soy Nuggets

Even the large meat companies have developed meat analogues. Swift and Co. (Chicago, Illinois) has evolved a process whereby soybean, usually in the form of grits or soy protein concentrate, is tempered with water, mixed with desirable flavors, and processed through a machine (Wenger Extruder, for example) in which the thick dough is exposed to high pressure and temperature. As the material emerges from the extruder, it develops a puffed structure, or emerges as a chewy, meat-like nugget.

Mold Mycelium-Based Meat Analogues

The Miller, Rank, Hovis MacDougall Research Group in England developed an alternative method of producing meat analogues. In their process, they grow an edible mold (_Fusarium_ sp.) on low-cost starchy substrates, adding inorganic nitrogen (for synthesis of protein) and minerals to produce a type of single-cell protein (SCP). The mold mycelium, which provides the fibrous meat-like texture, is grown in tanks, recovered by filtration, and meat flavors and fats are added (Spicer 1971 (a), 1971 (b)). The process is particularly adapted to production of synthetic chicken breast meat. It has been lincensed by a large American company, and eventually the mold mycelium meat analogues will likely be on the American market. They are already being market-tested in Europe.

These mold mycelium-based meat analogues are produced by highly sophisticated technology. They are entirely beyond the economic means of the poor in the developing world at present as are also, of course, all canned, frozen and most dehydrated foods that are so important in the developed world.

All of these developments have taken place in the Western world where meat consumption is a large and important part of the diet. They demonstrate ways of converting legumes to forms acceptable to meat-eating consumers. Wider use of lower-cost meat analogues may reduce the need for real meats.

SCP Production on Hydrocarbons

SCP production on inedible substrates such as hydrocarbons is one of the great developments in modern applied microbiology (Shacklady 1970). Single-cell protein consists of cells of bacteria, yeasts, mold, or algae containing, respectively, up to 80%, 50%, 40% protein on a dry weight basis. SCP production requires no arable land; it can be produced in the desert. While grasses such as elephant grass and alfalfa double their cell mass within 2 to 3 weeks, bacteria and yeasts double their cell mass within 2 to 4 hours. Thus, 1,000 kg of yeast doubling its cell mass in 2 hours can produce 12,000 kg of new cells containing 6,000 kg of protein in a 24-hour period. The selected microorganisms use hydrocarbons as a source of energy for growth, and inorganic nitrogen for synthesis of protein. Their remaining nutrient requirements are minerals and a sufficient supply of oxygen (Lipinsky and Litchfield 1970).

This "microbial farming" was so promising that it was estimated that by the 1980's, 3% of the total protein produced in the world would be in the form of SCP (Wells 1975). It was assumed that hydrocarbon grown SCP would be used primarily as animal feed, thus releasing vast quantities of cereal grains and legumes, for example soybean, for use in feeding humans. Unfortunately, the cost of petroleum unexpectedly rose so high that production of SCP on hydrocarbons can no longer compete with the cost of producing soybeans or fishmeal.

SCP Production on Ligno-Cellulose

Because of the limited supply of petroleum for energy and its consequent cost, it is unlikely that it can serve as a substrate for economical SCP production in the future. However, production of SCP on ligno-cellulose, the world's largest reserve supply of renewable carbohydrate, could become a practical alternative.

Ruminant Production of Protein

Cellulose cannot be digested by man, but, as a major component of fiber, it does play a role in the motility of the gastrointestinal tract. At present, the major practical converters of cellulose to useful products such as milk and meat are the ruminants - sheep, goats, and cattle. They have microorganisms in their rumens that can hydrolyze cellulose to glucose which, in turn, is used by the microorganisms for energy to synthesize proteins from inorganic nitrogen that can be supplied in forms such as urea. Minerals supply the other growth requirements for these microorganisms. The animal subsequently digests the microorganisms and synthesizes milk and meat proteins, which serve as major foods in the western world. Thus, the ruminants themselves are efficient SCP fermenters.

Hydrolysis of cellulose outside the ruminant is, at present, too slow to be a practical method of producing SCP. However, many laboratories are working on the problem, and it is likely that cellulose hydrolysis may become rapid enough to permit cellulose to be utilized as a major energy source for the production of SCP in the future.

Processes have already been developed to raise the protein content of straw to as high as 30% by growing a cellulolytic mold on it. This improves the straw as an animal feed (el Rawi and Steinkraus 1976).

Mushroom Production on Ligno-Cellulose

It is possible, also to use cellulose or ligno-cellulosic wastes such as waste paper, cotton waste, straw, wheat, or rice bran and go directly to a food. This idea has already been developed to a high degree in Asia in the production of mushrooms such as *Volvariella valvacea*, the padi mushroom, and *Pleurotus ostreatus*, the oyster mushroom, on cellulosic and ligno-cellulosic wastes (Chang 1972 and Edgar et al. 1976). Mushrooms contain 2 to 5% protein on a fresh weight basis, and from 30 to 47% on a dry weight basis (Kurtzman 1975).

As much as 1.25 kg of fresh mushrooms can be produced on 1 kg of straw. In Hong Kong there is an estimated 30,000 tons of cotton waste per year. This could serve as a substrate for production of approximately an equal weight of fresh mushrooms.

The padi mushroom is grown by many farmers in Asia using rice straw as a substrate. Thus, the Asians have demonstrated to the world a practical way to transform ligno-cellulosic wastes directly into highly acceptable food for man. They are literally growing a type of microbial protein (SCP) directly on cellulosic waste as a nutritious, delicious food.

The padi and oyster mushrooms can be grown under rather simple conditions. Paper or cotton substrates are shredded. Straw can be trimmed, coarse ground, or used directly. Five percent wheat or rice bran and 5% $CaCO_3$ are added, along with sufficient water to raise the moisture content to about 60%. This requires that approximately 1500 ml. water be added per kg of ligno-cellulosic waste. The substrate should then be steamed for 30 minutes. Alternatively, the substrate can be composted in heaps where microbial activity results in the temperature rising to about 55°C.

The substrate is then cooled and inoculated with mushroom spawn. The spawn is the desired mushroom species grown on soaked, sterilized, wheat or corn kernels or on rice straw. Approximately 160 grams of spawn are added to each kg of starting (dry weight) substrate. Within a few weeks, under tropical temperatures and humidities, several flushes of fresh mushrooms are produced (Steinkraus and Cullen 1978).

The developing countries in Asia have expanded significantly their production and use of mushrooms in the diet. Taiwan is producing canned mushrooms for export. In 1977, Americans consumed 163,000 metric tons of mushrooms, 22% of which were imported (Hayes 1978).

Production of Indonesian Tempeh

It was Asia that taught the world how to convert vegetable protein to meat-like flavors in the form of soy sauce (shoyu) and Japanese miso-soybean paste (Yokotsuka 1960, Shibasaki and Hesseltine 1962). And it was the Asians, particularly the Indonesians, who have taught the world how to introduce meat-like textures into vegetable substrates. A prime example is Indonesian tempeh in which soybeans are soaked, dehulled, briefly cooked, cooled, inoculated with the mold Rhizopus oligosporus, wrapped in wilted banana or other large leaves, and fermented from 36 to 48 hours (Figures 1,2,3). During this time the white mold mycelium knits the soybean cotyledons into a tight cake that can be sliced thin and deep-fat fried or cut into chunks and used in soups (Iljas and Peng 1977; Steinkraus, et al. 1960; Steinkraus, et al. 1965; van Veen and Schaefer 1950; Hesseltine, et al. 1963 and Steinkraus, et al. 1961). Tempeh is a major meat substitute in Indonesia, and it is produced daily by small factories in the villages.

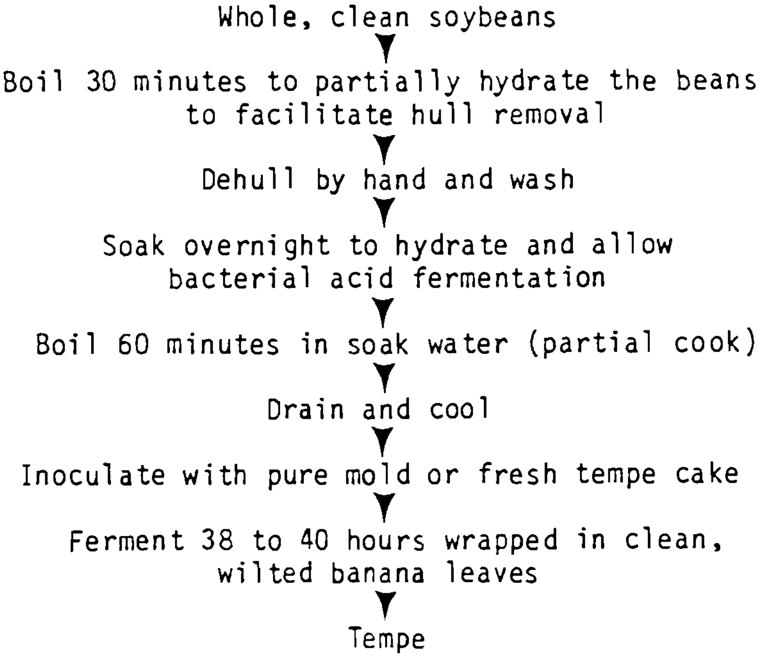
Containing nearly 47% protein, it is very nutritious and, in fact, kept thousands of Westerners alive in Japanese prisoner-of-war camps during World War II. The mold not only introduces textures, it also solubilizes the proteins and lipids, making them more digestible. It releases a peppery flavor that adds to the nutty flavor of the soybean substrate. The mold doubles the riboflavin content, increases the niacin level almost 7 times, decreases pantothenate slightly, and, unfortunately, decreases thiamine content; but surprisingly, vitamin B_{12} is found in nutritionally significant amounts (Steinkraus et al. 1961).

One of the problems of vegetarian diets is that vegetable foods generally do not contain significant amounts of vitamin B_{12}. It was found that a bacterium generally present with the mold is responsible for the vitamin B_{12} in tempeh (Liem et al. 1977). If the fermentation is carried out with pure mold, the tempeh does not contain B_{12}. If the bacterium is present, the tempeh will contain as much as 150 ng B_{12} activity per gram. Thus, this single food can provide both protein and vitamin B_{12} for vegetarians.

It has already been demonstrated that the tempeh process can be used to introduce texture into other substrates made, not only from soybeans, but from wheat and other cereals as well (Wang and Hesseltine 1966).

There is a similarity between the Miller, Rank, Hovis, MacDougall meat analogue process discussed above and tempeh production. In both cases, the texture is derived from mold mycelium, but the former process is sophisticated and relatively costly, while the latter is low-cost technology.

Tempeh has been adopted as a major protein source, replacing meat in the diet, by American vegetarians. The acceptance of this Indonesian food technology in the United States and Canada suggests that the technology could also be used in other countries where it is still unknown, thus improving the diversity and nutritive value of the diets of the poor.



Whole, clean soybeans

Boil 30 minutes to partially hydrate the beans to facilitate hull removal

Dehull by hand and wash

Soak overnight to hydrate and allow bacterial acid fermentation

Boil 60 minutes in soak water (partial cook)

Drain and cool

Inoculate with pure mold or fresh tempe cake

Ferment 38 to 40 hours wrapped in clean, wilted banana leaves

Tempe

Figure 1. FLOW SHEET: Indonesian household tempe process (18)

	Yield	Solids Loss (%)
Soybeans	1000 g dry beans	
↓ Hydrate overnight at room temperature in acidified soak water, Beans:Water, 1:3 (1% of 85% Lactic acid added)	2330 g (62% moisture)	4.9%
↓ Dehull in abrasive vegetable peeler	2020 g (64% moisture)	17.1%
↓ Remove hulls in running water		
↓ Boil cotyledons in acid soak water 90 minutes	1895 g (62.4% moisture)	1.6%
↓ Drain and cool to 37 C		
↓ Inoculate (1 g spores grown on wheat bran/kg cotyledons)		
↓ Incubate (stainless steel covered cake pans with 0.3 cm holes at 5 cm intervals) bean layers 3-5 cm thick (37C)		
↓ Tempe	1743 g (61.2% moisture)	3.9%
	Total	27.5%

Figure 2. FLOW SHEET: Laboratory tempe production (22)

Figure 3. FLOW SHEET: Small factory production of tempe (20)

	Yield	Solids Loss (%)
Size-grade raw dry soybeans (E-1)[1]	1000 g dry beans	
Heat 10 minutes at 93 C (E-3)		
Dehull in burr mill (E-2)		
Gravity-separate hulls (E-4)	80 g hulls	8% hulls
Soak cotyledons 2 hours at 25 C or 30 minutes at 100 C in dilute lactic acid (E-5)	920 g cotyledons	
Boil 90 minutes in soak water (E-5)	798 g dry solids	12.2% soak/cook
Drain and cool to 38 C		
Mix with mold inoculum (E-6)		
Spread on dryer trays (E-3)		
Cover with a sheet of waxed paper		
Incubate at 38 C (75-85% RH) for 18 hours		1.7%
Tempe		
Dehydrate (E-3)	781 g dry tempe (78.1% recovery of starting solids)	
Package in plastic bags		
		21.9% total solids loss

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[1] Parenthesis refers to equipment used (see Table 1).

Table 1. Equipment list for small factory production of tempe (20)

E-1	Ferrel, A. T., Co., Saginaw, Michigan. Model 297-AS Clipper pea size grader. Screens with oblong cross slots 4.8, 5.2, 5.6 and 6.0 by 19 mm (12/64, 13/64, 14/64, 15/64 by 3/4 inch) (capacity about 110 kg/hour).
E-2	Bauer Bros. Co., Springfield, Ohio. No. 148-2-E. Twenty-one cm (8 inch) laboratory mill.
E-3	Custom-built circulating hot-air cabinet dryer designed and built by Dept. of Food Science and Technology, New York State Agricultural Experiment Station, Geneva, New York, with controlled wet-bulb temperature, air velocity, and recirculation. The dryer accepts trays of 35 x 81 x 1.3 cm (14 x 32 x 1/2 inch). The trays are stainless steel with woven 3 mm (1/8 inch) mesh bottoms.
E-4	Oliver Mfg. Co., Rocky Ford, Colorado. Model 5A gravity separator (capacity 90 kg/hour).
E-5	Lee Metal Products Co., Inc., Philipsburg, Pa. Serial No. 559B. Seventy-six liter (20 gallon) stainless-steel steam kettle (capacity 28 kg hydrated beans).
E-6	Hobart Mfg. Co., Troy Ohio. Mixer Model H-600T (capacity 14 kg hydrated beans).
E-7	Fitzpatrick, W. J. Co., Chicago 7, Ill. Model D comminuting machine.
E-8	American Sterilizer Co., Erie, Pa. Autoclave, type LS 2138.
E-9	F. J. Stokes Machine Co., Philadelphia 20, Pa. Freeze-dryer, model 2004L3.
E-10	Quaker City Mill Co., Philadelphia, Pa. Burr mill F No. 4.

Fast-Cooking Foods

Fast-cooking foods are appreciated world-wide because fuel is costly. Tempeh fermentation reduces the cooking time for soybeans from about 5 or 6 hours to 1 hours or less boiling.

Increasing the Protein Content of High-Starch Substrates

SCP can easily be produced by growing suitable organisms on a starch substrate to which minerals and inorganic nitrogen are added. This is the basic process used by Miller, Rank, Hovis, and MacDougall to produce mold mycelium for their meat analogues.

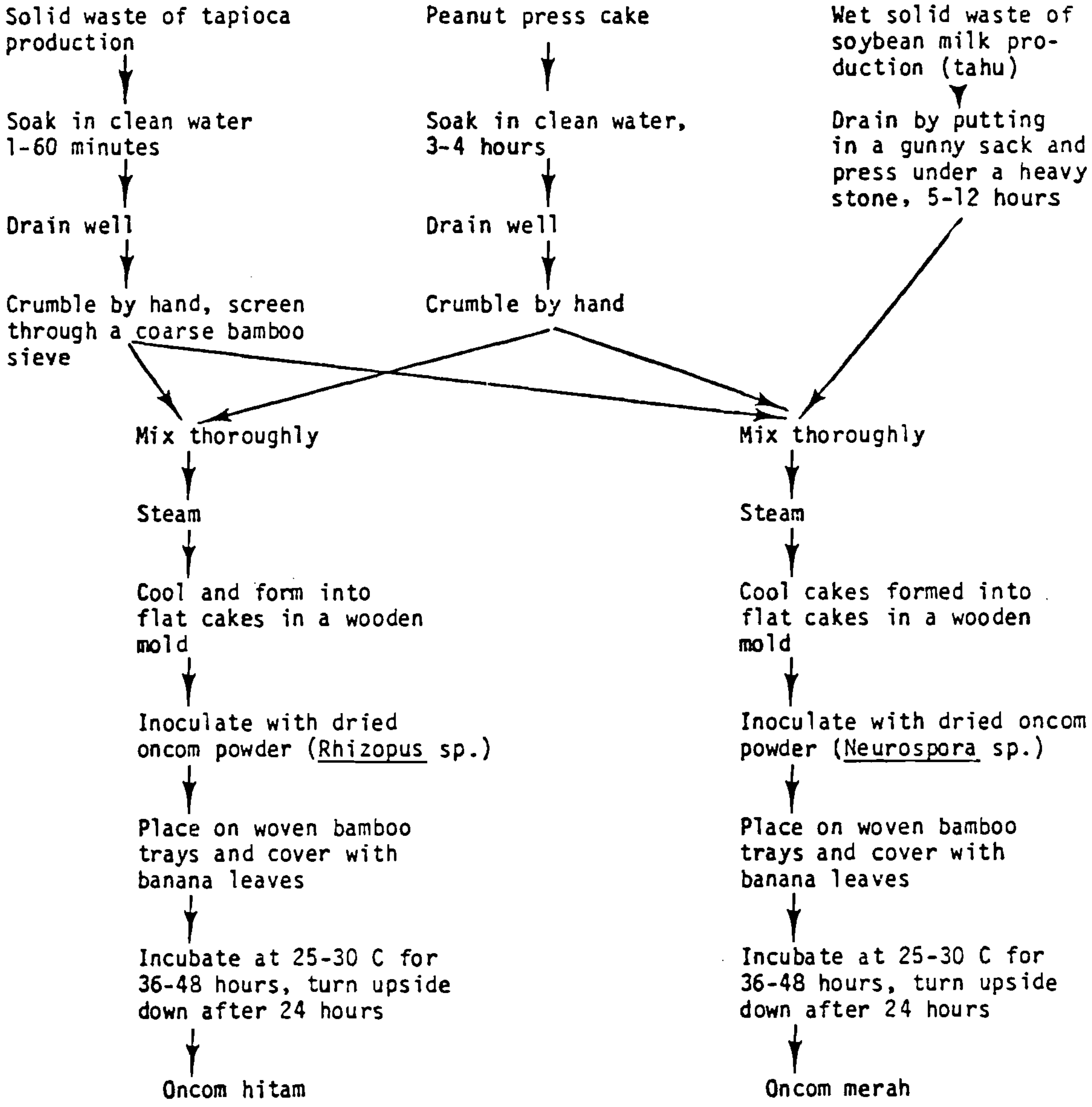
Unfermented cassava contains only 1 or 2% protein, insufficient to meet human protein requirements, yet millions of the world's very poor use cassava as a major staple food.

Indonesians have demonstrated to the world how to increase the protein content by growing edible microbes on starch substrates. The essential fermenting organisms are Amylomyces rouxii, a mold, and at least one yeast, such as Endomycopsis burtonii. They grow on the starchy substrate and not only increase the protein content, but triple the thiamine level and synthesize lysine, the first limiting amino acid in many high starch substrates. The acid, alcohols, and esters produced during fermentation add a flavor highly acceptable to the consumer (Cronk et al. 1977). The protein content of rice (tapé ketan) may be increased to as high as 16%, the protein content of cassava (tapé ketella) can be increased to 4 to 8%. In the form of tapé ketella, the protein quantity and quality of cassava are both improved. This process of improving the protein content of high starch foods could be expanded and extended to other countries.

Utilization of Food Processing and Agricultural Wastes to Produce High-Quality Foods

Indonesian ontjom and bongkrek. The Indonesians have also developed methods to convert food processing by-products such as peanut and coconut press-cakes, which the Western world has traditionally fed to animals, to human-quality foods called oncom [(ontjom) and bongkrek (Figure 4)]. They have done this by use of the basic tempeh process. The press-cakes are hydrated, coarse ground, formed into cakes, steamed, cooled, and inoculated with either the tempeh mold or Neurospora intermedia. The mold overgrows the particles, knitting them into tight cakes that can be sliced thin or cut into chunks and used in soups (van Veen and Steinkraus 1970, and Saono et al. 1977). These products are low-cost, protein-rich meat analogues. The basic changes are similar to those that occur during tempeh fermentation. In addition, it has been found that the content of aflatoxin, always present in peanut or coconut-press cake, is reduced (van Veen et al. 1968). The strains of Neurospora intermedia also contain cellulases that reduce the natural fiber content of the peanut or coconut press cake.

Figure 4. FLOW SHEET: Indonesian process for oncom production
Home and local industry (18)



These indigenous fermented food processes offer a unique opportunity for increasing the quantity and quality of protein in areas of the world where the staple food is comprised largely of starch.

SUMMARY

The Asians have provided the rest of the world patterns by which ligno-cellulosic and food processing wastes can be converted to human food either through the production of mushrooms or through fermentation by selected edible molds. As the world population increases to 6 billion or more over the next 50 years, these processes and those that can be derived from them will become increasingly important in feeding the human race.

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GREEN CROP FRACTIONATION
- AN ECONOMIC ANALYSIS

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A. Windram, and P.R. Foxell

INTRODUCTION

The reported economic analyses for the process of green crop fractionation have been for systems where all the products were intended for inclusion in animal feeds. Vosloh et al (1976) in the United States of America (USA) made a theoretical economic evaluation of a factory operation and that study has been updated by Enochian et al (1977). Bray (1977) has also evaluated this process for the USA.

In a previous study, Wilkins et al (1977a:131-142, 1977b:109) evaluated a number of possible systems for green crop fractionation under the economic conditions pertaining to the United Kingdom (UK). Unlike the USA studies, no economic value was attributed to the xanthophyll in the leaf protein concentrate (LPC). This paper extends that analysis to take account of our improved understanding of the input output relationships in the light of new research results, the possibility of making substantial reductions in fuel usage by recycling the exhaust gases of the crop drier and, thirdly, the financial value of the xanthophyll contained in the LPC.

As in our previous study, a factory operation was modeled in which the crop was purchased at the factory gate and the products were sold to the animal feed trade. In this analysis the income, costs and returns on capital for various feasible green crop fractionation systems are examined in relation to conventional green crop dehydration and a system of green crop dehydration involving substantial fuel economy. The economic variables relate to those ruling in the UK in April, 1978. The sensitivity of the results is examined in relation to variation in costs and efficiency of the process. The prospects for the commercial adoption of green crop fractionation are discussed.

DEFINITION OF TERMS

An outline of the process of green crop fractionation is shown in Figure 1. The juice is the cell sap extracted from the crop without further separation. The pressed crop is the residue remaining after the juice fraction has been mechanically extracted from the whole crop. The leaf protein concentrate (LPC) is the protein-rich fraction recovered from the juice. The juice fraction remaining is termed the deproteinized juice (DPJ). The extraction ratio (ExR) defined the proportion of the crop dry matter (DM) which is extracted in the juice. Likewise the separation ratio (SpR) is the proportion of the juice DM recovered as LPC.

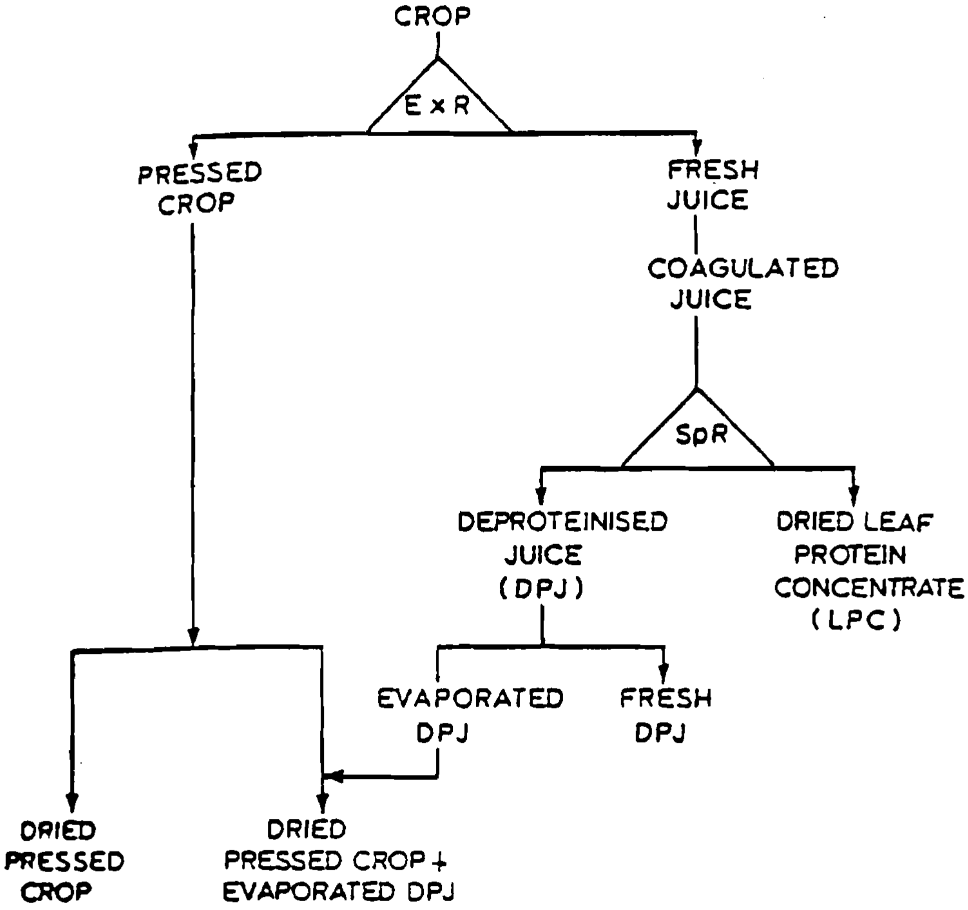

Figure 1. The flow diagram for the green crop fractionation systems.

Δ indicates proportional flow;
ExR, indicates extraction ratio;
SpR, indicates separation ratio.

SYSTEMS EXAMINED

The following systems, defined by the products of the process, have been compared in the present economic evaluation. In all cases 10 kt alfalfa DM were processed per annum.

System 1: Dried crop obtained from conventional green crop dehydration in which the exhaust gases from the drier were recycled as an aid to fuel economy.

System 2: Dried crop obtained from a system in which the incoming crop was heat treated and processed prior to dehydration (Figure 2). This system will be referred to as green crop dehydration with steeping. The recycled DPJ was heated and returned to the incoming crop so as to coagulate the protein within the crop itself. Some DPJ was removed from the steeped crop by a filter prior to further separation of the DPJ in a screw press. The DPJ in excess of that which was required for recycling was evaporated to 50% DM and returned to the pressed crop prior to dehydration. Fuel economy was achieved by recycling the exhaust gases of the drier through the drier itself and through the evaporator. Nearly all the energy for the DPJ evaporator was provided by the exhaust gases.

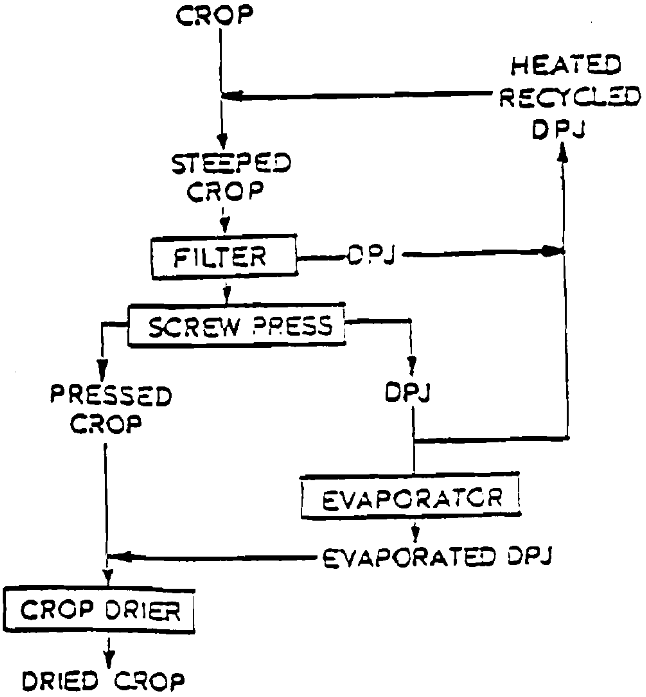

Figure 2. The flow diagram for green crop dehydration with steeping, System 2.

Three green crop fractionation systems were evaluated:

System 3: Dried pressed crop and coagulated juice.

System 4: Dried pressed crop with evaporated DPJ returned to the pressed crop and dried LPC.

System 5: Dried pressed crop, dried LPC and fresh DPJ returned to the land as fertilizer.

For these systems the crop was pulped prior to pressing with a screw press. The juice was coagulated with steam, and, when sold as coagulated juice, hydrochloric acid and sodium metabisulphite were added as preservatives. The LPC was recovered using a decanter centrifuge and dried in a fluidized-bed drier. Where the DPJ was returned to the pressed crop it was first evaporated to 50% DM in a multiple-effect evaporator using the energy derived from the exhaust gases of the crop drier. Where the DPJ was returned to the land the heat contained in the DPJ was recovered to preheat the water used to produce steam. The dried pressed crop was ground and pelleted before sale.

THE PRINCIPAL ASSUMPTIONS IN THE MODEL

The full listing of the assumptions and the data used can be obtained from the first author. Outlined below are the most important features of the model; the determination of ExR, the sale price of the products, the purchase price of the crop and the machinery costs.

The more efficient the process of pulping prior to pressing the greater will be ExR. There is also a negative relationship between ExR and the crop DM percent. In the analysis of the green crop fractionation systems it was assumed that an 18% DM crop was processed to give an ExR of 0.36 for crops pulped prior to pressing, and 0.22 for unpulped crops. The relative dry matter yields of the products obtained with these ExRs are shown in Table 1.

Table 1. The relative dry matter yields of the products from the process of green crop fractionation.

	Extraction ratio	
	0.36	0.22
Crop[1]	100	100
Juice:	36	22
LPC	16	8
DPJ	20	14
Pressed Crop	64	78

[1] 18 percent DM crop processed.

The basis for the calculation of the sale price of the products was their calculated content of metabolizable energy (ME) and digestible crude protein (DCP). It was assumed that the total production of ME and DCP was the same for all systems. The composition of the various products is shown in Table 2 and their economic values are shown in Table 3. The values of ME and DCP per unit were derived from the UK market prices of barley and soybean meal and their content of ME and DCP. In addition, the content of xanthophyll in the LPC increased this product's value. The value of a unit of xanthophyll was related to the cost of synthetic xanthophyll. The market price of coagulated juice was 10% lower than the price related directly to its nutritional value to allow for the greater difficulty in storing, transporting and utilizing such a product. The fresh DPJ was valued on the basis of its fertilizer value reduced by the cost of returning it to the land.

Table 2. The composition of the products from the process of green crop fractionation

	Extraction ratio 0.36					Extraction ratio 0.22				
	DM[1] g/kg	CP[2] g/kg DM	ME[3] MJ/kg DM	DCP[4] g/kg DM	Xan[5] g/kg DM	DM[1] g/kg	CP[2] g/kg DM	ME[3] MJ/kg DM	DCP[4] g/kg DM	Xan[5] g/kg DM
Crop	180	195	9.6	144	-	180	195	9.6	144	-
Juice	92	350	11.6	287	-	76	320	11.6	259	-
LPC	-	613	12.4	531	1.30	-	617	12.4	534	1.31
DPJ	57	150	11.0	102	-	51	142	11.2	95	-
Pressed crop	322	107	8.4	62	-	266	159	9.0	110	-

[1] Dry matter.
[2] Crude protein.
[3] Metabolisable energy.
[4] Digestible crude protein.
[5] Xanthophyll.

The purchase price of the fresh alfalfa was calculated to give the farmer a gross margin (income minus the direct costs of production) similar to that obtained from the production of barley grain. The calculation involved the yields and direct production costs for alfalfa and barley, and the sale price of barley. Harvesting and transport of the crop to the factory gate were considered as separate contract operations. In costing these operations allowance was made for the contractor's own return on capital.

Table 3. The sale value (ex factory) of the products from the process of green crop fractionation

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Economic paramters:

Price of metabolisable energy	0.65 p/MJ[1]
Price of digestible crude protein	15.0 p/kg
Price of xanthophyll	0.015 p/mg

In these circumstances the price for soybean meal is £ 148/tonne DB, for barley £ 96/tonne DB.

Sale value of the products, £/tonne DB:

Dried alfalfa crop	84	

	Extraction ratio	
	0.36	0.22
Coagulated juice[2]	107	103
Dried LPC	355	357
DPJ sold as fertilizer	10	10
DPJ returned to the pressed crop	87	87
Dried pressed crop	64	75
Dried pressed crop with returned DPJ	70	77

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[1] p = pence = £0.01

[2] The value of the juice on the basis of its composition has been discounted by ten percent.

Capital costs were derived from manufacturers' ex-works prices in April 1978. The maximum throughput rate required for the major items of equipment was calculated in the model according to that needed for a particular system, with an allowance for extra capacity to cover breakdown, maintenance and variation in crop DM percent. The cost of each machine was then calculated by linear interpolation from the manufacturers' prices for machinery of known capacity. This approach will have led to a total cost of machinery somewhat lower than that which would result from the purchase of currently available equipment, but was adopted because of the arbitrary choice in the model of the exact quantity of crop to be processed. If the process was sold commercially it is likely that the machines would be manufactured so that their capacities were balanced. The costs of installation, commissioning and small items of equipment such as conveyors, pumps and pipe-work were estimated as being 50% of the itemized processing equipment. Installation and commissioning can be as high as 20 percent of the capital cost of a machine. An estimate of the cost of buildings and providing services to the buildings was also made. The factory processing machinery was depreciated over 7 years and buildings over 15 years.

No allowance was made for the interest on the set-up capital or on the working capital. The average working capital could approach 50% of the production costs if most of the production was sold in the winter period. The calculated return on capital (profit divided by set-up capital) would need to provide for these two interest payments and also the profit.

INCOME, COSTS AND RETURN ON SET-UP CAPITAL

The income, costs and return on capital for the systems detailed above are presented in Table 4. For the green crop fractionation systems it was assumed that ExR equals 0.36. System 3 produced less revenue than System 1 as a result of the 10% discount for the coagulated juice. Systems 4 and 5 produced 36 and 17% more revenue than System 1 respectively because of the value added by the xanthophyll in the LPC. The fresh DPJ contributed only 2% of the revenue System 5.

The percentage that each cost item was of the total costs is shown in brackets in Table 4. The cost of the crop at the factory gate varied from 46% to 56% of the total costs. The cost of fuel and power for System 1 was 34% of the total costs, whereas it was only about 20% of the total costs for each of the other systems. The main fuel cost was for drying the fibrous crop fraction. The fuel and power costs of Systems 2 and 4 were 56% of that used in conventional crop dehydration. The depreciation charge varied between 11% and 19% of the total costs, which reflected the variation in set-up capital.

System 1 showed a loss and thus a negative return on capital. All other systems made a profit, with Systems 4 and 5 showing a substantial return on capital. Although System 4 had the greatest profit it did not have the greatest return on capital because the set-up capital was 45% greater than System 5. Even if the fresh DPJ was disposed of at no value the return from System 5 would still have been similar to that from System 4.

SENSITIVITY ANALYSIS

The sensitivity of the profitability of System 4 has been examined in respect of variation in the yield of LPC, in the revenue obtained from the sale of the products, and in the cost of various items. System 4 was chosen because it was considered more feasible than System 5, although the latter achieved a greater return on set-up capital.

Sensitivity of the Return to Variation in Extraction Ratio (ExR)

Two possibilities have been examined. In the first, System 4A, the yield of LPC was increased by reducing the DM percentage of the incoming crop from 18 to 15 by recycling some of the DPJ. Because of the negative relationship between ExR and the crop DM percentage it was possible to increase the yield of LPC by 8%.

Table 4. Calculated income and costs (£k) and percentage return on set-up capital for different processing systems for alfalfa.[1]

	Dried crop	Dried crop	Dried pressed crop coagulated juice	Dried pressed crop with returned evaporated DPJ Dried LPC	Dried pressed crop Dried LPC Fresh DPJ
System No.[2]	1	2	3	4	5
Income[3]					
Pressed crop	838	838	408	587	408
Juice	-	-	387	-	-
LPC	-	-	-	556	556
DPJ	-	-	-	-	20
Total income					
Costs					
Crop, harvesting and transportation	390(46)[4]	390(51)	390(56)	390(46)	390(54)
Fuel and power for					
Pulping	-	-	7(1)	7(1)	7(1)
Pressing	-	9(1)	10(2)	10(1)	10(1)
Steam generation	-	53(7)	23(3)	25(3)	20(3)
Separating and dewatering	-	-	-	4(1)	4(1)
Drying pressed crop	287(34)	94(12)	83(12)	95(11)	82(11)
Drying LPC	-	-	-	14(2)	14(2)
Evaporating DPJ	-	4(0)	-	4(1)	-
Preserving chemicals	-	-	32(5)	-	-
Labor	18(2)	18(2)	18(3)	28(3)	28(4)
Repairs + maintenance	37(4)	47(6)	29(4)	58(7)	38(5)
Depreciation	91(11)	121(16)	76(11)	157(19)	105(14)
Overhead + management	25(3)	34(5)	21(3)	45(5)	29(4)
Total costs	848	770	689	837	727
Profit	-10	68	106	306	257
Set-up capital	704	918	598	1176	813
% return on capital	Neg	7	18	26	32

[1] 10kt alfalfa DM processed/year

[2] For further description of the systems see text. For systems 3, 4 and 5 the extraction ratio equals 0.36

[3] The economic parameters are defined in Table 3 and the cost of fuel is 8p/litre

[4] Figures in brackets are the percentage that an item is of the total costs for the particular system.

This resulted in a small increase in return on capital (Table 5) compared to System 4 (Table 4).

The other possibility examined for influencing the yield of the LPC was to reduce ExR by not pulping the crop prior to pressing - System 4B. ExR was reduced to 0.22 and the resulting LPC yield was 54% of that obtained from System 4. In Table 5 it can be seen that this resulted in reduced income, only slightly reduced costs and set-up capital. So long as the xanthophyll content of the LPC has an economic value, reduction in LPC yield causes a reduction in revenue and consequent decline in the return on capital.

Table 5. The effect of manipulating the extraction ratio on the income, costs (£k) and the percentage return on set-up capital for System 4 producing dried pressed crop with returned evaporated DPJ and dried LPC.

	System 4A		System 4B	
	Extraction ratio			
	0.39		0.22	
	DM content of the crop reduced to 15 percent by recycling DPJ prior to pulping and pressing (yield LPC DM 1690t)		18 percent DM crop not pulped prior to pressing (yield LPC DM 840t)	
Income				
Pressed crop	568		704	
LPC	598		299	
Total income	1166		1003	
Costs				
Crop	390		390	
Fuel and power	164		180	
Pulping		7		-
Pressing		10		10
Steam generation		30		20
Separating and dewatering		6		3
Drying pressed crop		92		137
Drying LPC		15		7
Evaporating DPJ		4		3
Other costs	283		262	
Total costs	837		832	
Profit	329		171	
Set-up capital	1144		1064	
% return on capital	29		16	

[1] DM - Dry matter

Sensitivity of the Return to Variation in Income

In April 1978, the European Economic Community (EEC) producers of dried fodder and protein concentrates, derived from alfalfa or grass juice, were eligible for a subsidy of £19.5/tonne DM, so long as the crude protein content of these products was in excess of 130 and 450 g/kg DM respectively. This subsidy is intended to increase production of high protein animal feeds within the EEC. System 1A in Table 6 comes from the inclusion of this subsidy in the income of System 1. This resulted in a change in the return on capital from a negative figure to 26%. By comparison, the return for System 4 was only marginally increased by the addition of the subsidy (System 4E, Table 6), because the mean crude protein content of the pressed crop for System 4 was 117g/kg DM. Although there would be variation in the crude protein content through the year, it was estimated that only 26% of the pressed crop would have been eligible for the subsidy. Whereas if ExR was 0.22 all the pressed crop, with a mean crude protein content of 156 g/kg DM, was eligible. This had the effect of raising the return of System 4B from 16% to 34%, System 4F in Table 6. Thus with the subsidy, ExR had very little effect on the return on capital (compare systems 4E and 4F in Table 6).

Table 6. The effect of the inclusion of the EEC dried crop subsidy, and variation in the value of xanthophyll in the LPC on the income and percentage return on set-up capital.

	Dried crop	Dried pressed crop with returned DPJ dried LPC			
System number	1A	4C	4D	4E	4F
Value of Xanthophyll /tonne LPC		0	45	193	193
Extraction ratio	0	0.36	0.36	0.36	0.22
	k	k	k	k	k
Income					
Pressed crop	838	587	587	587	704
Subsidy	195	43	43	43	179
LPC		252	323	556	299
Subsidy		31	31	31	16
Total income	1033	913	984	1217	1198
Total costs	848	837	837	837	832
Profit	185	76	147	380	366
Set-up capital	704	1176	1176	1176	1064
% return on capital	26	6	13	32	34

The value of the xanthophyll contained in the LPC is also of crucial importance. In Table 4 this value was derived from the cost of synthetic xanthophyll and it added £193 to the value of one tonne LPC calculated on the basis of energy and protein alone. In the UK xanthophyll is required to color the yolks of eggs and least cost formulation analysis indicated that xanthophyll had a much lower value than the cost of synthetic xanthophyll because dried green crop could be included in the ration to provide xanthophyll. It was estimated that for layer's rations the xanthophyll in LPC added only about £45/tonne to the value of the LPC. The full value of the xanthophyll is only likely to be obtained where the LPC is fed to broilers to color their flesh. The market effect on return on capital of varying the value of xanthophyll is illustrated in Table 6, systems 4C, 4D and 4E. With no subsidy as well as no value for the xanthophyll the return from System 4 was little better than traditional green crop drying, System 1.

Sensitivity of the Returns to Variation in Cost Items

The major cost items in Table 4 are those of the crop at the factory gate, the fuel and power, and the investment capital.

The cost of the crop at the factory gate ranged between 46 and 56% of the total costs for the systems in Table 4 and a reduction in this cost would have a major effect on the profitability of all those systems. This reduction could arise from increased DM yields of the alfalfa crop, a reduction in the alfalfa production costs or a gross margin return to the farmer lower than would be achieved from growing barley. It is unlikely that it would be possible to lower the alfalfa production costs appreciably but the consequence of varying the other two factors is examined in Figure 3A. Varying both factors had a very similar effect.

The proportion that the fuel and power costs were of the total costs was very similar for Systems 2, 4 and 5 and substantially less than that for System 1. Thus an increase in the fuel cost had a much greater effect on the profitability of System 1 than for the other three systems whose relative profitabilities remained unchanged (Figure 3B). The benefit of recycling the exhaust gas to evaporate the DPJ was substantial. The fuel and power costs for System 4 were 21% lower than those for a similar system in which the exhaust gases were not recycled to the evaporator. The benefit was greater with increasing cost of fuel.

The charge for the capital invested in the factory, measured by profit and return on capital, could be reduced by the following methods.

1. An increase in the number of weeks the plant is operational resulting in a reduction in the overhead costs per tonne processed. Lengthening the processing season from 22 to 30 weeks, an increase of 36%, raised the return on capital from 26 to 43%. It was assumed that in the additional operational weeks, crop

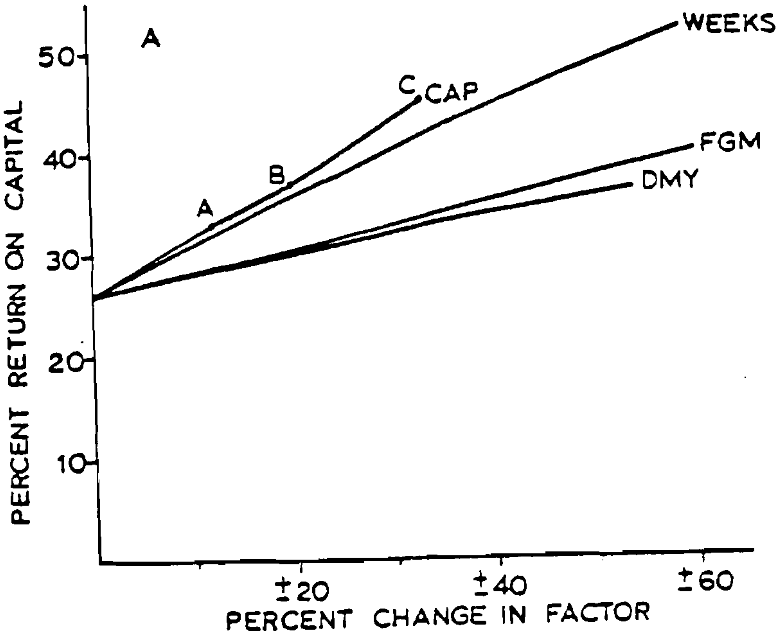

Figure 3A. The effect of a percentage change in the value of certain factors which results in a positive change in the percentage return on capital for green crop fractionation, System 4, producing dried pressed crop with returned evaporated DPJ and dried LPC. The factors are alfalfa DM yield per hectare (DMY), farmer's gross margin per hectare (FGM), potential number of operational weeks per annum (WEEKS) and set-up capital (CAP). Point A represents zero cost of the pulper and press, point B partial sharing of the set-up capital with another process and point C a capital grant of 33%.

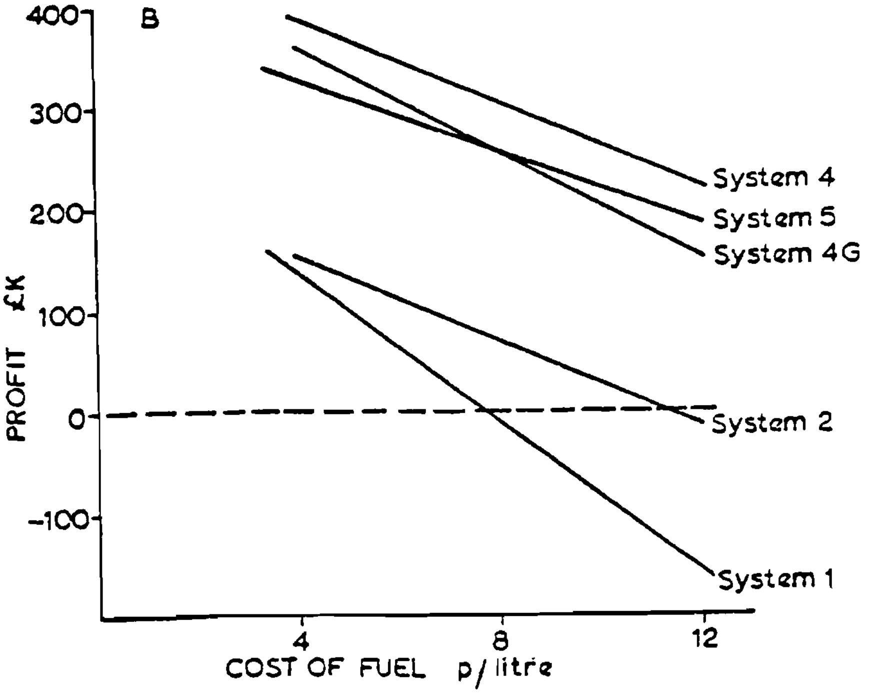

Figure 3B. The effect of the cost of fuel on the profit achieved by various green crop dehydration and green crop fractionation systems. System 1 is conventional green crop dehydration with gas recycling. System 2 is green crop dehydration with steeping (see text for details). System 4 green crop fractionation producing dried pressed crop with returned evaporated DPJ and dried LPC. System 4G, as System 4 but with no exhaust gases recycled from the drier to the evaporator. System 5 green crop fractionation producing dried pressed crop dried LPC and fresh DPJ. Cost of fuel for standard runs 8p/litre.

similar to alfalfa would be available.

2. A reduction in the capital cost of the machinery. Work currently in progress at Wisconsin University (4) holds considerable promise of a substantial reduction in the cost of the pulper and press being realized. In System 4 these two items of equipment represented 14% of the cost of the plant machinery. However, reducing their cost to zero only raised the return on capital from 26 to 33%; a reduction in cost of these items of machinery will only have a modest effect.

3. A reduction in the set-up capital costed to the green crop fractionation factory by sharing at least some of the machinery and buildings with another process operating outside the alfalfa processing season. With the assumption that 25% of the processing machinery could be shared with an alternative process and with the overhead charge for this shared machinery and buildings allocated between the two operations then the return on capital was raised from 26 to 37%. The alkali treatment of straw, sugar beet processing and the wet processing of cereal grain milling by-products have been suggested as alternative processes.

4. The receipt of a capital grant. It is possible that a green crop fractionation plant would be eligible for a grant from the EEC under the Agricultural Products Processing and Marketing (Improvement Grant) Regulations and the total grant would be up to 33% of the capital invested. Such a level of grant raised the return on capital from 26 to 45%.

The effects of these possibilities are compared in Figure 3A where it is evident that an increase in the number of operational weeks had an effect very similar to a reduction in the set-up capital.

DISCUSSION

Greater emphasis should be placed upon the relative differences between systems than upon the absolute level of returns. We consider that those cost items which have a market effect on the relativity of the systems have been adequately estimated. However, certain costs were difficult to estimate, such as those for buildings, provision of services and crop transport, but variation in these, although affecting the absolute rate of return, have little effect on the relative differences between systems. The percentage returns on capital for the systems under various pricing situations are summarized in Table 7. It should be remembered that these returns have to cover the set-up and working capital interest payments.

Compared with conventional green crop dehydration, System 1, the fuel and power economies of Systems 2, 4 and 5 were similar and substantial. The fuel and power costs for Systems 2 and 4, the products of which were all dried, were only 56% of the fuel and power costs of System 1. Unfortunately the set-up capital was increased by 30% and 67% respectively. These differences

Table 7. The percentage return on capital for the systems under selected pricing situations.

		No subsidy	Plus subsidy
System 1	Conventional green crop dehydration	Neg	26
System 2	Green crop dehydration with steeping	7	29
System 3	Dried pressed crop and coagulated juice		
	ExR[1] = 0.36	18	18
	ExR = 0.22	16	41
System 4	Dried pressed crop with returned evaporated DPJ, and dried LPC		
	Xanthophyll £0/t LPC		
	ExR = 0.36	<1	6
	ExR = 0.22	<1	19
	Xanthophyll £45/t LPC		
	ExR = 0.36	6	13
	ExR = 0.22	4	23
	Xanthophyll £193/t LPC		
	ExR = 0.36	26	32
	ExR = 0.22	16	34
System 5	Dried pressed crop, dried LPC and fresh DPJ (ExR = 0.36)		
	Xanthophyll £0/t LPC	NEG	NEG
	Xanthophyll £193/t LPC	32	35

[1] ExR - Extraction ratio.

in set-up capital to a large extent negate the advantages in fuel economy especially when no value is attributed to the xanthophyll content of the LPC.

With no subsidy payment and the highest value placed on xanthophyll there was considerable advantage to be gained from System 4 rather than from either of the crop dehydration systems. As Enochian et al (1977) also calculated, the return on capital under these price circumstances increased with increasing ExR because of the value added by the xanthophyll content of the LPC. The highest value that could be attributed to the xanthophyll in the LPC in the UK in April 1978 was £193/tonne LPC DM but as already argued, the value in the UK is likely to be only around £45/tonne LPC DM. As a result the advantage of System 4 was removed and crop dehydration with steeping, System 2, was marginally more attractive.

With a subsidy equivalent to that received by producers in the EEC and the highest value of xanthophyll the advantage of System 4 over System 1 was much diminished. With xanthophyll valued at £45/tonne LPC DM, crop dehydration was again a more attractive proposition.

The results for System 1 and System 4 - with a subsidy, no value attributed to the xanthophyll and an ExR of 0.22 - may be compared with the systems producing similar products from our previous study (1977a, 1977b). The differences in return on capital between the two systems are remarkably similar, although somewhat smaller in this study. This is in spite of an increase in this study of the subsidy payment from £4.5/tonne to £19.5/tonne **DM.** DM. This increase was compensated for by a much greater estimate of capital requirements and a smaller increase in product prices compared with the increase in costs since 1975.

The returns on capital reported by Enochian et al. (1977) were much greater than the corresponding figures reported here, in spite of their inclusion of capital interest charges. The principal reason for the difference was that they assumed that their plant would operate to capacity throughout the processing season, whilst this study has assumed substantial seasonality in fresh crop supply resulting in a potential capacity 156% greater than that required to process the average daily production. Thus the overhead charges in the USA study (Enochian et al., 1977) were spread over a much greater throughput resulting in improved returns on capital. We believe that it would not be possible to arrange for an even flow of crop to the factory throughout the processing season. In addition the costs of crop and energy were relatively much cheaper and the depreciation periods longer in the USA study, all of which contributed to the higher returns.

System 3 producing dried pressed crop and coagulated juice compared favorably with Systems 1 and 2, and with System 4 or 5 where no value was attributed to xanthophyll. The coagulated juice can only be fed to pigs and the output from a factory processing 10kt alfalfa DM per annum would supply sufficient juice (ExR = 0.22+ during a 22 week processing season for the daily requirements of 24,000 pigs with a mean weight of 80 kg (calculated from Braude et al., 1977:47-55). This system would only be attractive in regions of the world with large-scale pig enterprises.

Our results demonstrate that the attractiveness of green crop fractionation System 4 over System 1 or 2 is entirely dependent upon the value of xanthophyll in the LPC and whether a subsidy payment is paid. In the absence of a high value being attributed to the xanthophyll in the LPC, the prospects in the UK for the large-scale commercial exploitation of green crop fractionation to produce animal feeds are not encouraging.

SUMMARY

A theoretical model has been constructed in which income, costs and return on set-up capital have been calculated for factory scale systems of green crop dehydration and green crop fractionation. The returns from these systems are compared and the sensitivity of the results to variation in product income, product yield and certain cost items is analyzed. Substantial fuel economy can be achieved by adopting a modified green crop dehydration system involving pretreatment of the crop prior to drying and by systems of green crop fractionation. The return on set-up capital achieved by systems of green crop fractionation producing leaf protein concentrate is particularly sensitive to the value of the pigment xanthophyll. It is concluded that without a high value being attributed to the xanthophyll the prospects for the commercial exploitation of green crop fractionation to produce animal feeds in the United Kingdom are not encouraging at present.

RÉSUMÉ

Un modèle théorique a été construit, consistant à calculer le revenu, les coûts et les profits d'un capital pour un grand nombre de systèmes de fractionement de plantes fourragères placés dans des situations économiques très diverses. Les systèmes varient des productions simples de jus coagulé pour l'alimentation des porcs et de fourrages fraîchement pressés pour l'alimentation des ruminants, aux procédés de fabrication sophistiqués produisant des concentrés de protéines de feuilles séchées et des plantes fourragères séchées auxquelles sont ajoutées du jus déprotéinisé. Ce travail examine en détail le résultats considérés comme étant possibles de certains de ces systèmes nécessitant des procédés de fabrication annuels de l'ordre d'au moins 10 kt de matière séchée. Ces résultats sont comparés avec ceux calculés pour le séchage conventionnel de plantes fourragères utilisant divers procédés de réutilisation de la chaleur.

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PROTEIN AND FAT RECOVERY FROM FOOD PROCESS EFFLUENTS

R.A. Grant

Waste effluents from meat, poultry and fish processing plants contain large amounts of protein and fat and usually have much higher values of biochemical oxygen demand (B.O.D.) than town sewage. Such effluents are highly polluting and can impose heavy loads on public sewage treatment works.

It has been estimated that between 2 and 5% of the total carcase protein is lost in the effluents from abattoirs and poultry processing plants. In the U.K. this amounts to tens of thousands of tonnes per annum with a potential value at present in the region of £200 per tonne, for the world as a whole, this loss needs to be multiplied by a factor of about 100. At the present time when world population is increasing rapidly and outstripping food production in many areas such a wastage is hard to justify if the means of preventing it are available.

Conventional biological effluent treatment plants suffer from the inherent disadvantage that potentially valuable materials such as protein and fat are degraded to useless sludge which in itself presents a disposal problem. On the other hand, in the case of physico-chemical treatment plants designed to recover fat and protein the revenue from the sale or recycling of by-products can be used to defray either in whole or part, the capital and running costs of the plant.

In the past, various processes have been proposed involving the use of chemical precipitants to remove protein from solution. These have usually employed toxic compounds such as iron salts which results in the precipitated protein being useless for nutritional purposes. The Aquapure process allows the recovery of protein in a completely non-toxic form suitable for feeding to both domestic and farm animals.

Effluent Treatment

The process consists essentially of a flocculation reaction whereby soluble protein together with insoluble suspended protein particles is removed from the effluent, the floc entraps fat globules which are removed simultaneously with the protein. The flocculated protein plus fat is separated from the effluent by air flotation and skimming in the form of a sludge containing up to about 15% total solids. The relative amounts of protein and fat in the separated sludge are dependent on the composition of the effluent. In general, the protein/fat ratio is higher in the case of slaughterhouse effluents than for poultry processing effluents. Where the effluent contains exceptionally large quantities of fat as in the case of cooking and bone degreasing effluents the bulk of the fat may be recovered in a separate air flotation stage. It has been found from analytical studies on a large number of effluents that the B.O.D. and C.O.D. (chemical oxygen demand) levels can be reduced by about 70-90% of the initial value with virtually complete removal of fat and suspended solids.

By-Products

The protein content of a typical slaughterhouse effluent by-product is given in Table 1. Other samples of recovered meat works effluent protein were analyzed for amino acids and the results (Table 2) are compared with various reference proteins. The amino acids were found to be quite evenly distributed with no major deficiencies. The contents of essential amino acids in two specimens are shown in Table 3 compared with the FAO recommendation for human nutrition, apart from tryptophan which was not determined, the essential amino acid content appeared adequate. A similar analysis for amino acids was carried out on a sample of protein recovered from poultry processing effluent (Table 4). In certain instances, as in the case of effluents from cooking and rendering operations the effluent may contain fat which is firmly complexed with protein in addition to free and emulsified fat. Even with a separate fat recovery stage the by-products from such effluents usually have a low protein/fat ratio. However, the presence of fat does not appear to impair the value of the protein as an animal feed.

The nutritional value of recovered meat works effluent protein was determined in a standard feeding trial on chicks. The basal ration consisted of wheatmeal, maizemeal, barley, lucerne and salts and contained 13% of protein. This comprised 50% of the diet and contributed 6.5% protein. The remainder of the diet consisted of sugar and sufficient casein, meatmeal, fishmeal or effluent protein to contribute a further 6.5% pf protein. The relative growth rates, feed consumption and feed efficiencies are shown in Table 5. The 280 chicks used were crossbred WL/AO cockerels randomized in groups of 14. The ratio of feed consumption to weight gain shown in Table 5 is a measure of the efficiency of the feed. The dried effluent protein was approximately equal to the meat meals and casein in nutritional value,

Table 1. Composition of by-products recovered from slaughterhouse effluent.

Batch No.	1	2	3	4	5	6	Means
Nitrogen	10.5	11.0	11.3	11.5	11.5	10.6	11.1
Protein	65.5	68.0	70.5	72.0	72.0	65.5	68.9
Total Organics	74.5	78.3	77.6	77.4	76.2	72.7	76.1
Ash	21.8	17.7	18.5	19.1	20.0	23.6	20.1
Moisture	3.7	4.0	3.9	3.5	3.8	3.7	3.8

Table 2. Amino acid composition of recovered solids from meat works effluent (g amino acid/16 g nitrogen)

Amino Acid	Recovered Solids		Reference proteins			
	Fraction		Fibrin	Haemoglobins	Serum proteins	Casein
	A	B				
Lysine	8.8	8.5	9.1	9.1	10.0	8.5
Histidine	3.9	5.9	2.9	8.0	3.3	3.2
Arginine	4.4	4.7	7.8	3.9	5.8	4.2
Aspartic acid	14.3	9.4	11.9	9.8	10.3	7.0
Threonine	7.9	4.5	7.3	5.6	12.6	4.5
Serine	7.7	5.7	12.5	5.5	18.2	6.8
Glutamic acid	19.3	10.0	15.0	8.1	14.2	23.0
Proline	6.6	3.2	5.3	4.7	5.5	13.1
Glycine	5.5	3.5	5.4	5.3	2.0	2.1
Alanine	8.8	6.8	4.0	9.8		3.3
Half-cystine	trace	trace	3.8	1.0-2.2	7.0	0.8
Valine	11.0	8.2	5.6	9.0	7.5	7.7
Methionine	2.8	3.2	2.6	1.3	4.0	3.5
Isoleucine	5.5	4.1	5.6	0.2	3.4	7.5
Leucine	17.1	15.0	7.1	14.4	10.1	10.0
Tyrosine	5.5	3.2	6.0	2.9	5.5	6.4
Phenylalanine	9.9	7.9	4.5	7.8	5.2	6.3
Ammonia	-	1.1	-	-	-	-

Table 3. Essential amino acids (g amino acid/16 g nitrogen).

Amino Acid	FAO*	Egg	Fraction		Casein
			A	B	
Isoleucine	4.2	6.8	5.5	4.1	7.5
Leucine	4.8	9.0	17.1	15.0	10.0
Lysine	4.2	6.3	8.8	8.5	8.5
Phenylalanine	2.8	6.0	9.9	7.9	6.3
Tyrosine	2.8	4.4	5.5	3.2	6.4
Threonine	2.8	5.0	7.9	4.5	4.5
Tryptophan	1.4	1.7	-	-	-
Valine	4.2	7.4	11.0	8.2	7.7
Sulphur containing:					
Total	4.2	5.4	2.8	3.2	4.3
Methionine	2.2	3.1	2.8	3.2	3.5

*Food and Agricultural Organization 'provisional pattern' of essential amino acids for human nutrition; Rome, 1957.

Table 4. Amino acid analysis of protein recovered from poultry processing plant effluent (umoles/100 umoles).

Aspartic acid	10.8	Threonine	5.1
Serine	7.7	Glutamic acid	11.5
Proline	4.5	Glycine	6.9
Alanine	8.9	Cystine (half)	1.2
Valine	7.4	Methionine	1.5
Isoleucine	5.3	Leucine	9.1
Tyrosine	2.3	Phenylalanine	3.8
Lysine	6.6	Histidine	2.3
Arginine	4.9		

Tryptophan not estimated.

Table 5. Chick growth, food consumption and feed efficiency of experiment rations.

		Body weight gain/chick 1-4 weeks	Food consumption/ chick 1-4 weeks	Feed consumption(g)/ weight gain
A	Reference ration (casein)	137.0	359	2.62
B	Mm 41	147	400	2.74
C	Mb 43	103	347	3.38
D	Mb 44	100	302	3.02
E	Mm 45	166	413	2.49
F	Mb 46	83	282	3.42
G	Mm 47	141	386	2.73
H	Grass protein	104	338	3.16
I	Fishmeal 6	169	418	2.48
J	Effluent protein	125	345	2.75
	MSD 5%	25	91	0.54

Table 6. Pig trial rations and results.

	Effluent By-Product %	Whey %	Control %
Barley	42.0	31.2	43.0
Maize	41.75	31.2	43.0
Meatmeal (60%)	11.0	10.0	13.75
Whey Mix (13.4%)	-	26.75	-
Trace Nutrients	0.25	0.25	0.25
Steamed Bone Flour	-	0.6	-
Effluent By Product	5.0	-	-
	100.0	100.0	100.0
Estimated Total Protein %	17.0	16.9	17.0
Results			
Original liveweight (kg)	14.0	14.4	14.3
68 trial days liveweight (kg)	39.5	33.4	41.6
68 day gain (kg)	25.5	19.0	27.3
Average daily gain (kg)	0.38	0.28	0.40

slightly inferior to fishmeal but superior to the meat and bone meal and protein extracted from grass which were tested at the same time. It is evident that the effluent protein could be used as a concentrate for poultry production. There was no evidence of toxic side effects which could be attributed to the recovery process. Samples tested bacteriologically had low total counts and were negative for coliform organisms.

A further feeding trial on the effluent protein was carried out using pigs. The composition of the experimental rations and the results obtained are shown in Table 6. A satisfactory growth rate was obtained over 68 days, when the diet included effluent protein at the 5% level.

Ion Exchange

In cases where the flocculation/air flotation process does not reduce the pollution level sufficiently for discharge the quality of the effluent may be improved by further treatment with novel ion exchange resins[1]. These are derived from crosslinked regenerated cellulose by the introduction of anion or cation exchange groups. The resins are granular in form and can be produced in a range of particle sizes. They have markedly superior hydraulic properties and physical stability compared with ion exchangers based on fibrous cellulose which have hitherto been employed for protein absorption. Conventional condensation or synthetic polymer ion exchange resins have negligible capacities for protein whereas the new resins have capacities of the order of 0.5g protein per g dry resin. These resins have been evaluated in various applications ranging from laboratory scale enzyme production to effluent and water treatment and may be used in conventional type ion exchange plants. For effluent treatment the weakly basic, diethylaminoethyl form has been found most applicable although other types are available. Adsorbed protein is readily desorbed by washing the resin with alkaline brine (1-2% NaOH + 3 - 5% NaCl). Protein may be recovered from the spent regenerant solution by neutralising to about pH 4.5 followed by heat coagulation. The coagulated insoluble protein is readily dewatered by mechanical means prior to drying. Protein sludge from the flocculation/air flotation stage may be similarly heat coagulated and dewatered before drying. Since the ion exchange resins can be made selective for individual proteins, they are particularly useful for recovering high value proteins such as bovine serum albumin, gamma globulin and enzymes in a pure state.

Applications

Reduction in the B.O.D. and C.O.D. levels obtained with slaughterhouse effluents are given in Tables 7 and 8. The best results from the point of view of effluent quality were obtained using the combined process. However, there is great variability in the strength and composition of effluents from different plants and also in the consent conditions laid down by local water

Table 7. Residual BOD (%) in treated slaughterhouse effluent.

	Sample					
Treatment	1	2	3	4	5	Means
Flocculation	38	41	31	23	27	32
Ion exchange	10	13	23	19	18	17
Flocculation+ ion exchange	-*	5	12	7	-*	5

-* Value too low for measurement by standard method.

Table 8. Residual COD (%) in slaughterhouse effluent after treatment.

	Sample							
Treatment	1	2	3	4	5	6	7	Means
Flocculation	19	40	31	37	35	31	31	32
Ion exchange	18	31	31	28	25	27	15	25
Flocculation+ ion exchange	-*	14	9	22	-*	11	-*	11

-* value too low for estimation by standard method

Table 9. Reduction of chemical oxygen demand and by-product yields for poultry processing effluents.

Specimen No.	1	2	3
Chemical Oxygen demand 1^1	6050	5920	7400
2^1	1150	1040	945
% reduction in COD	81.0	82.4	87.0
By-product yield g/L	3.4	3.2	4.0

1^1 and 2^1 - before and after treatment authorities for discharge to sewers, so that, depending on circumstances either the first stage only or both stages may be employed. In some cases it may be preferable to recover fat and protein separately. Table 9 shows the C.O.D. reductions obtained with poultry processing effluents together with the yields of dried by-product for different effluent strengths. In the case of a fish processing effluent the C.O.D. level was reduced by 90% using the flocculation process only with a dry product yield of 2 g/L. Although, in general, the concentrations of protein found in effluents are relatively low, ranging from 1000-2000 p.p.m. on average, since large volumes are involved the ultimate yield of by-product may be considerable. For example, at 1000 p.p.m. a yield of about 1 tonne per million litres (4.5 tonnes per million gallon) would be obtained.

Vegetable Wastes

Vegetable processing effluents may also contain significant amounts of protein which can be recovered by suitable chemico-physical treatment for use in animal or human nutrition. It has been found possible to recover the soluble protein from rice starch factory effluent by flocculation and air flotation in a yield amounting to about 5% of the weight of the rice processed. Since the possibility of contamination with excreta or pathogenic organisms does not arise in this case, the product will be suitable for human consumption and have a relatively high value.

In the case of the palm oil industry vast quantities of centrifugation sludge and sterilizer condensate are produced having extremely high B.O.D. values in the region of 30,000. By means of flocculation followed by centrifuging or air flotation and drying a product containing about 12% protein and 80% low grade carbohydrate was obtained in a yield of about 4% W/V and possibly useful as a ruminant feed. This treatment reduces the B.O.D. level by about 75% with virtually complete removal of residual oil and suspended solids.

Economics

From the economic point of view rapidly escalating costs of water, effluent disposal and animal feed protein are making the case for protein recovery much more attractive. In terms of plant size, the new system is considerably more compact than conventional sewage type of biological treatment plants and compares favorably in terms of capital and running costs. The costs of biological treatments have been evaluated by Chipperfield[2]. He concluded that the evidence casts considerable doubt upon the traditional view that biodegradable industrial wastes are most effectively and cheaply treated at local sewage works. The evidence suggests that liquid wastes should be treated at source. The possibility of **reuse** of water should also be considered carefully in view **of** rapidly increasing water costs.

The question of disposal of industrial effluents with domestic sewage and the related costs have also been reviewed by Calvert[3]. He estimated the cost at 10-25P/1000 gallons in 1970, however this figure has increased considerably since then and at present one may quote a cost per 1000 gallons for a poultry processing effluent with a C.O.D. value of 4,000 of 99P and for a meat works effluent with a C.O.D. of 2000 of 65P/1000 gallons. The same author also states that biological treatment on site is not always desirable and the fact that it may appear economical may be a fallacy of the Mogden formula.

In view of the foregoing it now appears that a very strong case can be made for physico-chemical effluent treatment on site in the food industry with by-product recovery to offset capital and running costs. This appears to apply particularly in the case of meat and poultry works effluents.

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THE AEROBIC TREATMENT OF WASTE WATER FROM LIVESTOCK PRODUCTION UNITS AND THE PRODUCTION OF MICROBIAL BIOMASSES

M. Ringpfeil and K. Kehr

THE PROBLEM

Over the last few decades, farm livestock production has undergone major changes. These included large concentrations of animals at single places and the introduction of industrial methods in animal production. Thus, conditions were provided for increasing the rate of meat production with a substantial saving in manpower. A negative aspect of this development is that waste disposal requires additional technical efforts causing considerable capital and operating costs. This is true especially for hog production which is not usually dependent upon the availability of farmland, thus permitting large concentrations of livestock and, simultaneously, making difficult the disposal of wastes.

The results of a systems analysis of hog production and scientific and technological studies has given rise to suggestions that processes combining the microbial production of protein-enriched biomass for feeding purposes with the purification of liquid wastes from livestock production units be used. The process has been investigated on a laboratory scale. Pilot scale experiments, economic feasibility studies, and feeding trials are planned for the further development of this process. It seems advisable that PAG and IUPAC examine their recommendations for nutritional and safety aspects with respect to these novel protein sources of animal feeding in order to validate this new type of biomass production.

The process should be ready for commercialization when the pilot plant studies and economic considerations based on these studies have proved its technical reliability and economic efficiency and feeding trials have shown that the biomass produced is safe. The time until commercialization can be started will depend on the time required for the feeding trials. These trials will take about five years from the time when representative samples are first available.

The principles underlying this process are not limited to hog wastes but can also be applied to other wastes suitable for biomass production.

An Example

In the German Democratic Republic there are concentrations in swine breeding allowing for an annual production of 200,000 animals for slaughter in one factory. At such places no more than approximately one fifth of the waste produced can be used in the neighboring farmland. The output of liquid waste to be treated is, on average, as high as 3,000 m^3/d.

Previously, the methods used were similar to those employed in the treatment of municipal and industrial sewage. Suitable degrees of purification could be obtained by a sequence of aerations directed towards decomposing carbon compounds and converting nitrogen from the reduced form into the oxidized form and, finally, into molecular nitrogen. This particular approach has the advantage of eliminating adverse effects on the environment, provided, of course, a limited agricultural area is available for year-round overhead irrigation using partially purified waste water.

This new development aims at rationalizing this multi-staged process and at combining sewage purification with the production of microbial biomass.

The New Process

Urine and faeces from the livestock production unit are washed away into collecting tanks. Solids are separated by a sieving process and may be used as fertilizer and as raw material for microbial conversions. The remaining sewage contains dissolved and finely suspended matter from the excreta of hogs. Following intermediate storage, it is subjected to aerobic fermentation. The majority of the dissolved and suspended materials are converted into biomass, carbon dioxide and water. The output of biomass may be substantially increased by adding an additional carbon source during fermentation.

The biomass produced is subsequently concentrated by the use of separators. The aqueous residue is used for the irrigation of farmland. The biomass-containing part is chemically and thermally treated in special apparatus and is subsequently dried or directly used for feed preparations (Figure 1).

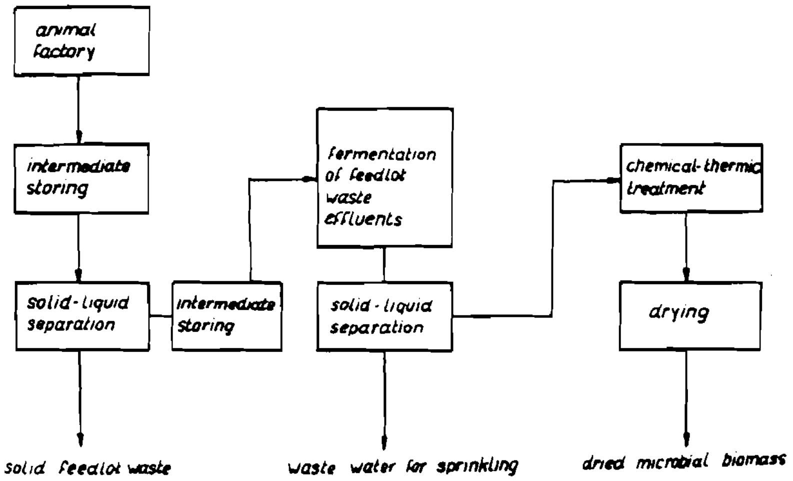

Figure 1. Flow scheme of the combined sewage treatment biomass production process.

It is during the storage of the diluted waste prior to aerobic fermentation that significant changes take place in the composition of the organic matter. About sixty to seventy percent of the carbon-containing substances are transformed into lower fatty acids. More than fifty percent of the organic nitrogen is converted into ammonia due to uncontrolled anaerobic microbial action.

At every stage of its anaerobic conversion the aqueous urine-faeces mixture contains smaller amounts of organic carbon (C) than are required for the aerobic microbial conversion of the entire nitrogen (N), phosphorus (P), and potassium (K) into biomass. Adding organic substances results in a more complete conversion of the inorganic matter. Complete conversion will occur in those cases where the C:N:P:K ratio of the substrate is equivalent to that of the biomass with regard to the necessary conversion of carbon into carbon dioxide. The amount of potassium in waste water is, in general, such that the proper adjustment of the ratio by the addition of carbon, nitrogen, and phosphorus is virtually impossible.

Nitrogen may be utilized almost completely providing carbon and some phosphorus are added. If phosphorus is added in the form of phosphoric acid, then it will be possible for an acid pH value to be maintained during fermentation. This mode of adjusting the C:N:P:K ratio of the substrate was chosen.

Methanol proved to be a suitable source of additional carbon. It is available in large quantities. It is a concentrated carbon source for use in fermentation. It is easily transportable and not too expensive. However, other organic substances may also be used. Glucose is a model substance because of its potential availability from agricultural sources.

Fermentations of sewage and sewage supplemented by glucose were most successful at neutral pH values with the application of neutrophilic microorganisms. The fermentation of sewage supplemented by methanol could be carried out advantageously at acidic pH values with the application of acidophilic microorganisms. A suitable acidophilic methanol-assimilating bacterium called MB 58 was isolated and used for inoculation of the methanol-enriched sewage.

Acidophilic bacteria offer a number of advantages especially in those cases where it is intended to use biomass produced for feeding purposes.

Compared with fermentations at neutral pH values, the proportion of components of microbial cultures grown under acidic conditions changed significantly. More than eighty percent of the culture corresponds to the strain of inoculated micro-organisms (Figure 2).

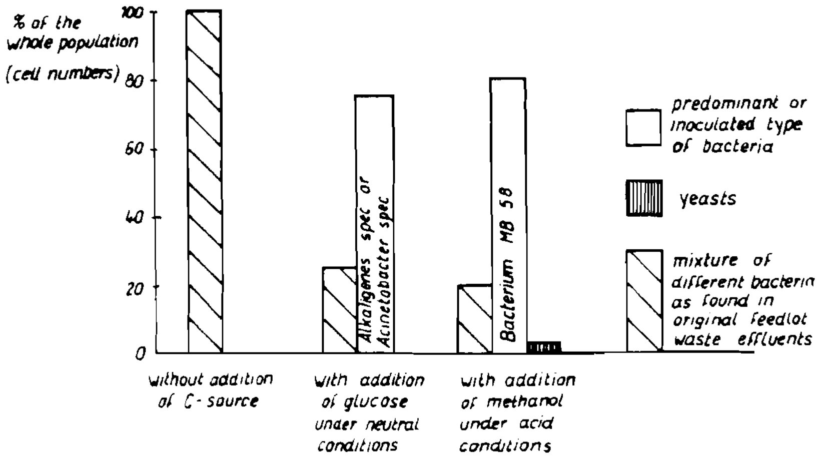

Figure 2. Quantitative distribution of microorganisms in feedlot waste effluents after different types of aerobic fermentation

Consequently, the properties of the biomass produced will come close to those of the pure culture of this strain (Table 1). The acid pH value prevailing during fermentation causes the majority of inorganic ions to remain in solution so that the separated biomass contains only a low percentage of inorganic matter (Table 1).

system	crude protein % dm (Nx6,25)	nucleic acids total % dm	lysin g/kg dm	ash % dm
MB 58/MeOH/feedlot waste effluent	72	7 - 10,5	32-40	6 - 7,5
MB58/MeOH	75	9,6-11,0	36	4,5-5,5
biosludge from an aerobic activated sludge process	40 - 60	6 - 9	10 -25	15 -30

Table 1. Chemical composition of biomasses derived from different fermentation systems

Under acidic conditions the growth of pathogenic microorganisms is strongly inhibited.

In contrast, the growth of microorganisms which decompose the organic matter of the sewage is not inhibited under these conditions as is apparant from the degree of purification achieved (Table 2).

	NH_3-N [mg/l]	PO_4-P [mg/l]	K [mg/l]	COD [mg/l]
feedlot waste effluent	1500 - 5000	50 - 500	500 - 1200	12000 - 60000
fermented without C-addition	750 -2500	20 - 200	400 - 1100	2400 - 18000
fermented with methanol addition	80	10 - 20	400 - 800	2000 - 5000

Table 2. Nutrient loading of feedlot waste effluents before and after fermentation

Moreover, it is even possible to accomplish a higher degree of purification in as little as one tenth of the time required for the conventional three-stage process. The latter takes from 50 to 70 h, whereas fermentation in the acidic pH range may be completed in 5 to 7 h.

As a result, the aeration volume will also be reduced considerably.

Conventional separators are used for the separation of cells. As in the case of conventional sewage purification, the remaining aqueous phase still has residuals of both organic and inorganic matter, so that it cannot usually be discharged into rivers or other natural bodies of water (Table 2). However, the amount of residuals provide for year-round overhead irrigation of neighboring farmland. An even further reduction in the content of organic matter would still require purified water to be used for spray irrigation because it is not possible to completely remove potassium by biological processes.

As far as chemical parameters are concerned, the quality of the biomass produced by acidic fermentation of methanol-enriched sewage is comparable with that of the microbial biomass produced by well-known industrial processes using pure raw materials. Of course, the composition of the microorganisms derived from the new process is not homogeneous (Figure 2). To make this biomass suitable for use as a fodder ingredient it is necessary to provide for a method of radical destruction of cells in the process. For this, high-temperature short-time alkalini zation was chosen. This causes destruction of the cell walls. Following this treatment, it was no longer possible for living cells to be found in the suspension.

The destruction of cell walls also results in an increase of digestibility of the biomass.

The conditions selected for the chemical-thermal operation did not result in a significant decrease of essential amino acids in the biomass (Table 3).

Amino acid	g per 16 g N before	 after
	procedure	
Threonine	4.2	4.2
Methionine	1.8	1.8
Cysteine	0.75	0.56
Valine	4.9	4.1
Leucine	6.9	6.9
Isoleucine	3.9	3.9
Lysine	4.7	4.5
Histidine	2.1	1.8
Phenylalanine	3.8	3.8
Tryptophan	1.0	1.0
Arginine	4.8	4.5

Table 3. Changes in the content of essential amino acids during the high-temperature short-time alkalinization

To date, it has not been possible to obtain any results regarding questions of chronic toxicity and other long-term factors.

Range of Application and Advantages of the Process

The process developed seems to be suitable for use in livestock production units in which the output of waste water is greater than 1,000 m^3/d and where partially purified sewage can be used for year-round spray irrigation of neighboring farmland. An additional carbon source may be chosen in accordance with local conditions. The quantity to be used may be varied within limits. However, use of the purified sewage for overhead irrigation should not be restricted by an increase in nonconverted nitrogen, nor should an increased heterogeneity of organismal composition of the biomass be allowed to detract from the quality.

A rough comparison of industrial swine production including sewage purification by conventional means and by use of the new process showed (Figure 3) that the latter would save costs by combining sewage purification and biomass production (C compared to B'' + C'). The cost of raw materials (A compared to A'), and the purchase of protein feedstuffs (B compared to B'), would also be lower.

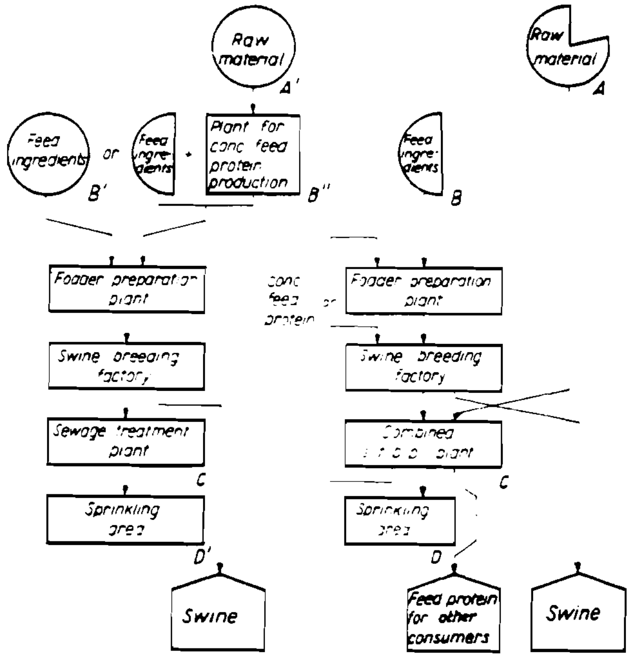

Figure 3. Conventional and proposed scenarios of industrial swine production

Use of the new process will even allow biomass to be supplied to other consumers.

The area of neighboring farmland to which the purified sewage is applied by sprinkling may be smaller than in the case where conventional processes are used due to a lower content of residual organic and inorganic matter.

The process is performed continuously under conditions which tend to diminish the effects of unavoidable variations in waste composition upon the qualities of biomass and sprinkling water.

The industrial nature of the process provides for continuous control of the biomass quality.

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A SURVEY OF THE LATEST TECHNOLOGIES OF FOOD PRODUCTION FROM BY-PRODUCTS AND WASTES

Bohuslav Vencl

Existing projections on world population and food supply suggest that an increase in the deficiency of the raw materials currently used in concentrate feeds in systems of animal production is likely to develop in the forseeable future. This deficit is probable because the world population will increase more rapidly than the production of food crops. We have to try to make up this deficit by improving the utilization of raw materials and by upgrading other resources currently considered unsuitable. The residues from cereals and other crops, forest products and animal wastes are examples of alternative sources available in relatively ample supply (Burt, 1973).

By-products and waste materials may be defined as subsidiary components left over from the production of main products in agriculture. The use of these for feed production, which is the topic of this article, is a satisfactory way of increasing feed resources and a direct method of supplying food to the human population. By linking waste products to methods of utilizing substances environmental pollution can also be reduced. It is usually necessary to improve their poor quality and transform nutrients which can be utilized by animals for feed. There are physical, chemical and biological ways of achieving this purpose.

THE PRETREATMENT AND USE OF LIGNOCELLULOSIC MATERIALS

Lignocellulosic materials contain 70-80% carbohydrates, mostly in the form of cell wall polysaccharides and are a potential source of dietary energy for ruminants. The amount of cellulose waste from crop production and industrial processes is estimated to be 100 000 mil. tons/annum by Dyer et al. (1975). However, before such carbohydrates can be extensively digested in the rumen it is necessary to pretreat these especially woody materials. Treatments have included delignifying agents, ball milling, liquid ammonia and sodium hydroxide, which increase the digestibility of organic matter in the rumen. The treatments may be grouped according to Dekker and Richards (1973) under two headings: treatments aimed at the degradation of lignin (which is thought to protect polysaccharides from digestion) and other treatments which change the crystal structure of cellulose, thus increasing its swelling capacity in aqueous solutions and providing greater accessibility to the rumen microorganisms and their associated enzymes.

The Conditioning and Use of Lignocellulose from the Processing of Wood Matter

Wood matter constitutes the richest source of lignocellulose. 70-75% of the volume of wood is composed of polysaccharides. As seen from FAO data, 1,350 million tons of wood represented the total world wood output in 1962. Twenty per cent of this amount is waste. The polysaccharides of wood are bound with lignin. If the digestibility of lignocellulose materials is to be increased and the materials are to be used in animal nutrition, the lignin-saccharide bond, particularly the structural polysaccharides of cell walls, must be destroyed by alkaline or acid hydrolysis or by microbial cellulases.

The chemical composition of wood and straw (%)

	spruce sawdust	beech sawdust	straw
lignin	27	22	19
cellulose	50	47	40
hemicellulose	19	30	30
pentosans	10	24	25
ash	1	2	6
nitrogen	0.1	0.15	0.3
extractive substances	2	3	1.5

The digestibility of different lignocellulosic materials (%)

	lignin	digestibility
cellulose	0	83-86
straw	19	40-48
beech sawdust	24	3-5
spruce sawdust	30	0-2

Other materials need to be hydrolyzed before being considered as food for animals. It should be noted, for instance, that peat reduces the availability of feed ration nutrients (Vencl, 1977).

The digestibility of beech sawdust, conditioned by hydrolysis with 1% H_2SO_4 at 100-130°C for 2 hours, was only at a level of 3.54%. Further hydrolysis with 3% nitric acid for another two hours at 100°C which increased digestibility to 61.64%. De-fibred beech sawdust, hydrolyzed with 2% acetic acid at a temperature of 85°C and pressure of 1.2 MPa for 10 min. had a digestibility of 43.98% (the digestibility of unconditioned beech chips, by comparison, was 5.6% - (Jalc et al., 1979). The hydrothermic conditioning of beech sawdust with sodium sulphite increased the nutritive value of sawdust. Digestibility of organic matter increased to 50%. Hydrolysis with NaOH gave good results for straw conditioning.

Little increase in the digestibility of sawdust was obtained by ball-milling or steam treatment with NH_4OH solutions. Treatments with the NaOH dry method in which a concentrated alkali solution is employed to prevent loss of soluble compounds of nutritional value, followed by ball-milling, showed a considerable increase in digestibility. Using a wood to NaOH ratio of 10:1 (by weight), the apparent digestibility of the organic matter of beech was increased from 5 to 50, of oak from 14-42. The organic matter digestibility of coarse-ground straw, without ball-milling, was increased from 46 to 82 (Hartley and King, 1973).

Wood waste can be subjected to complete hyrolysis in order to produce saccharides. Besides hemicelluloses, cellulose is also hydrolyzed and the end product is glucose. The treatment of hydrolyzates from 1 ton of wood matter can produce:

180 litres of ethyl alcohol
1.5 litres of methyl alcohol
2 kg. of acetic acid
22 kg. of fural
1.5 kg. terpentine and
50 kg. of fodder yeasts

It is thought that a reduction by a third of the lignin content in hard wood, and by two-thirds of soft wood lignin content, can increase digestibility by as much as 60%. However, available methods of conditioning are too costly. Therefore, wider use can be expected in the by-products of the paper-and-pulp industry where delignification already begins during wood processing when the main product is manufactured.

Wood processing in pulp mills leaves large amounts of liquid waste which, if not used as raw material for further products, pollutes water sources. After thickening these wastes contain 37% pentoses and hexoses. Use of these wood molasses is similar to that of cane molasses. If urea is added, it can be fed to ruminants. Wood molasses contain 50.5 TDN, whereas cane molasses contain 53-60.5 TDN.

Fibre is generated as a waste product of sulphate pulp manufacture. This fibre can be separated mechanically. It contains about 40% pure cellulose with a higher energetic value than that of meadow hay.

The Use of Wood Processing Waste for the Synthesis of Microbial Protein

Liquid waste extracts which carry away 50% of wood matter are generated during the production of cellulose by the sulphite method. They are traditionally used in the production of ethanol. Alcohol is separated by distillation and the sulphite stillage is mixed with the washing waters from the production of pulp, and fodder yeasts are produced by subsequent fermentation (T. utilis, O. lactis). With each 100 kg. of cellulose produced, 0.9-1.2 m^3 of extract containing 57 kg lignin and 198 kg saccharides, is generated. The sulphite extract contains 9-19% dry matter, 10-20% of ash and organic matter, including lignosulphonic acid or calcium ligno-sulphonate, and reducing substances (pentoses, hexoses).

Saccharide content in wood upon hydrolysis (%)

	Spruce	Beech
Arabinose	17	73.9
Glucose	28.9	20.1
Galactose	4.2	0.1
Manose	42.7	3.3
Fructose	4.0	-

Hexoses are used in alcohol fermentation, the remaining pentoses are used for the production of yeast protein. In this way river pollution is reduced and biological oxygen demand decreases by 30% in the production of alcohol from sulphite leaches. In the production of yeasts the biological oxygen demand decreases by about 60% and the utilization of wood matter is thus increased by 70%.

The increased production of synthetic ethanol stimulates the processing of sulphite extracts especially for production of yeast protein. Besides the traditional calcium bisulphite method of cellulose production, natrium and magnesium bi-sulphite methods are being introduced. The extracts generated by these new technologies can be used readily for the microbial production of protein. When alkaline hydrolysis is used, the sulphate extracts contain mainly hydroxy acids. After an adjustment of the pH value, removal of lignin and dilution with water, the yield was 40-50% when C. tropicalis culture was used (Sandula et al., 1979). Cultures of C. utilis and C. arbora were suitable for cultivation on beech wood extracts. Good results were obtained from the technological process in which synthetic ethanol was added to the sulphite extracts. The sulphite-ethanol yeasts were found to have a higher biological value of protein (69.4) than sulphite yeasts (65.8) (Simecek, 1971). If the biological value of yeast protein is to be increased, yeasts should be fortified by an addition of 0.5% of synthetic DL methionine and 400 Mcg of vitamin B_{12}. It is recommended that 4% yeasts admixture be added to feed rations (Hudsky, Bartosova, 1980).

Straw Conditioning Technology

The low digestibility of straw is a result of the incrustation of cellulose by lignin and silicates. The alkaline or oxidative method can be applied for delignification and the removal of silicates. The use of acids is not suitable, because silicic acid is not released and pentosans transform into furfural.

Methods of improving the nutritive value of cereal straw have aimed at overcoming low intake and low digestibility. Originally these methods (Beckmann, 1921) involved soaking straw in a diluted solution of sodium hydroxide, in order to raise the digestibility from 40 to 65%. This method was labor-consuming and required large quantities of water for neutralisation. Wilson and Pigden (1964) described a dry process in which hammer-milled straw was mixed with only a small volume of concentrated NaOH solution, which was then neutralized with an organic acid. Alkali treated straw may be fed without neutralization, with silage. Swollen cellulose is more easily penetrated by rumen fluid and this would account for the greater digestibility of cellulose from treated roughage. Sodium hydroxide probably hydrolyzes such ester linkages which would also contribute to the higher digestibility of alkali treated straw. The increased digestibility of treated as opposed to untreated roughage is a result of solubilization by alkali and is shown in the additional amount actually digested by the animal.

There is a linear increase in digestibility with increasing amounts of alkali up to a level of about 10 g. NaOH/100 g. straw and a levelling off thereafter. Larger increases in digestibility values were achieved when roughage was pressure cooked with alkali solutions. Digestibility and voluntary intake increased up to a level of 3-6 g. NaOH/100 g straw (Jackson, 1977). Rexen and Thomsen (1976) proposed factory-scale treatment of straw using the NaOH spray treatment process.

The "Technology of Nutritionally Improved Straw" proposed by Silcock, Ltd. (United Kingdom) includes plant chopping, drying, when necessary, grinding and spraying of straw with 4.5-5% NaOH, and extruding (Cuthbert et al., 1978).

The treatment of straw with NH_3 results in an increase in digestibility for ruminants. The advantage of NH_3 over NaOH is that undesirable excess chemicals evaporate freely into the air. Ammonia, bound to the straw during the reaction, can serve as a source of nitrogen for microbial protein synthesis in the rumen. Maximum digestibility could be obtained e.g. with 2.6% NH_3, at a temperature of 62°C and a 4-day incubation period (Waagepetersen Thomsen, 1977). In Europe, 8 weeks and a rate of 3.5 kg NH_3/100 kg. straw is recommended (Sundstol et al., 1977). Dry matter digestibility is in this case increased by 17%. During pelleting of wheat straw, after 2% urea has been added, digestibility improved by only 8%. In Czechoslovakia 5-10 l of ammonia water (25%) per 100 kg. of straw is used. A disadvantage of the NH_3 method used and described is that about 2/3 of the ammonia used remains unchanged and this represents a waste of valuable NH_3.

Microbial Decomposition of Lignocellulose Materials

Besides the chemical hydrolysis of lignocellulose materials, decomposition by microbial cellulase can also be applied. One ton of straw can yield 250 to 300 kg. saccharides from which up to 125-150 kg. of dry yeasts can be obtained.

Bauer et al. (1979) used mutants of T. viride with increased production of cellulolytic enzymes for the decomposition of straw. Upon hydrolysis, cultivation was effected with the yeast strains of C. utilis and T. bovina. Upon the chemical hydrolysis of straw, with the addition of a nutrient medium to the desired level, and an adjustment of the pH value, yeasts (e.g. C. tropicalis) can be similarly grown on the substrate produced. One ton of straw also yields 250-300 kg. saccharides after chemical hydrolysis. Hydrolyzed straw can be partially utilized as a component in shaped feeds (pellets and the like).

The cultivation of the fungus Plerotus florida on sawdust and straw substrates reduced the content of lignin by 24%. The content of cellulose also decreased, whereas the digestibility of straw increased. The rise in the digestibility of sawdust was lower than in the case of hydrothermic treatment (Kosar et al. 1975). Lignin is degraded by fungi which prefer lignin to cellulose - e.g. the white rot fungi.

Fungal treatments involved the addition of a diluted medium to sawdust or straw, and the white rot fungus was allowed to grow through substrate. The highest digestibility was obtained with Fomes lividus on oak sapwood, and organic matter digestibility increased from 14 to 36%.

The most successful modification of sawdust was achieved using F. lividum followed by NaOH treatment. Digestibility value increased from 5 to 59%. In the case of straw treated with P. Sunquineus followed by NaOH, it increased from 46 to 70%. Such treatments could provide a basis for economic methods of wood waste and straw conversion to useful animal feed components (Hartley and King, 1973).

THE PRODUCTION OF MICROBIAL PROTEIN FROM OTHER WASTES AND BY-PRODUCTS

Besides the products of cellulose material processing, raw materials from petrochemicals, isolated pure N-alkanes, lower alcohols, methanol and ethanol can also be used for the production of microbial protein. Some of the early studies on the production of yeasts from petrochemical raw materials proved successful, but numerous problems were encountered when the production process was put into practice. This is due to high oil prices, the risk of aromatic compound content,as well as the content of fatty acids with branched chains or odd-carbon fatty acids in the yeasts produced. Sulphur compounds (sulpho acids) constitute a toxicological problem. The most developed technology is the production of SCP from isolated N-alkanes and ethanol. The use of methanol and methane from natural gas is being studied (Stros, Rosa, 1976).

The yield of biomass in the cultivation of yeasts on methanol is 40%. In the case of fermentation from acetic acid, the yield is 30 to 35% (with a maximum of 50%). However, this production process has not yet been introduced.

Other available sources include stillage from the production of ethanol from molasses, lyes from the production of citric acid, etc.

Another possibility is offered by the use of non-saturated sugar-beet juice. The advantage of this method is a higher yield of biomass (65-68%). This technology does not generate effluents since all non-sugars remain in the product. The final product contains 8-8.5% ash and the non-sugar part of the raw material (Flam, 1969).

Substrate requirement for the production of 1 t. of dried fodder yeast

sulphite extracts	62 t
molasses	4 t
sulphite extracts + ethanol	31 + 0.82 t
ethanol	1.64 t
n-alkalenes	1 - 1.1 t
sugar-beet	10 t

THE PROCESSING OF OTHER AGRICULTURAL AND FOOD WASTES

Whey

Whey in native form is directly used in animal nutrition. Besides this, whey can also be condensed (thickened) and dried. Thickened whey can be used as "cement" in the production of shaped feeds. Dried whey is used as a component in piglet and calf feed mixtures (2.5 to 5%). Whey can be similarly used after the removal of lactose (delactosed whey).

Whey fermentation by means of a culture of Lactobacillus bulgaricus and the adjustment of pH to 5.5 by NH_3 infusion yields a product containing about 75% nitrogen as ammonium lactate. When 27% of total protein in cow feeds was replaced by fermented whey, the nutritive value was the same as that of soy meal (Huber et al., 1976).

Skin Treatment (Tannery) Wastes

These wastes can be subjected to hydrothermic treatment together with the rendering-plant raw materials (animal cadavers) to produced meat-and-bone meals. The so-called lime protein is produced from tanning liquors after technological processing.

The chemical composition of lime protein and glue stock (%)

	Dry matter	N - compounds	Crude fibre	Ether extr.	Ash	N-free Extract
lime protein	88.94	60.2	2.52	3.15	20.21	2.50
glue stock	94.42	67.77	1.77	8.30	12.12	7.19

In broiler feed mixtures lime protein or glue stock can be used to replace fish meal or meat-bone by 2%. In the case of 4% replacement, weight gain decreased and feed conversion deteriorated (Nedopil, Koucky, 1975). Among the wastes of the tanning industry, karaglutin and hydrolyzers of colagen are used in animal nutrition. The digestibility of these hydrolyzers is 85% in poultry and 66% in pigs. At higher doses of skin meal (5-6%), the growth capacity of the animals decreased and chromium was found to be retained in the parenchymatous organis (Dilworth and Day, 1970). Doses up to 3% are therefore recommended.

Feather Hydrolyzates

Pressure hydrolysis of feathers breaks the keratin bond and increases the digestibility of protein. Feather meal contains little methionin, lysine, histidine and tryptophan which should be complemented to due levels prior to administration. The meal contains 70-85 mcg vitamin B_{12}, 2 mcg vitamin B_2, 9 mg pantothenic acid, 20 mg nicotinic acid and 100 mg choline (Vavak, Fischerova, 1975).

Sewage Sludge

The lack of protein-containing feeds leads us to search for new protein sources. Dried sewage sludge is among the non-traditional sources. The composition of the sludge depends on its origin (city, industrial), and on the type and operation of the sewage treatment plant (pre-cleaning, aeration). The sources of this raw material are ample. In the FRG, 4-6% mechanically thickened sludges were used for feeding purposes in 1971. Activated sludge is a better material for use as feed. Micro-organisms constitute a large portion of the sludge.

Industrial composition of activated sludge and yeasts (%)

	activated sludge	fodder yeasts
Dry matter	93.61	94.13
N-compounds	50.53	57.85
Fat	9.90	8.05
Ash	13.62	6.88

Sludge must not contain any toxicous substances. The presence of heavy metals is a hygienic problem. A procedure was worked out to enable a reduction of the content of heavy metals. Dried biologically activated sludge, SOBIVIT B, is produced in Czechoslovakia and is used in the nutrition of farm animals at a level of 3%. The sludge is produced in aerated activating tanks to which a nitrogen and phosphorus source is added. Activated sludge is separated by decanting, then it is contrifuged to be thickened to contain 6-10% dry matter; then follows drying in a drum drier.

The materials suitable for this processing include city sewage and wastes from the production of wood fibreboards. The sludge should be thermically conditioned prior to administration. Activated sludge can also be dried together with yeast cream (Rybarova and Stros, 1976).

The inclusion of 2% activated and additionally sterilized sludge in the feed of broilers was not found to exert an unfavorable effect on the health and growth of the birds (Petkov et al., 1979).

Poultry Waste

Broiler litter - an accumulation of poultry excreta, feathers, wasted feed and bedding - is valuable as feed for ruminants. Nitrogen was efficiently utilized by sheep when up to 50%, in the case of cattle up to 25%, was substituted. Although no serious health problems have resulted from feeding broiler litter, there is the danger of pathogenic organisms in the litter. Fontenot et al. (1971) reported that dry heat was effective in destroying bacteria present in broiler litter. But a natural means of destroying microorganisms, such as ensiling litter with high grain corn forage, would be more economical than the use of artificial heat. Lower coliform numbers in litter silages than in controls suggest that ensiling may be an economical means of eliminating the potential hazard of the possible presence of pathogens in the litter (Harmon et al., 1975).

Poultry waste products are similar to uric acid and sodium urate but superior to urea or biuret when used as nitrogen supplements (at a level of 40% dietary nitrogen) for beef cattle fed forage diets (Oltjen and Dinius, 1976).

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ECONOMIC ASPECTS OF THE DEVELOPMENT OF NEW TECHNOLOGIES
(In the Non-Traditional Production of Feed and Food)

Yuri Khromov

The title of this report is too comprehensive to give a brief, exhaustive characterization of the problem as a whole. Therefore, I chose to concentrate on a methodical approach to the solution of the given problem and thus indicate the economic expediency and vast prospects of the non-traditional production of agricultural produce and foodstuffs.

When considering the advantages of non-traditional technologies, we have to mention briefly the constraints of traditional production and how these are partially removed in non-traditional production.

The rate of world agricultural development is not as rapid today as it was 20 or 30 years ago. The efficiency of additional investments in agriculture is declining. One needs considerable amounts of mineral resources, machinery, money and labor to increase agricultural output. Investments will have to increase sixfold and energy resources threefold for world agriculture to double its crop yields. For these yields to treble, it is necessary to increase investments twentyfold and energy resources sixfold. What is more, this will call for a considerable increase in the use of nonrenewable resources, mainly oil products. For instance, a twofold increase in crop yields in the developing countries will require an elevenfold increase in the production of fertilizers and sixfold increase in the output of pesticides (Dennis L. Meadows et al. 1974.) The amount of mined energy (fuel) spent on agriculture is greater than the energy obtained in the form of food. Moreover, one should take account of the continuous growth of prices of energy resources in the world, as well as the growing demand for environmental protection, both of which will tighten the constraints on farm production in the future. On the whole, normal agricultural development requires 6 to 10 times more investment in the related industries (chemistry, mechanical engineering, transport) than in agriculture itself.

The low efficiency of agricultural production is due to a number of factors, including:

- the traditional unchangeable nature of the general technological scheme;
- the seasonal fluctuations in production;
- the inevitable losses during storage;
- the sporadic use of machinery;
- the geographical scattering of production, which involves high transportation costs;
- the non-standard nature of the produce;
- the large volumes of highly nutritive waste, which is used either directly for feed (i.e., ineffectively), or denatured;
- the deterioration of the environment;
- the continuous growth of energy intensities.

All these constraints on agricultural production explain its instability under conditions of stable, growing demand for its produce; they also hinder the flow of capital into this branch of the economy, are responsible for the slow recoupment of capital investments, which are risky, and lower the effectiveness of planning and regulating the volume and structure of production.

But the major contradiction of the contemporary food system consists perhaps in mass hunger and malnutrition caused by the way it functions. Moreover, this takes place while the per capita production of staple nutritive (protein) and energy (caloric) components is on the average twice as high as the minimal required standard.

However, the inequitable distribution of foodstuffs both between individual regions and inside individual countries results in over 15 per cent of the world's population directly experiencing a shortage of energy-containing food (hunger), whereas two-thirds experience a protein deficit. Starvation and the diseases it causes account for the loss of 30 to 40 million human lives annually. The most striking contrasts are to be observed when comparing the diet levels in the industrial and developing countries. For example, while per capita minimum energy requirements have been estimated at 2,220 kilocalories per day for the countries of Asia and the Pacific, 2,340 for Africa, 2,390 for Latin America, and 2,460 for the Middle East, the per capita production in the developing countries is less than 2,150 kilocalories per day, whereas in the industrial countries this figure is over 3,000. Furthermore, an adult needs 80 to 100 grams of protein a day, including 50 grams of protein of animal origin. (As far as his survival is concerned, the needs are less). According to FAO data, the world's food protein resources (grams per person per day) are distributed as follows:

	1961-1963	1975	1985(forecast)
1. Industrial countries:			
protein	85.6	89.4	92.4
including animal protein.	45.3	50.6	54.6
2. Developing countries:			
protein	54.8	61.3	67.1
including animal protein.	10.9	13.9	17.5

Since in many countries the further intensification of the use of traditional agricultural techniques does not result in any appreciable growth of efficiency in this primary important branch of the economy, and more and more often leads to undesirable ecological consequences, scholars, economists and politicians have of late been increasingly concentrating on so-called non-traditional or unconventional methods of production of foodstuffs and feed. Of course, new methods of food generation will not be able to replace traditional agricultural production which will remain the leading method of food production. Moreover, traditional agriculture will continue to play a key role as food supplier, while being at the same time a major resource base for non-traditional methods of foodstuffs and feed production. However, this well-known fact cannot diminish the importance of the non-traditional production of foodstuffs and feed as a highly effective method for solving the world's food problem, primarily for decreasing the food protein shortage.

There are three ways of using secondary produce and agricultural and industrial waste, namely:

1) direct use of the given resources for feeding cattle;
2) microbiological synthesis of protein as a basis for producing feed and foodstuffs;
3) production of new types of food.

The latter two options seem the most promising.

The Microbiological Synthesis of Protein may, in the coming years, markedly reduce the quality feed protein deficit in many countries because of the high efficiency of this production. Microorganisms such as yeast, bacteria and fungi grow hundreds of times faster than plants and thousands of times faster than animals. Some microorganisms, for instance, double their biomass over twenty minutes. Some types of yeast, bacteria and microscopic fungi, when dried, contain 50 to 75 per cent of protein. By way of comparison, dried corn contains 8 per cent protein, wheat grain - 18 per cent, soybean meal - 49 per cent and fish meal - 61 per cent.

In quality (amino-acid composition, assimilation coefficient etc.) protein produced by way of microbiological synthesis is superior to vegetable protein and is close to animal protein. When properly purified and sterilized, such protein may be used for food in the form of additions to foodstuffs or for the production of new types of food.

Resources for microbiological protein synthesis are widespread.

Pulp, a virtually unlimited resource, is a basic raw material for the microbiological synthesis of protein. It is widely spread throughout the world, and continuously replenished by photosynthesis. It is present in all agricultural waste and in the waste of some industries. Among the largest sources of pulp suitable for microbiological protein production are straw (1400 mill. tons d.w. per year, worldwide), green mass of plants (leaves and stalks), corn cobs, reed, cotton-seed, rape, linseed and sunflower cake, paper production waste, non-standard timber, etc. Microbiological protein production has the following advantages:

1) it does not depend on geographic, climatic or seasonal conditions as a process;
2) it does not require large areas for efficient production;
3) it makes use of renewable natural resources.

It should be noted that the microbiological synthesis of protein has long been carried out in various countries with the use of carbonic raw material (oil, natural gas, ethyl alcohol). However, owing to the energy crisis and growing world oil prices, this nonrenewable resource continues to lose its importance as a source of protein synthesis.

At the same time account should be taken of such an inexhaustible source of carbon as the ocean, with an average annual yield of 3,600 million tons, which exceeds mankind's requirements several thousand times over. The use of algae for the microbiological synthesis of protein may produce a positive effect. In amino-acid composition, for example, the Sprirullina algae grown in man-made reservoirs approaches ideal protein, while its high productivity (up to 80 kg of carbon per day per 1 hectare of water surface) justifies the economic efficiency of its growth.

Thus, the further increase in the volume of microbiological protein will in large measure be conducive to meeting the needs of animal husbandry in quality feed. Moreover, agriculture will experience no additional loads, since use will be made of various types of secondary raw material and agricultural and industrial waste, as well as other non-traditional sources.

Another noteworthy feature of feeding protein is its low coefficient of conversion into animal protein. The conversion of this protein in pork production, for instance, is 10 to 20 per cent, in fowl-flesh production - 20 to 25 per cent, in egg production - 25 to 30 per cent. On the whole, the conversion of feeds into an animal product in terms of protein ranges between 6 and 40 per cent. And if account is taken of the preparation of a product for food, the conversion drops to between 3 - 30 per cent. In a beefsteak, for example, protein losses during the conversion of a feeding product into an animal product and then into a foodstuff amount to 95 per cent. It is no mere accident, therefore, that beef protein is 50 times as expensive as the protein of fat-free soybean flour.

Such an uneconomical attitude to protein, which is so Limited as a food component (two-thirds of the world's population is experiencing a protein shortage), has impelled scientists and specialists in many countries to investigate non-traditional techniques for producing foodstuffs, and thus bypass the stage of cattle breeding. In this case the conversion of protein from a vegetable product into a foodstuff reaches 80 to 90 per cent.

Resources from the production of new types of food (also called texturized, structurized or artificial foodstuffs) are, first and foremost, protein-containing agricultural products, namely, seeds of oil-producing plants and cereals, grass and the biomass of plants, as well as secondary raw materials and food industry wastes such as skimmed milk and serum, the waste from the finishing and meat-packing industries, and the like. Of late, the production of new types of food has marked the emergence of a new branch of food production in a number of industrial countries.

Scientists in the Soviet Union have elaborated the scientific principles of processing protein into various new forms of food and processes for obtaining a number of new forms of food which are "universal as to protein", i.e., suitable for processing diversified sources of protein into foodstuffs and additions to meat products with the requisite composition and properties. Some of these processes have already found application in or are being mastered by Soviet industry.

The major tasks being tackled by the new food-stuffs industry are the following:

Firstly, a substantial increase in the production of foodstuffs in the form of food analogues (primarily meat and dairy products) and additions thereto. The United States, for example, has already achieved a 10% replacement of meat in mince products by protein additions. Between 1985-1990 the production of new forms of food is expected to reach 10 or more per cent of the food processing industry in some developed countries. One disadvantage of the new industry lies in the fact that in many countries (the USA and Japan above all) the major raw material is soya, which means that the price of this relatively cheap resource may skyrocket in the future if new resources for the production of unconventional food and feed are not explored and utilized.

Secondly, the new technologies make it possible to lower the cost of foodstuffs owing to the comprehensive industrial processing of traditional and non-traditional food raw materials and the increased conversion of protein into food products. What is more, the new foodstuffs are easier to preserve and transport. Their production is not affected by seasonal or weather changes and can be organized near the places of consumption. Moreover, the boundless possibilities for mechanizing and automating this type of production will ensure the continuous growth of its efficiency in the future.

Thirdly, the new industry makes it possible to provide standard products with any desired qualitative components, precooked or ready-for-use products for infant, medical and preventive diets, and also to organize high-quality food supply for people living in unusual conditions or in distant areas.

Summary of microbiological synthesis of protein and the production of un-conventional foods as a whole:

1. It does not depend on geographic, climatic or seasonal conditions;
2. It partially solves the problem of non-used wastes and by-products;
3. It does not require extra acreage;
4. It makes use of renewable natural resources;
5. It is in some cases cheaper than the traditional agricultural production of protein;
6. It is favorable for safeguarding the environment;
7. It creates products which are preservable and easy to transport.
8. It makes possible standardized products with any desired qualitative components.
9. It provides the possibility for mechanization and automation of production.

The work begun at IIASA to study the given problem and, in particular, the holding of a Task Force Meeting on this subject in September 1980, make it possible to analyse some main scientific trends in the field of non-traditional production of protein from agricultural waste and to identify the most promising of them. Research into new technologies will be considered from the standpoint of their interaction with the resources of agriculture and the environment. Therefore, one should regard as optimal not only those technologies which are most effective economically but, first and foremost, those which are both economical and do not exert an adverse influence on the limited resources (i.e., are based on widespread and renewable resources, are not energy-intensive, etc.) and on the environment in the long term. Systems analysis is indispensable in the investigation of this problem, and IIASA is making extensive use of this.

In spite of all the advantages of non-traditional food and feedstuffs production, its growth is observable so far only in a small number of countries. As for new forms of food, the reason behind their insufficient spread lies in the conservative habits of the consumer. Therefore, requirements are made on the new foodstuffs which even many traditional products fail to meet; the major demand made on the new products is, as a rule, not their better chemical composition, but the traditional physical parameters: 1) appearance (color, shape and size); 2) familiar taste; 3) attractive flavor; 4) texture; 5) temperature; 6) quick cooking.

There are a group of factors in non-traditional protein production which ought to be considered by decision-makers.

1. Biochemical types of waste, by-products and end products.
2. Technical feasibility of waste utilization.
3. The availability of wastes and by-products.
4. The economics of the utilization of wastes.
5. The socio-economic aspects of waste utilization.

In order to view the waste problem systematically, one should not consider it as only a technical, resourcal or economic dilemma. It is a complex problem. Whether agricultural wastes are utilized or not depends on economic and social constraints in the long run. It is often difficult to explain the present form of waste treatment in terms of its profitability.

Among the economic requirements which the new product should meet are as follows:

1) the price of a new product should be the same or lower than that of a traditional product;
2) a new product should be offered where it is advantageous for the buyer, where the consumer has fewer opportunities to buy traditional products;
3) quick and inexpensive to cook;
4) the new product should be attractively packaged and this should be in relation to the price of the product;
5) new products should improve on traditional ones especially where factors such as preservation and storage are better.

In conclusion I would like to stress that in dealing with agricultural wastes, economic considerations are inevitably taken into account. In some cases there is a lot of concern about the treatment or disposal of waste as far as the environment is affected. In other cases waste utilization means an increase in available resources. Anyhow environmental and resource aspects have an economic background.

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MODELING THE USE OF AGRICULTURAL WASTE - TAKING A BULGARIAN REGION AS AN EXAMPLE

M. Albegov, and T. Balabanov

The objectives of this study are as follows:

a) to formulate the core of the problem as it is seen by the authors (with respect to a particular region in Bulgaria);
b) to indicate the technical-economic data used in the calculations and their significance for the conclusions;
c) to show the results of the implementation of the integer program solution and to discuss their stability.

STATEMENT OF THE PROBLEM

Regions with a developed agricultural production and/or food processing industries have substantial cellulose residues such as:

- crop waste, sugar cane, threshing, crop stubble;
- animal dung;
- oil cakes, pressed mud from sugar factories, etc.

At present, these are partially utilized, after intermediate storage, as fertilizer, or burnt or destroyed by some other means, with harmful effects on environmental quality. This in turn results in additional expenditure. One way of utilizing fully agricultural by-products, and a means of cutting storage and processing costs, is transforming them into biogas and sludge (the latter which has great value as a fertilizer) by means of an established process of anaerobic digestion.

This process is characterized by several factors:

- the need to collect and transport the residues to the place of treatment;

- the capital and O & M costs of installing the digesters which depends to a great extent on the scale of biogas production;
- sludge and biogas have separate storage requirements;
- product distribution depends on consumption patterns and means of transportation;
- the utilization of non-conventional energy sources (such as solar heating) in order to accelerate the process of anaerobic digestion requires substantial amounts of additional capital; and
- the corresponding adjustment of the existing burners utilized also requires additional investment.

The importance of considering the overall implications of the introduction of this technology leads to the need for a comprehensive evaluation of its effectiveness. An evaluation of this kind was carried out in an agricultural region in Bulgaria (namely, the Silistra region). In order to include all the costs of the process and to choose optimal levels of production and storage under the given set of constraints, and supply and demand patterns, a linear programming model was constructed by Prof. M. Albegov and T. Balabanov with the assistance of Dr. Pitelin from the Central Mathematics Economics Institute of the Academy of Sciences of the U.S.S.R.

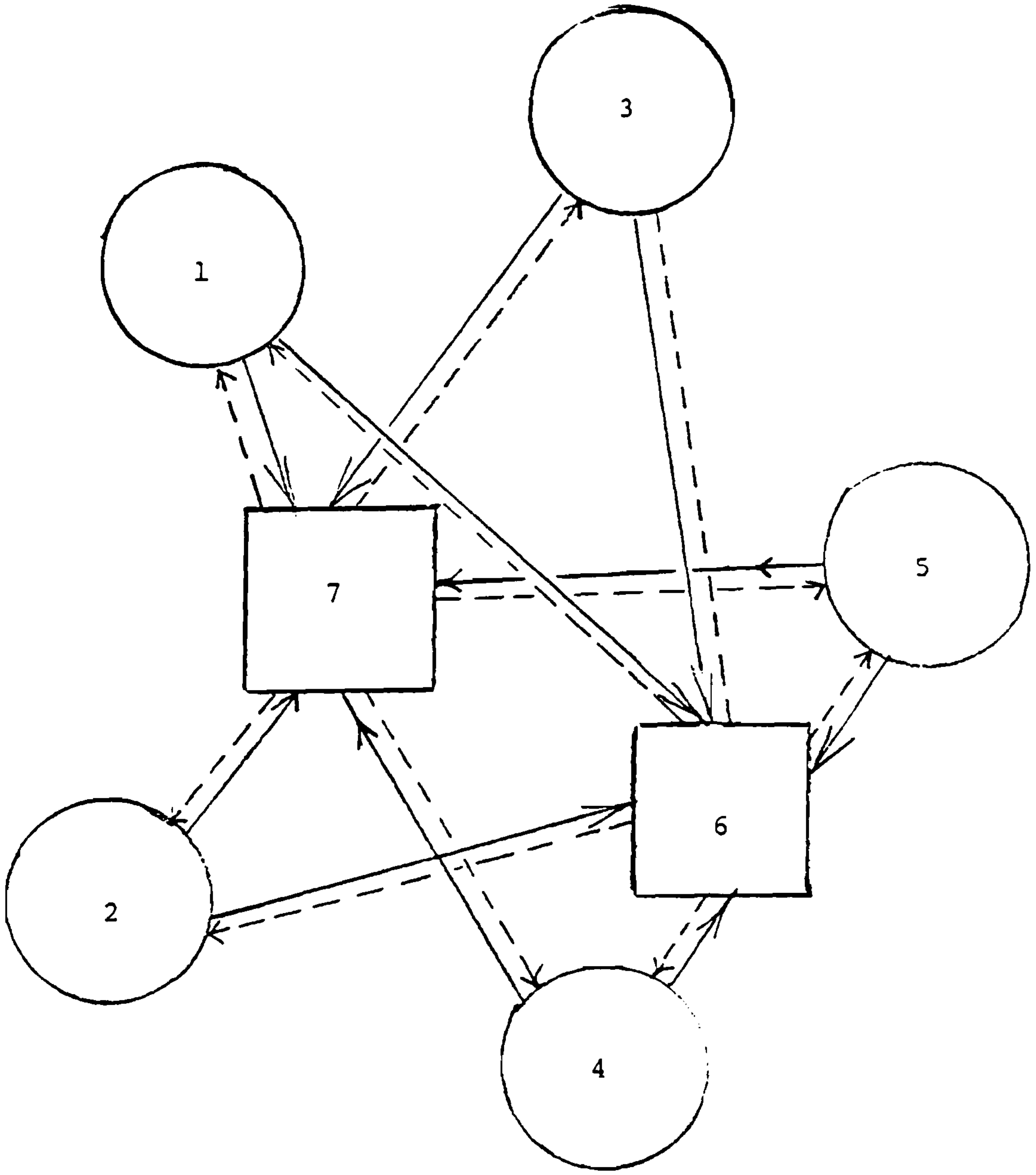
The model considers the following items:

- agricultural residues, treated as transportable (e.g. straw) and non-movable (e.g. animal manure), are distributed in several locations (see Figure 1, a simplified example);
- for each of the locations 1-7, seasonal patterns of residue production and fertilizer and biogas consumption are assumed;
- several (up to 6) production capacities (for the digester) are considered in order to be able to take into account the scale of the economy;
- the production system under consideration is described in Figure 2;
- it is assumed that the production system could be located in either of the locations 6 & 7;
- the products (biogas and sludge for fertilizer) could be transported to each of the locations 1-7; and
- the objective of the model is to maximize the replacement of conventional fuels (such as oil, gas or coal) and fertilizers.

A Description of the Case Study for the Silistra Region

This region has the following features:

- 7 locations of residue concentration and product consumption
- after a preliminary analysis, 3 of the 7 locations having digester installations were chosen;



1, 2, 3,...,7 points of concentration of the residues
6 & 7 possible locations of the digester, coinciding with the concentration of the non-movable residues

1-6; 1-7
2-6; 2-7
3-6; 2-7
4-6; 3-7
4-6; 4-7
5-6; 5-7

transportation distances multiplied by the average specific transportation cost of raw materials (in opposite direction gas and fertilizers are delivered including corresponding costs)

Figure 1. Sample of the layout of the locations and their transportation links for the region under consideration.

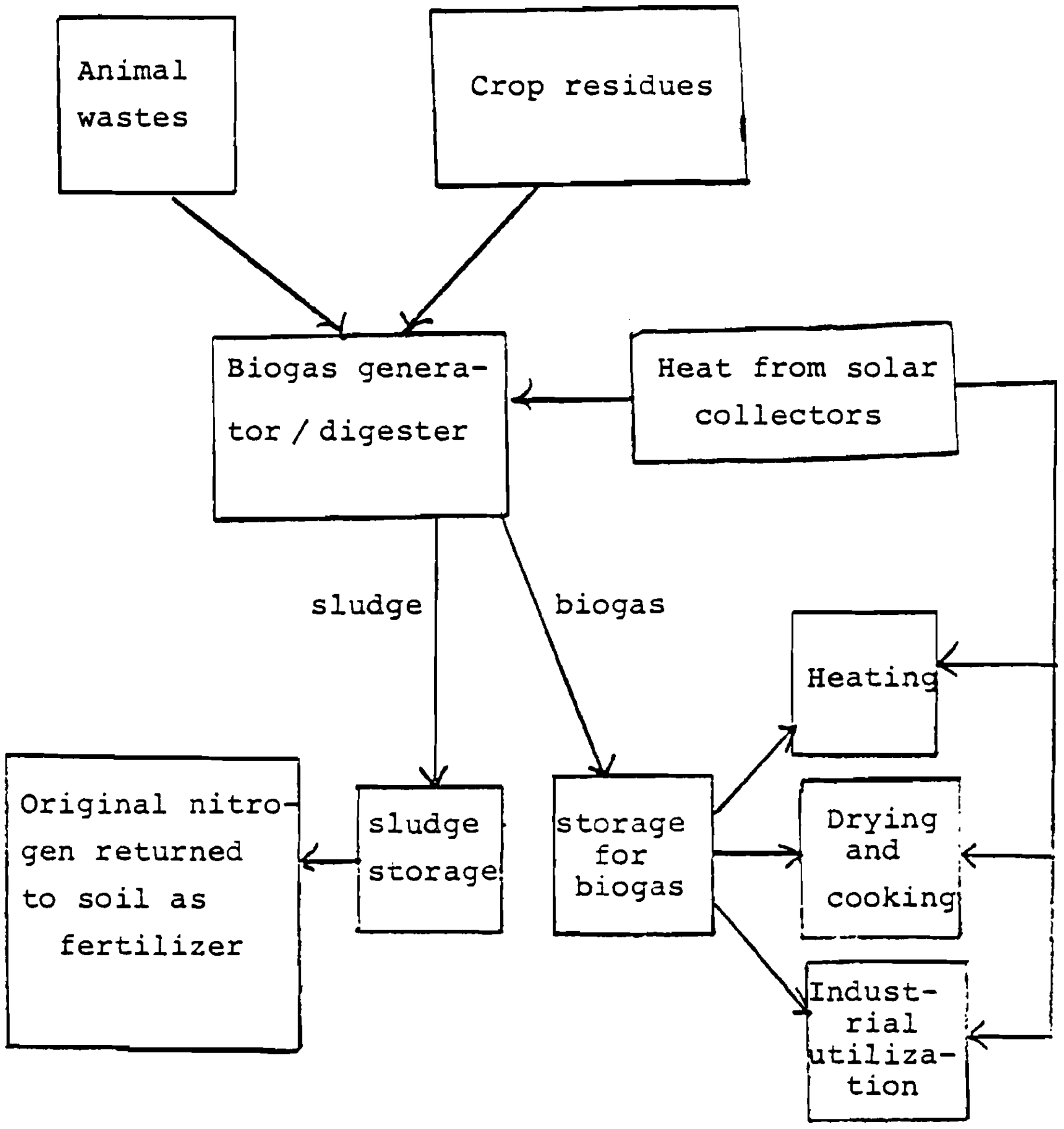


Figure 2. The production in the system under consideration.

-- transportation distances (km) were assumed to correspond with the existing road network, and a transportation cost of approximately 0,1 lv/t.km was calculated;

-- four types of residue were considered:

1. agricultural residues (movable);
2. pig manure (movable);
3. poultry (movable);
4. cattle manure (non-movable).

The problem was formulated bearing in mind seasonal differentiations in residue production during three periods of four months each (January-April, May-August, September-December). The pattern of maximal consumption of the products (1 = biogas; 2 = sludge for fertilizer) in the region under analysis is shown in Table 1 where biogas consumption is measured in $10^6 m^3$/period and sludge consumption is measured in 10^3t/time period.

The Results

The results showed that the justified production capacities for each point are 150, 50 and 50 $10^6 m^3$ biogas per year (Table 3). Fertilizer storage was built in two of the locations with a storage capacity of 18.27 and 14.54 10^3t/year. Fertilizers stored in the second period of time are used in the third period of time in accordance with the consumption schedule. Fertilizer distribution enables the fulfilment of the consumption schedule in all of the points.

It is clear that the construction of digesters is highly efficient: while the sum of discounted capital investments O & M and transportation costs did not exceed $1,9.10^6$ leva annually, the yearly benefit is 2.2 10^6 leva. This means that while the prices of fuels and fertilizers remain at their existing high level, the construction of large digesters and storages is very efficient.

Table 1. Seasonal variation in consumption.

Products & time periods	biogas				sludge	
	period				period	
location	1	2	3	1	2	3
1	120	32.4	120	21.6	7.2	0
2	12.34	3.3	23.34	18.	6.	-
3	16.3	4.35	16.3	14.4	4.8	-
4	-	-	-	20	6.8	-
5	-	-	-	12.1	4	-
6	-	-	-	16.8	5.6	-
7	-	-	-	16.8	5.6	-

Four production capacities were introduced whose costs of construction and exploitation are shown in Table 2.

Table 2. Cost of construction and exploitation.

Indexes	Scale	Annual productivity of digester (10^6m^3)			
		100	50	25	12,5
Capital investment per unit of production	leva/m^3	0.0529	0.066	0.076	0.0948
Total capital investments	10^6 leva	5.29	3.3	1.9	1.185
Operation and maintenance cost	10^6 leva/yr	6.3	5.4	3.6	3.6

Prices of fuel and fertilizers are very important for the economic efficiency of the digester construction. Bearing in mind the high level of fuel prices in Bulgaria, the price of substituted fuel was chosen: 250 leva/t oil, (or 125 leva/ 1000m^3 biogas), and a conditional price was given for fertilizer sludge: 70 leva/t.

Table 3. - CASE 1

Points of location			1			2						Total Supply		
Time Period t.p.		(4 months)	1	2	3	1	2	3	1	2	3	1	2	3
Capacity		10^6 m^3/tt	150			41.8			48.9					
Production of Bio-gas		10^6 m^3/tp	49.85		16.75	13.95		13.95	16.3		11.1			
Storage of Bio-gas		10^6 m^3				-1.65		+1.65						
Distribution of Bio-gas		10^6 m^3/tp	49.85		16.75	12.3		15.6	16.3		11.1			
Consumption of inputs: non transportable		10^6 m^3/tp	33.5		33.5	27.9		27.9	22.2		22.2			
transportable	1	10^6 m^3/tp	41.6	20.97										
transportable	2	10^6 m^3/tp												
transportable	3	10^6 m^3/tp							9.83		22.2			
Total Consumption of Inputs		10^6 m^3/tp	98.1		33.5	27.9		27.9	32.03		22.2			
Production of fertilizers		10^3 t/t	65.31		21.9	18.0		18.27	22.37		14.54			
Distribution of fertilizers	1	10^3 t/tp	21.6	7.2								21.6	7.2	
	2	10^3 t/tp				18.0	6.0					18.0	6.0	
	3	10^3 t/tp							14.4			14.4	4.8	
	4	10^3 t/tp	20.0	6.8								20.0	6.8	
	5	10^3 t/tp	12.1	4.0								12.1	4.0	
	6	10^3 t/tp	11.61	3.94					5.185	1.6		16.8	5.6	
	7	10^3 t/tp				12.27			4.25	5.6		16.8	5.6	
Storage of fertilizers		10^3 t				+12.27	+6.0	-18.27	+2.48	+12.06	-14.54			
Total distributed fertilizers		10^3 t/tp	65.31	21.94		30.27	6.0		24.85	12.06				

FARM AND COMMUNITY SCALE ETHANOL PRODUCTION

Roy Black, John Waller and Jon Bartholic

INTRODUCTION

The objective of this paper is to outline key issues in the production of ethanol at the farm and community levels and to illustrate the research paradigm used by the Michigan State University Agricultural Experiment Station and Cooperative Extension Service in approaching these questions. Additionally, inferences that can be extrapolated to large scale production that will be discussed. Our focus is upon the integration of biological systems, in conjunction with physical systems, that is required by the reduction in liquid fuels that society faces.

KEY ISSUES

The debate over the efficacy of ethanol production from feed grains has been far ranging, with two polar cases that are illustrative. On the one hand, it may be argued that the prevalent "state-of-nature" is one of excessive supplies of feed grains in North America and that these supplies ought to be used in the production of ethanol to reduce North America's dependence upon imported oil. In contrast, a second group believes alcohol production fermented from feed grains results in no net gain in liquid fuel production. It's like planting a bushel of corn to get a bushel back.

MSU scientists began by asking "if done properly, can alcohol production from corn contribute to net liquid fuel supplies?" Second, if net fuel supplies can be enhanced, "Under what conditions is ethanol production for fuel economically viable?" and "Is the potential impact to national gasoline supplies and for agricultural markets significant?"

UNRAVELING THE ISSUES

Table 1 depicts an estimate of the energy required in the production of corn, including the energy embodied in the fertilizer, herbicides, and pesticides, and in the production of ethanol from corn. Use of corn is assumed since it is the dominant feed grain in the United States, and the most widely discussed "near term" candidate. The implications of the energy balances are clear. If liquid fuels are used thoughout in the production of corn, in the fermentation and distillation of ethanol, and in the drying of the by-product (distillers dry grains with soluables, DDGS) there will be 0.25 gallon of "gasoline equivalent" reduction in liquid fuel supply per gallon of ethanol produced. In contrast, if solid fuels such as wood or coal are used, the net gain can be as high as 0.80 gallon per gallon ethanol produced. Thus, potential gains exist and it is relevant to ask "Is ethanol production from corn economic?" and "What size of plant is optimal?"

There are substantial economies of size, particularly capital and equipment in alcohol plant. The investment per gallon in a community scale plant of 5 million gallons of ethanol per year is two to three times larger than of a 50 million gallon per year plant. Economies accrue and labor and marketing as well. Further, a size is reached at which the carbon dioxide that is produced during fermentation is economically viable, and is closely tied to related infrastructure in the manufacturing industries.

Where, then, does ethanol production at smaller scales fit, or will it not be economic? On farm and smaller scale production offers three opportunities for enhancing energy gain and economics. If corn can be used in a high moisture form, 20 to 30% of the energy used in corn production can be eliminated. Further, if corn is grown in rotation with a legume or if interplanting with legumes can be achieved without sacrificing yield, an additional 20 to 30% of the energy required can be saved. If properly integrated, the transportation linkage to haul corn to the ethanol plant is eliminated if the ethanol plant is on the farm. If the ethanol can be used in the agricultural operations without being in anhydrous form, 20 to 30% of the energy used in distillation can be saved, and if the by-product can be fed on the farm the energy required for drying, which is 25 to 35% of the distillation and drying total, can be saved. Additionally, the transportation of the by-product from the ethanol plant to feed manufacturers and back to the farm can be eliminated. Last, a non-liquid energy source, such as biomass from the farm is required to close the linkage and to meet the objective of reducing the usage of liquid fuels in the entire ethanol production process. The potential net gain is as high as 7 gallons ethanol/gallon (liquid fuel gasoline equivalent) used in its production. That compares with a net gain of 3.0 gallons in a well integrated industrial scale plant.

Table 1 (a) Energy Required in Corn Production.

Operation	Percent of Energy Used
Tillage	7.7
Fertilizer	53.2
Herbicide and Pesticide Use	3.0
Harvest	2.5
Drying	28.0
Transportation	5.6

SOURCE: CAST Report 68, 1977; Energy Use in Agriculture, DOE (1979); and USDA (1980). Percentages vary with soil management group, cultural practices, and management.

Table 1 (b) Energy Required to Produce One Gallon of Ethanol from Corn (gallons of gasoline equivalents).

Task	Energy	
	Debit	Credit
Corn Production	.30 - .40	
Ethanol Production, including drying DDGS[1]	.35 - .90	
Ethanol (1 gallon)[2]		.80 - .90
By-product Credit[3]		.11 - .12
Energy Saved in refining by octane enhancement		.06

[1] Vendors of new technology claim 0.35 - 0.40 is feasible with current energy recovery techniques. Liquid fuel use (gasoline, diesel, natural gas) is near zero for this phase if coal or wood is used.

[2] Assumes a 2 to 3% increase in thermal efficiency of combustion when ethanol is combined with gasoline at low rates.

[3] Energy released by not growing and processing 52% Soybean Meal: 48% Corn "protein supplement" that has the same crude protein and energy as DDGS.

SOURCE: Black and Christenson (1980); DOE (1979).

We have illustrated some of the preconditions necessary for enhancing liquid fuel gains by small, and potentially community scale, production. The next question that must be asked, is, "Can these problems be solved?" and if they can be solved, "Will the resultant economic gain make the small scale plant potentially competitive with the large scale plant where economies of size prevail?"

RESEARCH PARADIGM

Michigan State University investigators analyzed the questions raised and concluded that the answers to potential technical and economic efficacy were positive. A program was initiated aimed at each of these issues. The analytical framework, depicted in Figure 1, takes a whole farm approach and looks at each of the linkages in an integrated biological context. The whole farm "model" was run under conventional technology and under our best estimate of what the parameters would be if research were successful (Parsch, et al, 1980; Jackson, et al, 1980). Linkages, as can be seen, involve critical ties between feed production and livestock diets, in labor utilization across subsystems, in the relationship between fermented feeds and the presence of the protected protein by-product DDGS in the animal diets, of the relationship between protein balance from alfalfa versus DDGS in the animal diets, and balance of energy required in the production of corn through its integration with legumes. Failure to place the question in this context dooms analyses to failure by both understating potential gains in some instances, while overstating gains in others.

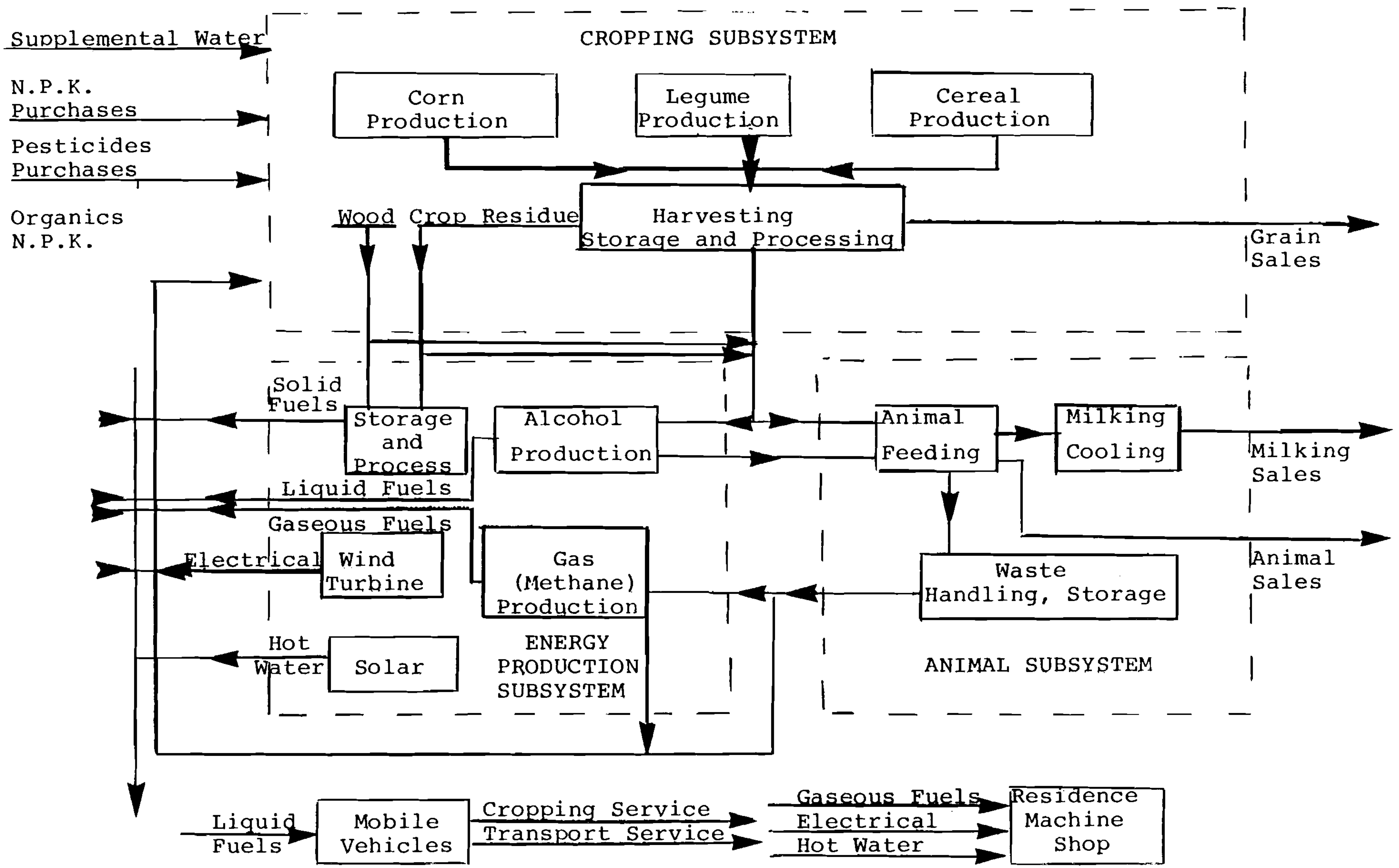
Research was divided into six subsystems: energy production for steam from biomass (e.g. corn stalks, corn cobs); preparation, cooking and fermentation of alternative feedstocks including dry (15% moisture) and high moisture (25 to 30% moisture) corn, sugar beets, potatoes, and fruit and vegetable processing industry waste; distillation of ethanol from solution including consideration of the energy and economic impacts of distillation to alternative percentages of ethanol; by-product (i.e. distillers grains) handling, storage, and feeding; utilization of ethanol; and economics, management, and energy balance analysis. The next section will outline research initiated in each of these areas, and results to date.

RESEARCH SUBSYSTEMS

Overview

MSU scientists have taken a general, as contrasted to situation specific, research approach. Multi-disciplinary teams with participants from agricultural and chemical engineering, agricultural economics, agronomy, animal science and microbiology have developed a research philosophy that focuses upon the development of simulation models to permit inferences to specific situations based upon a knowledge of general system properties. Thus, experimental designs focus upon more than "treatment" effects; the estimation of subsystem and system model parameters

Figure 1. Overall systems diagram.



is a primary objective. The "hardware", whenever possible, is highly controllable and has extensive monitoring capabilities, and control includes the ability to simulate the consequences of nonoptimal operating strategies.

The development of general systems modelling capability facilitates commercialization since an ability exists to develop "good" design and management systems for site specific applications. Too, the concept is consistent with objectives of MSU's Cooperative Extension Service programs in technology and management development and transfer.

An example from the livestock and poultry feeding and nutrition subsystem will be used to add concreteness to the concepts discussed. The unique protein characteristics of the by-product of ethanol production from corn, distillers grains with soluables (DDGS) provides a focal point. MSU scientists, and others, have developed biological simulation models of the lactating dairy cow and the growing and finishing feedlot animal (e.g. Bergen, et al, 1978; Fox, et al, 1977; Hlubik, et al, 1980; Waller, et al, 1979; Waller, et al, 1980). These models were developed: to provide a framework for understanding biological system input/output relationships; to obtain a better understanding of research needs; and to give a framework for development of site specific feeding systems including amounts to feed per animal per day and economic implications. These models include explicit consideration of key characteristics of feedstuffs and include the impact of method of harvest and preservation on these characteristics. Too, the system modelling approach permits integration of information from a wide range of experimental groups, thus not restricting inferences and system design and management recommendations to MSU investigations.

The issue is not "Can DDGS be fed?", but "How can the farmer and the feedlot manager utilize the DDGS to optimize its value?". Thus, technology transfer includes development of field calculator and computer models, adopted from the research models, that can be used by feed manufacturer salesmen and by university agricultural extension agents when working with individual and small groups of farmers (Black and Fox, 1978; Black and Hlubik, 1980).

Energy Production

A number of institutions in North America are investigating alternative means of production of steam from biomass including direct firing and gasification. Dr. Srivastava of MSU's Agricultural Engineering Department, for example, is working on the development of gasification units that could use either corn stalks or cobs. Economic studies by Loewer, et al, 1980, indicate this practice will become economic by the mid 1980's if natural gas prices continue to rise at recent rates.

The ethanol production unit at the MSU Beef Cattle Research Center uses natural gas as an energy source for the steam boiler. The objective, however, is to obtain a controllable source with the ability to vary steam output in a known way for the cooking, fermentation and distillation phases. The final farming systems analysis, however, will include a simulation framework that integrates Srivastava, and others, research.

Alternative Feedstocks

Michigan, because of its varied climate and soil management groups, raises a wide range of commodities and is in the top five states in the United States in the production of 25 commodities. As a consequence, there are a large number of alternative feedstocks, including wastes from the fruit and vegetable processing industry. Initial work was begun with 15 percent moisture corn as a reference, or standard, feedstock. The production scale (as contrasted to bench scale) production unit has been in operation for two months. Starch removal and conversion to glucose has resulted in 2.3 to 2.5 gallon (100% alcohol equivalent) per bushel of corn. That compares favorably, in a start up mode and with simple processes, with 2.6 gallons/bushel in the beverage alcohol industry. Initial work has begun on high moisture corn and the results look promising. The lactate which results from fermentation during ensiling reduces the potential yield, but this has been partially offset by the ease with which the starch can be separated from the corn kernel. Work is currently underway which focuses on the impact of alternative storage structures and management schemes on the extent of fermentation of high moisture corn, hence lactate production.

MSU facilities include bench-level fermenters as well as 500 gallon fermenters, a size that can be reasonably scaled upwards to make inferences to large scale systems. Initial research protocol is developed using the bench fermenter, with promising candidates then scaled upwards to the 500 gallon fermenter.

The fermentation and distillation processes have been studied from the point of view of "end point control" as contrasted to "time" control. Development of control mechanisms which would permit an ethanol system to run under automatic controls, somewhat as a continuous flow grain dryer operates, is under consideration.

Distillation

Distillation design was coordinated with the ethanol end use design. Work has shown that ethanol can be used in turbocharged diesel engines using alcohol injection processes at 100 proof (50% ethanol, 50% water). Thus, the distillation column was designed by Drs. Hawley and Grulke of the Chemical Engineering Department to permit stripping out 100 proof alcohol from the fermented feedstocks in the first phase. The column, a plated column, was designed to permit re-distilling of the alcohol/water mixture to upgrade alcohol to as much as 190 proof. The column has glass walls which permits observation of its properties, and can be taken apart with plates restructured in a number of ways to test the efficacy of alternative design and management systems. Additionally, glass construction has proven exceptionally fruitful from a demonstration perspective.

One of our objectives is to work with ethanol production unit manufacturers on system design and management. Too, a system that can be used as part of an instructional program for farmers and operators of community scale ethanol production units is important.

Ethanol Use as a Liquid Fuel

The fuel use subsystem includes three components. First, a simulation model of cash grain and livestock farms developed by MSU scientists is being used to develop load factors to better understand the conditions under which ethanol would be used. Second, a duel fueled diesel engine and a spark-ignition engine converted to use alcohol are being studied in the context of alternative loads and field conditions. These are taking place under the direction of Dr. Rotz of the Agricultural Engineering Department. Third, by understanding loads that will exist and by understanding the properties of ethanol under alternative fueling sustems, the efficacy of alcohol as a fuel can be examined under the wide range of conditions which occur in Michigan agriculture, not just a particular single condition observed in a study. Results of duel fueling indicate a replacement of 25% diesel is possible under certain load conditions. An increase in thermal efficiency with alcohol as a fuel has also been noted.

By-product Use

The utilization of the by-product in high moisture form involves questions of storage and handling as well as feeding. Thus, the protocol was to develop and characterize handling and storage properties, particularly those that result because of the contamination that occurs in the practical operations of moving material through pipes, troughs, and other vehicles. Storage life has been ranged from as little as one day to as high as a week, depending on how the material was handled and whether it was done under lab or field conditions. The objective in the MSU study is to understand characteristics under field conditions, and to examine potential additives which might extend storage life.

Consideration of alternative separations systems is included in the project. This is critical for "within" feedstocks issues such as the utilization of distillers' grains versus distillers' soluables from corn. Also, the properties of by-products from new ethanol sources such as fruit and vegetable waste are largely unknown.

Nutritional work begins with a biological model which provides focus on the subtleties of protein and energy metabolism, then involves individual animal invivo studies to assess the parameters that are used in the biological simulation model, feedback updating the parameters of the biological model, and conclusion with "feed and weigh" experiments based upon diets expected to optimize by-products nutritional properties. That is, feeding trials are designed based upon regimes predicted to be optimal by the biological model; these by-product diets are compared to well-known, standard diets, such as use of soybean meal or urea as protein sources. Data gathered include average daily gain, feed efficiency, and carcass quality.

Research, to date, has focused on biological model development and updating, including joint investigations with the National Research Council By-products subcommittee chaired by Waller, and animal dry matter intake and in vivo studies.

Economics, Management, and Energy Balance

The ultimate question is, "When integrated into a whole-farm context, what is the economic efficacy of alternative design and management strategies?" Concommitantly, what are the associated labor and management skills required for alternative degrees of farming system performance.

RELEVANCE TO LARGER SCALE PRODUCTION UNITS

ENERGY BALANCES, INCLUDING EMBODIED ENERGY FLOWS PRE- AND POST-INVESTIGATIONS

Many of the results from the smaller scale design and management systems are relevant to larger scale units. For example, the outcome of feeding experiments of high moisture by-products are relevant for community scale ethanol production units that are integrated into livestock production systems, as well as in the smaller scale system. High moisture corn investigations can be translated to any size of system. Work delineating the impact of storage systems is of relevance across all scales of operation. Additionally, the pilot scale nature of the system at MSU is critical in the delineation of the ethanol production process from new products that have not previously been tried. The controllable nature and the highly monitored nature of the MSU process is particularly valuable here.

CONCLUSION

Institutional arrangements for successful research include the need for multidisciplinary teams, controllable systems with adequate monitoring, and the ability to simulate from first principles and existing knowledge base to a wide range of alternative environments. MSU investigator's experiments have found operation under that research philosophy is necessary for success.

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ENGINEERING FEASIBILITY FOR PRODUCTION OF ENERGY FROM FOOD PROCESSING WASTES

Dennis R. Heldman

INTRODUCTION

The current research efforts at Michigan State University began in 1976. At that time a research proposal was funded by the National Science Foundation under the title "Food Losses and Wastes in the Domestic Food Chain of the United States". The overall objective of the research effort was to establish the magnitudes of food losses and wastes between harvest or assembly and delivery of the food product to the consumer.

The research conducted leading to the results presented in the NSF report was divided into three parts: a) losses and wastes occurring between harvest or assembly and the processing plant, b) losses and wastes occurring during processing and packaging of the product and c) losses and wastes occurring during distribution of the packaged product to the eventual consumer. The research was conducted by an interdisciplinary team of research scientists from Agricultural Engineering, Food Science, Agriculture Economics, and Marketing and Transportation Administration.

The definition of a food loss or waste is very important to the interpretation of results found in the published literature. Although it is possible to define a loss or waste in many ways, the discussion to be presented will use a single definition. This definition indicates that a loss or waste is equivalent to the mass of raw food commodity that is not a part of the primary product delivered to the consumer. Although this definition does have limitations, it provides for consistency of interpretation throughout the food chain. The losses and wastes presented in the NFS report deal with four commodities including apples, potatoes, fluid milk and fresh beef.

A summary of the losses occurring during delivery of fresh beef to the consumer are presented in Table 1. These results illustrate that approximately 1.3% of the animals weight is lost prior to slaughter while over 40% of the loss occurs during the slaughtering and trimming process. Following slaughter and trimming, the amount of loss occurring during distribution depends upon the manner in which distribution is handled. An overall approximation of losses indicates that cumulative losses are approximately 47 to 48% or yield would be in excess of 52% of the original animal weight. It is obvious that the majority of the loss occurs during the slaughter process and it is recognized that some of these materials are already used for various types of by-products.

The losses occurring during handling, processing, distribution of fluid-milk are summarized in Table 2. When considering overall losses it is clear that they will be less than 7% of the original amount of raw milk entering the food chain. The highest proportion of this loss occurs during processing but it seems evident that there is not sufficient magnitude to be considered for by-product utilization.

The losses occurring during handling, processing and distribution of apples and potatoes are presented in Tables 3 and 4. An analysis of these results indicates that the overall magnitudes of loss are very similar for the two commodities. Yields are just less than 40% indicating that losses of mass are 60% or slightly higher for both apples and potatoes. The two commodities are similar in that approximately 10% of the loss occurs during post-harvest handling and storage. The cumulative losses increase to approximately 25% during pre-processing sorting and handling. Depending upon the specific processed product considered, the overall losses increased to around 60 to 62.5% during processing. The losses in mass occurring during distribution of various apple and potato products is relatively small. In both cases the mass losses occurring during pre-processing and processing appear to be significant and should offer opportunities for by-product utilization as well as other considerations such as energy production.

CURRENT RESEARCH

Current research being conducted at Michigan State University deals with several aspects of losses and wastes in the food chain. The overall objective of the research can be stated in the following manner: to optimize the utilization of the raw food resource. In general, this research involves a more in-depth analysis of the losses and wastes occurring in the food chain for various commodities.

The specific objectives of the current research effort include: a) to determine the magnitudes of the liquid and solid waste streams from food processing operations, b) to measure the composition of liquid and solid waste streams from food processing operations, c) to conduct energy and mass balance

Table 1. Cumulative beef losses in the food chain

			Cumulative	
			%Loss	%Yield
PRESLAUGHTER HANDLING				
Ranch to)				
Feedlot to) Transit		0.05% loss		
Auction yard to) Non-transit		1.28%		
Slaughter plant)				
			1.3	98.7
PROCESSING LOSSES				
Condemned pre-slaughter		0.03%		
Condemned post-slaughter		0.30%		
Dark cutting beef (devalued)		0.50%		
Slaughter losses		40.00%	40.8	59.2
Hide	(11%)			
Blood	(3%)			
Offal (edible)	(3%)			
Offal (inedible)	(23%)			
Chilling/aging		5.00%		
Trimming		2.00%		
			44.93	55.07
DISTRIBUTION (% beef into each option)				
Carcass to retailer (20%)		7.50%	49.06	50.94
/or/			/or/	
Central cutting (15%)		6.00%	48.23	51.77
/or/			/or/	
Boxed beef (65%)		2.50%	46.31	53.69
Weighted average:		4.025%	47.65	52.35

Table 2. Cumulative fluid milk losses in the food chain

		Cumulative	
		%Loss	%Yield
HANDLING AND TRANSPORT			
Load at farm	0.10%loss		
Haul	1.20%		
Unload (spills)	0.03%		
Wash tanker	0.05%		
Total farm to plant	0.0875-1.2% (1%)	1	99
PROCESSING (assumes no spills or leaks)			
Receive	0.18%		
Clarify/standardize	0.072%		
Raw storage	0.18%		
Pasteurization/homogenization	0.72%		
Pasteurized storage	0.18%		
Fill	0.27%		
Convey/cold storage	0.18%		
Returns	0.45%		
Total processing losses	2.23%	3.97	96.03
DISTRIBUTION			
Marketing	0.5-1% (1%)		
Retailing	2.00%		
Total distribution losses	3.00%	6.93	93.17

Table 3. Cumulative apple losses in the food chain

				Cumulative	
				%Loss	%Yield
POST-HARVEST					
Handling		1% loss			
Storage		0-50%			
Transit		2%			
				10	10
PRE-PROCESSING					
Culls		6-18%			
Bruised[1]		20-70%			
				25	75
PROCESSING LOSSES					
Peeling		4-16%	(12%)		
Coring		5-8%	(7%)		
Trim		0-12%	(5%)		
"Splatter"		1-2%	(2%)		
Specific products					
Slices, canned		47%			(39.75)
frozen		30-40%			(48.75)
dried		87.5%			(9.38)
Sauce		20-40%			(52.50)
Juice		10-45%			(22.50)
				60	40
DISTRIBUTION					
Table stock:	wholesale	3%			
	retail	2%			
				(70)[2]	(30)
Processed:	transit	0.7%			
	wholesale	0.05%			
	retail	0.1%			
				60.4	39.6

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[1] Apples are highly susceptible to mechanical damage, and may be marketed or processed in spite of bruising. Literature discussions focused on damage but not on actual losses. Moreover, specific crop situations change from year to year and influence losses.

[2] Eating apples are more carefully culled than processing apples, but we have not considered those apples diverted into processing "losses." If we had, the loss figure would be much higher.

Table 4. Cumulative potato losses in the food chain

				Cumulative	
				%Loss	%Yield
POST-HARVEST					
	Handling	0.8%	loss		
	Storage	6-25%			
	Transit	1%	(5-20% bruised)[1]		
				10	90
PRE-PROCESSING					
	Soil	1.5-3.0%			
	Culls, pickouts	0-62%[2]			
				25	75
PROCESSING					
	Peeling	1-50%	(17%)		
	Cutting, slicing, washing	10-40%			
	Leaching	5-6.5%			
	Specific products				
	Chips	74-80%			(42.24)
	French fries (raw cuts)	25-50%			(48.75)
	(finish fried)	55-70%			(30.00)
	Canned	5-10%			(67.50)
	Dried, flakes	16-22%	(solids)		(20)
	Dried, slices	30-40%	(solids)		(10)
				62.5	37.5
DISTRIBUTION					
	Table stock: wholesale	1.5%			
	retail	4.0%			
				(69)	(31)
	Processed: transit	1.0%			
	wholesale	.05%			
	retail	0.1%			
				(63.2)	(36.8)

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[1] Highly susceptible to mechanical injury, potatoes are marketed and processed despite damage, and the literature focused on damage rather than on discards.

[2] Table stock may be selectively culled for size and quality, but the rejected tubers will not be discarded. Thus, we have not included that "loss" in the cumulative column.

analyses on individual unit operations within the food processing plant and d) to select the most appropriate technologies for utilization of the waste streams from processing operations. The research is focusing on losses and wastes occurring at the processing operation in an effort to determine whether the magnitude of the losses and wastes is sufficient to satisfy existing technologies for utilization of these losses and wastes. Hopefully the appropriate scale of technology can be selected so that transportation of the waste materials will not be required in order to make use of the technology.

An example of the magnitude of losses occurring during the slaughtering operation from fresh beef is presented in Table 5. Based on the results presented 541 lbs. of waste material are generated from each 1000 lb animal. Overall, based on 1975 production figures in the United States, 18,940 million lbs of waste material are generated by the beef slaughtering processes. Although this represents a very significant figure, it must be recognized that these wastes are generated at dispersed locations and any technology that might be utilized to recover these waste materials must be scaled to the size of existing slaughtering operations. A more specific analysis of apple processing operations is evident from results in Table 6. It is evident that the majority of the waste materials occur due to bruises on raw apples and that peeling is the primary processing operation leading to waste materials. Other reductions in mass may be classified as intentional losses associated with removal of water from the product.

A more in-depth analysis of the potato processing operation can be attempted by first recognizing the various processed products based on raw potatoes. The illustration in Figure 1 indicates that potato products can be placed in 5 categories including potato chips, potato flakes, french fries, dried potatoes and canned potatoes. It is also evident from the illustration that many of the preliminary steps for handling the raw product are the same for various final products. An in-depth analysis of the losses and wastes occuring during processing potatoes is summarized in Table 7. In this table all results are presented as kilograms of product loss per kilogram of raw potato. A review of these results indicates that peeling as well as slicing and cutting of the raw product generate significant magnitudes of solid waste for each of the 4 final products. For potato chips and french fries the magnitude of the losses are nearly .25 kilograms per kilogram of raw potato. Although magnitudes of losses are large in the case of frying for potato chips and drying in the case of potato flakes, these values are almost entirely water removed from the original product. It is evident that any interest in recovery of potato solids that are currently lost should focus on the peeling, slicing and cutting operations.

The conclusions based on our preliminary analysis of potato processing operations would indicate the following: a) most waste potato solids are associated with peeling, slicing and cutting operations and these waste streams should be segregated from other streams to assure efficient utilization, b) thermal waste streams from frying and dehydration operations should be analyzed more

Table 5. Summary of typical losses and yields during beef processing[1]

	Single animal[2]		Total 1975 production[3]	
	Losses	Yields	Losses	Yields
	lb.	lb.	B.lb.	B.lb.
Live weight		1000		35
Slaughter losses				
Blood	34		1.19	
Hide	89		3.12	
Offal (inedible)[4]	208		7.28	
Processing scrap[5]	42		1.47	
Edible organ meat		27		.95
Carcass weight		600		21
Aging losses				
Moisture	30		1.05	
Trim	12		0.42	
Aged carcass weight		558		19.53
Division losses				
Into primals and retail cuts[6]	126		4.41	
Yield retail cuts		432		15.12
Total losses	541		18.94	
Total edible yield		459		16.07
Muscle meat		432		15.12
Organ meat		27		0.95

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[1] Realizing that each animal is different, this summary attempts to combine information found into "typical" loss picture.

[2] 1000 lb., yield grade #2 (See table 9).

[3] In fiscal year 1975, 34,906,670 beef cattle were slaughtered and passed inspection. For purposes of this report, 35 billion lb. live weight, yield grade #2, was assumed.

[4] Partially recoverable, variable economic return.

[5] Product lost in removing hide, bones, splitting carcass, etc.; value influenced by skill and care of employees.

[6] Includes bones, suet, scrap; influenced by skill and care of cutters as well as management policy on degree of trim.

Table 6. Summary of losses during apple processing

Pre-process losses			
Culls	6-18%	(12%) (diverted into juice)	
Bruises	21-70%	of fruit may require trimming	
Rots	0-50%	depends on storage conditions	
Processes losses			
Peel (caustic)	4-7%		
Peel (mechanical)	11-16%		
Core	5-8%		
Trim	0-12%	(If > 12%, fruit most likely diverted into press)	
Apple sauce			
Peel, core, trim:	lower limits		(20%)
Finisher	4-10%		
"Splatter"	1-5%		
Yield (plain)		60-80%	
(added sugar and water)		80-100%	
Slices			
Peel, core, trim:	upper limits		(43%)
Broken slices:	5-9%		
Yield (before pack)		55-60%	
(after pack) -	canned	53%	
	frozen	60-80%	(5:1 with sugar)
	dried	12.5%	
Press (juice)			
Yield		55-90%	(65-75%)

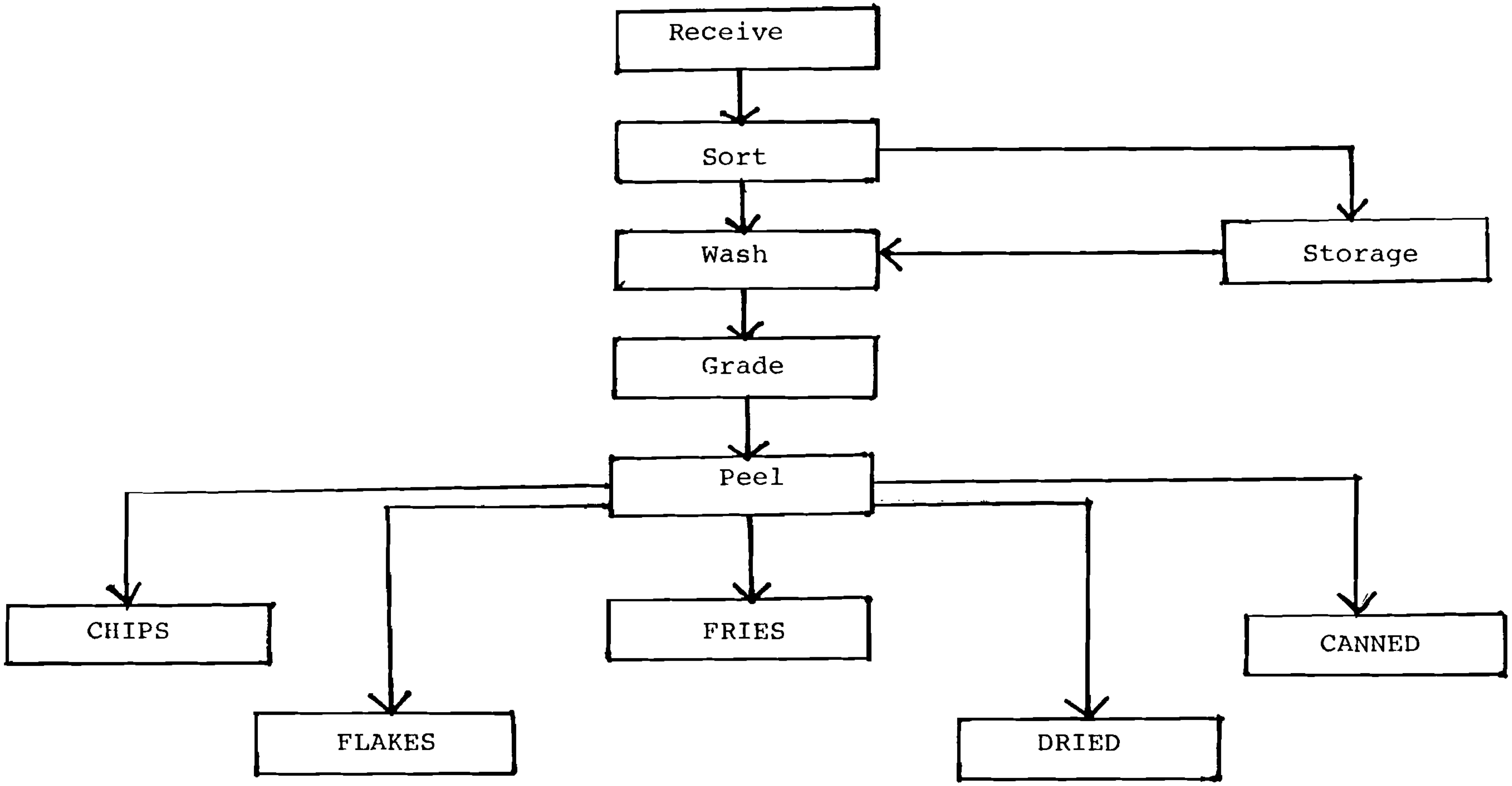

Figure 1. Preparation sequence for processed potato products

Table 7. Estimated waste stream magnitudes from various unit processes for potato products. (All values represent kg loss/kg raw potato).

Unit Operation	Potato Chips	French Fries	Canned Potatoes	Potato Flakes
Pre-processing	0.05	0.05	0.05	0.05
Peeling	0.095	0.095	0.057	0.095
Slicing-Cutting	0.13	0.13	0.014	0.086
Washing	0.04	0.04		
Frying	0.52			
Blanching		0.014		0.008
Par frying		0.27		
Canning			0.0018	
Drying				0.686
Total	0.835	0.599	0.1228	0.925

thoroughly to evaluate opportunities for energy recovery, and c) preliminary estimates indicate that between .97 and 2.9 liters of ethanol could be generated from waste streams for each 100 kilograms of raw potatoes.

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APPENDICES A & B

APPENDIX A: LIST OF PARTICIPANTS

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APPENDIX B: LIST OF WASTES, BY-PRODUCTS AND OTHER RAW MATERIALS REFERRED TO IN PAPERS PRESENTED AT THE TASK FORCE MEETING ON NEW TECHNOLOGIES

Wastes or By-Products:

Cotton seed husks
Tannery wastes
Wood waste
Straw
Peanut press cake
Coconut press cake
Poultry feathers
Molasses
Palm oil extraction waste
Rum and other alcohol distillation residues
Coffee processing waste
Deproteinized leaf juice (from green crop fractionation)
Potato, wheat and maize starch processing wastes
Citrus pulp
Citrus molasses
Banana waste
Fruit and vegetable processing wastes
Distillers dried grains
Slaughterhouse effluent
Rice starch factory effluent
Corn bran
Cotton stalks
Potato processing industry wastes
Cheese whey

Broiler litter
Sewage sludge

Sulphite waste liquor
Paper production wastes

Sugar beet juice
Sugar beet pulp
Sugar cane stalks

Sunflower (flower head after seed removal)
Sunflower husks

Olive oil extraction waste
Olive seed waste

Other Raw Materials:

Methanol
Ethanol
Alfalfa leaves
Cassava (manioc)
Soya beans