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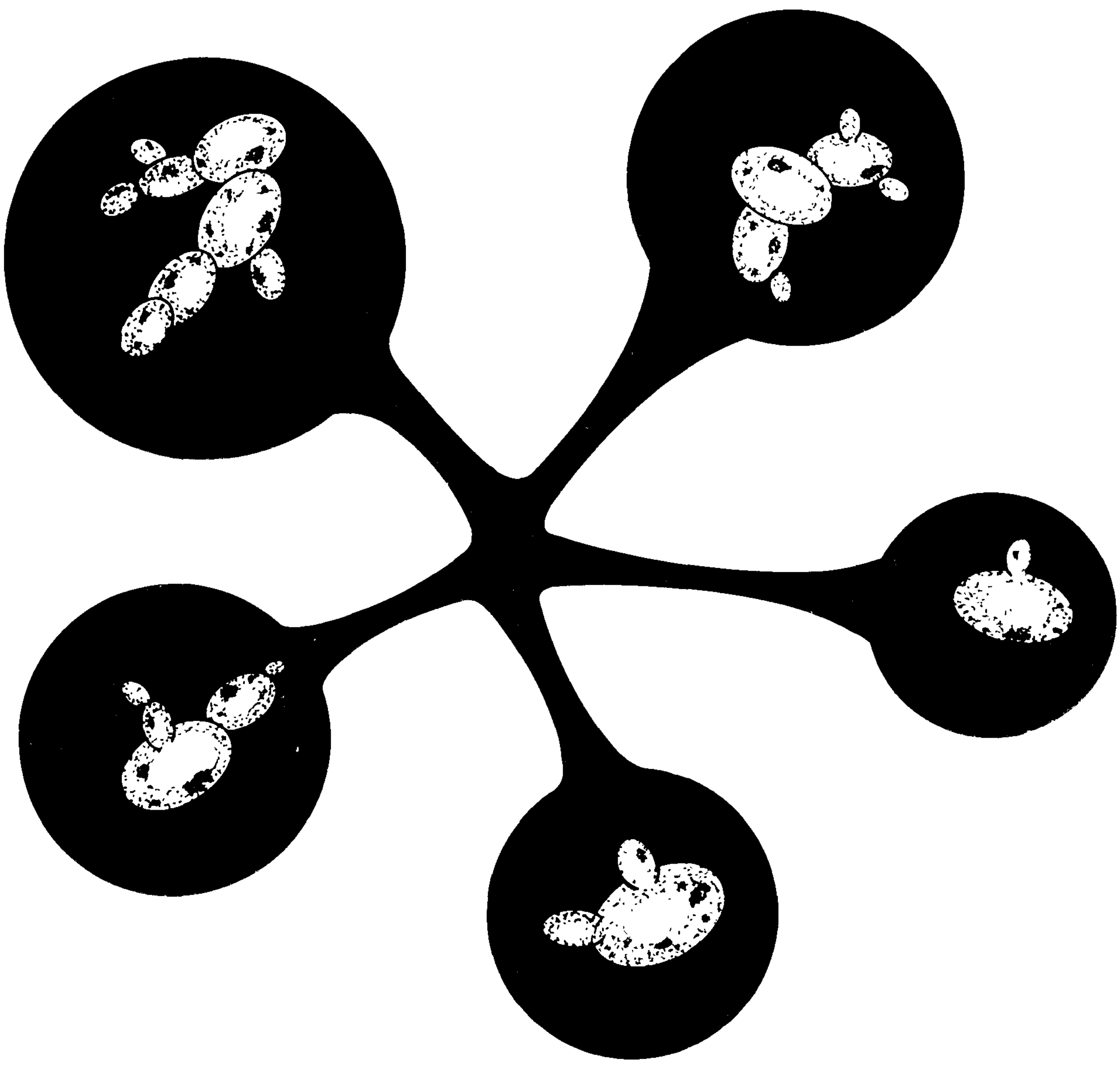
CONVERSION OF ORGANIC SOLID WASTES INTO YEAST

...an economic evaluation



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CONVERSION OF ORGANIC SOLID WASTES INTO YEAST

An Economic Evaluation

This report was prepared for the Bureau of Solid Waste Management
by Floyd H. Meller
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F O R E W O R D

This publication on the economic evaluation of the conversion of organic wastes into edible protein will be of particular interest to readers in universities and research-oriented organizations. The work was performed under contract during the period 12 June 1967 to 11 February 1968, and the subsequent report is reproduced herein exactly as received from the contractor, so that it can reach researchers as quickly as possible.

The present volume is another facet of the many demonstrable results now forthcoming from passage of the 1965 Solid Waste Disposal Act, the purpose of which was to initiate and accelerate research to better manage the nation's solid wastes. This Act directs the Secretary of Health, Education, and Welfare to carry out most responsibilities under the Act, and the Bureau of Solid Waste Management was created for this purpose. Some technical investigation and research are conducted by the Bureau in-house. However, the vast research effort needed for learning how to manage the nation's yearly volume of 3.5 billion tons of solid wastes requires intellectual focus and cooperative studies from all possible quarters. Capabilities of universities and other nonprofit organizations are being tapped through research grants and other types of grants. Engineering applications are being tested by institutions and communities across the nation through demonstration grants. Grants to States for planning and to various smaller regional groupings for study and investigation will lead to widespread application of the results of this research and demonstration. The contract mechanism, which is resulting in reports such as this, has made it possible to use the trained research staffs and accumulated practical experience of commercial and professional consultants.

A nationwide effort is thus surging through the scientific and technical community,-- gathering the substantive data, the fresh ideas, and the momentum that will make possible the management of the steadily growing quantity of solid wastes.

--RICHARD D. VAUGHAN, *Director*
Bureau of Solid Waste Management

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INTRODUCTION

GOLD FROM GARBAGE is the euphemism attributed to the goals of current research efforts and investigations into the utilization of the solid waste materials generated by our society. Conservative estimates place the yearly solid waste load at more than 165 million tons. By 1980, the burden will increase to an estimated 260 million tons per year. The useful application of this current national liability will result in a raw material asset from which viable industries of the future must evolve.

The adage of Waste Not, Want Not applies here. The conservation of raw materials through reuse has been applied in the solid waste field in the past. This has been particularly apparent during periods of national strife when raw materials are in short supply. A case in point was the increased utilization of paper wastes during World War II. During normal economic periods however, the laws of the market place are king in a free economy and technically useful materials are relegated to the waste bin for economic reasons.

The assigned purpose of this study, therefore, is the economic evaluation of one approach to the utilization of urban and agricultural organic wastes. The direction of the study has been to investigate the economic feasibility of converting urban and agricultural solid wastes to edible protein. The approach to conversion of organic wastes to edible protein utilizes a two stage process of hydrolysis and fermentation. The operation and economics of each stage is examined in order in the text.

Wastepaper and bagasse were selected for specific study based on the availability of economic data and the feasibility of a central supply for these waste commodities. Wastepaper has the secondary advantage of having been on the waste commodity market for a significant period of time so that fluctuations of supply and demand on price can be evaluated. It should be kept in mind that this selection of materials was made as a convenience for economic evaluation and does not imply a limitation of the process to these raw materials. In the case of urban wastes, the processing of mixed paper and organic garbage is felt to be feasible and reasonable and is in fact considered as a third major raw material source in this report.

The design of the hydrolysis process is based on work carried out at the Forest Products Laboratory in Madison, Wisconsin. Saeman and co-workers developed the necessary kinetic data for the hydrolysis of wood. This information while not specifically applicable to wastepaper and bagasse should give a conservative estimate of process economics due to a slower rate of wood chip permeation by the hydrolyzing acid as compared to pulped fibers.

Fermentation processing follows the traditional lines of the required aerobic process for the propagation of cells. Special considerations of plant location economics are evaluated and discussed.

Marketing considerations are based on the production of protein of the general character of Torula Yeast (Candida utilis). Although other single cell protein may actually be employed in the process due to economic considerations such as propagation rate, the use of Torula Yeast as a product choice gives a framework for market analysis based on established nutritional values of a material that is capable of propagating in the mixed sugars supplied to the fermentor from the hydrolysis plant.

The potential markets for protein supplements in the human food and animal feed areas are considered in light of the present technology and of current market trends. Marketing problems and competitive or alternate product approaches are evaluated on a domestic and international basis.

No consideration is given in this report to the possible valuable by-products that can emerge from the processing steps utilized. The exact nature and quantity of by-product materials can only be derived from a laboratory study of the processes using the actual waste materials being considered. Process maximization for by-products of significant value will of course, alter the overall economic picture.

It is not surprising that many assumptions had to be made in developing this study. Qualifications and documentation have been included as justification insofar as is possible. Unfortunately, marketing projection for the primary protein product is beclouded at this time by much opinion and conflicting data.

Acknowledgements

Grateful recognition is given to Professors Richard I. Mateles and Daniel I.C. Wang, Department of Nutrition and Food Science, Massachusetts Institute of Technology for their contribution to the fermentation section of this report as well as their help in obtaining meaningful information on yeast and protein markets.

Special recognition is accorded Kenneth J. McNulty of Ionics Research Department who is responsible for the work on hydrolysis including the addendum report to this volume.

Special thanks are given to the many individuals in industry, government agencies and academic institutions who have contributed to this story.

CONCLUSIONS AND RECOMMENDATIONS

THE FOLLOWING CONCLUSIONS and recommendations summarize the problems and prospects discovered in pursuing the goals of this study. Much work lies ahead before the economic utilization of the wastes of our society become a reality.

A. Conclusions

Economics of Waste Materials:

The economic consideration of solid waste raw materials is a complex subject. Although wastes can be categorized into two main subdivisions of urban and agricultural residues, this is insufficient for a quantitative look at the raw material economics.

Problems involved in the definition of economics for urban wastes include the composition of the refuse, the manner in which collection affects refuse composition, the volume of refuse and the geographical and population factors that affect both composition and volume. Studies to date indicate that each municipality has unique characteristics and problems in waste generation and collection. This would imply that processes utilizing solid urban wastes as a raw material must be evaluated for the source of supply on a local basis. In order to accomplish this task methods must be developed to accumulate "standard engineering data" on municipal solid wastes. Sampling and analytical techniques, while under current development, require much improvement. The development of this data is bound to be expensive since refuse composition is seasonal in nature requiring year long studies to produce meaningful data. Perhaps predictable ranges of refuse compositions will develop on regional geographic areas with qualifying inputs for degree of affluence, etc. as more local studies are completed. In any event the need for a "standard method" of sampling and analyzing solid urban wastes is paramount.

When evaluating the economics of urban solid wastes it is impossible to ignore the tremendous cost involved in collecting and transporting this refuse to the disposal site. Although not directly associated, it is desirable for new waste utilization schemes to have the latitude to accept wastes that are transported to the plant site by means other than motor truck. Possibilities include pneumatic or hydraulic transmission, both of which appear to be technically feasible.

The proposal of a utilization system for disposing of waste materials ultimately brings the confrontation with current methods of disposal and their economics. In the case of this study the use of urban wastes as a feed to the hydrolysis-fermentation process must consider and condense the myriad possibilities of raw material costs and credits that can be concieved. Municipal dumping fees as currently used in compost plant evaluations appear to be a realistic starting point. These plant credits however must be tempered with raw waste preparation costs and possible salvage markets. In this study two values were used for urban refuse: One designated as "Organic Urban Refuse" applied dumping fee credits, considering waste preparation costs to equal salvage values obtained on segregation of organic wastes from cans and bottles, etc. at the source; the second category designated "Mixed Urban Refuse" included an economic penalty for the preparation of mixed raw refuse before introduction to the hydrolysis plant. These two categories should bracket the economic situations that can exist in a real application and therefore represent a total range for the utilization of urban wastes by the hydrolysis-fermentation operation.

As another approach to the raw material economics the use of a segregated waste such as wastepaper which appears as a product on the secondary materials market was considered in detail. The use of the lower grades of wastepaper can be economically feasible and present a more uniform feed to the hydrolysis operation. However, the price of this material is controlled by the business cycles of the pulp and paper industry which has experienced some wide fluctuations in the past twenty years. These price swings could be disastrous to the economics of products produced by the hydrolysis-fermentation process if wastepaper were the sole raw material source. Paper wastes, however are stable in storage and may be utilized to balance seasonal feed availability cycles for primary urban organic refuse utilization plants.

Agricultural wastes are self segregating with regard to their economic usefulness as a feed to utilization plants. One major group of agricultural wastes available in very large quantities are the residues left in the fields after harvest of the primary crop. This includes straw, cornstalks and cobs and other plant wastes where field harvesting has become highly mechanized. The cost to collect these residues preclude their use as a raw material feed to hydrolysis plants in the United States at this time.

A second major group of agricultural wastes are the solid residues collected at canning plants. These wastes have the advantage of being available at a central location and at a probable negative cost to the utilization process. Their production however, is limited to a very short season. This coupled with a high perishability factor requires immediate treatment of the wastes and hence a large facility representing a large capital investment for the yearly (3 month/year operation)production of hydrolyzate sugars.

One agricultural waste seems to combine the best features of the two categories discussed. Bagasse, or sugar mill residues, is available in very large quantities, is collected at a central location and can be stored with minimum decomposition for periods of one year. It is currently used as a fuel in the sugar mill and economic evaluations are based on fuel value considerations of bagasse. The cost evaluation shows bagasse at the sugar central to compete favorably with the current market alternate for fermentation sugar, molasses.

Of the raw waste materials considered in this study as a feed to the hydrolysis plant, urban organic waste shows the best economic promise.

Hydrolysis:

The hydrolysis process kinetics and hence the plant designs are based on data assembled in the late 1940's at the Forest Products Laboratory in Madison, Wisconsin. This work represented a substantial improvement in the German weak acid or Scholler process for the hydrolysis of wood. It is believed that the use of wood hydrolysis data for the development of hydrolysis plant costs will result in a conservative economic estimate due to the physical differences of wood chips and pulped fibers.

Reaction rates may be significantly higher for the pulped fibers resulting in higher sugar production rates or smaller plant size with the parallel reduction in product costs.

It is apparent from process parameters that a stagewise continuous process will result in minimum loss of sugar due to secondary degradation and hence is the most desirable process. Calculations show that a three stage continuous reactor represents the optimum economic condition, with low hydrolysis acid concentration and maximized temperatures being preferred operating conditions. As is normally expected with processes of this type product costs decrease with increasing plant size.

Valuable by-product credits were not considered in the economic evaluation and represent a valid source for additional process revenues. Conclusions on this aspect cannot be made until laboratory studies of the process using the selected waste feed are conducted.

Fermentation:

The fermentation plant was designed on traditional proven standards. The application of new technologies could have a significant influence on the product cost from this operation. The fermentation step as presented in this study represents the larger fraction of the final product cost.

Several items can be considered in attempting to reduce costs of the fermentation step. Two discussed in the report are the material of construction of the fermentor and the method of cooling used. In the case of fermentor construction significant savings can be realized by making this vessel of coated wood. Concrete construction may also be a favorable alternate. Cooling costs, however, represent a prime cost reduction area for special geographic situations. The availability of large bodies of surface cooling water such as sea coast locations can have a profound effect on product costs when this cooling water source is used in place of refrigeration-cooling tower systems.

Recycling of process water from the fermentation plant to the hydrolysis plant and operation of the fermentors at lower pH levels than considered in the hydrolysis plant calculations can result in overall process economies that are worthwhile. These logical considerations should insure conservative economic figures for this process phase.

The choice of organism for the fermentation plant is an important consideration. Candida utilis was chosen for the study because process information and marketing data are available for this species. The fact that this material has been marketed also results in a wealth of preliminary knowledge of the organism with respect to its value as a food and animal feed source. Other microorganisms may be selected for laboratory studies that have special value to the economics of a process such as the hydrolysis-fermentation complex. For example, species with higher reproduction rates can reduce fermentor size, thermophilic organisms may operate at temperatures that reduce the high cost cooling problem, or perhaps species can be developed that will reproduce directly in the acid hydrolyzate liquors eliminating the neutralization step. These factors must be considered in detail in a laboratory study. If successful, animal feeding studies using protein from the new organism must be made before a material of marketable status evolves. It is significant to note however, that most early work on wood hydrolyzate fermentation for the production of yeast employed the Candida utilis species, popularly called Torula yeast.

Market Analysis:

The product of the hydrolysis-fermentation plant as conceived here is Torula yeast. This material is useful as a protein supplement in human food or a vitamin and protein supplement in animal feeds. Although many minor markets exist for this commodity such as pharmacuetical applications, food flavors, etc. the bulk markets are the food and feed supplements.

Much work has been done by various national, industrial and international groups to quantify the world protein needs and find acceptable solutions to this ever increasing problem. The availability and possible limits of expansion of traditional protein sources, meat, milk, eggs, fish, grains, pulses, etc. indicate needs by the year 2000 beyond the capability to produce. Then too, some of the traditional protein sources are deficient in some essential amino acids such as lysine, etc. requiring supplementation. The general concensus is that new protein sources will be needed and welcomed in the market place if they can be produced as economical and acceptable foods. Various market contenders under development include fish protein concentrates, oilseed meals, yeasts, algae, fungi and bacteria. Chemical supplementation of amino acids is finding favor in some current applications. On a long term basis, a food market seems to be available to all competitive sources of protein.

Today, however, and probably in the long term also the marketing of "new" foods seems to be a monumental task. Several factors contribute to the problem of which the fact that the largest market need is in countries that are least able to pay is not the least significant. Where economies are strong the preference for animal protein is always in evidence. This seems to indicate, along with other factors, that the animal feed market is the probable goal for any new large volume protein supplement products.

Current high protein supplements for animal feed include soybean meal, cottonseed meal, and animal and fishmeal products. Calculated costs for Torula yeast from hydrolyzed solid wastes are at best at the high end of the current high protein supplement price range based on the cost figures developed in this report. These costs for Torula yeast however, are less than half of the present price cited for the same product from sulfite waste liquor. Sulfite waste liquor yeasts are in current use as high protein supplement for animal feeds in special situations in the United States and on a more common basis in Europe.

Serious penetration of the high protein animal feed supplement market in the United States by yeast from hydrolyzed solid wastes is a function of process improvements evolving from laboratory studies of a combined hydrolysis-fermentation operation.

B. Recommendations

Results of this general economic study have been encouraging as to the prospects of a hydrolysis-fermentation approach to the disposal of certain organic wastes. While certainly not a panacea, the application of this technology to the utilization of urban organic refuse appears quite promising.

As is pointed out in the text the costs for the hydrolysis process were developed from the kinetics of a similar but different feed material. Valuable data on by-product production and processing problems cannot be anticipated in this way and therefore directs future work to evaluations of the process using wastes of the presumed composition and physical nature to be employed in a working system. A laboratory and pilot plant study on the hydrolysis of organic urban wastes is indicated here.

If organic urban wastes are to be considered in the laboratory evaluation of hydrolysis, a more basic problem must be considered. That is, what is the composition, or more nearly, what is the composition range of organic urban wastes? Studies of this factor are under way, but published meaningful data will be necessary to aid the investigator in utilization process development. Continued support and emphasis on these study programs is strongly recommended.

The influence of "tramp" substances such as plastic wrapping material and aluminum foil on the hydrolysis process must be investigated and should, of course, be included in any laboratory study on this process. However, the manner in which these materials affect the fermentation operation must also be determined. Fermentation rate studies based on various hydrolyzates and impurities therein from organic urban wastes represents a third important area for recommended study. This phase should include animal feeding studies.

The development of continuous culture techniques and the fermentation process optimization have a strong influence on the overall process economics. A detailed study on a laboratory and pilot plant basis is needed to define the working system.

The culmination of the laboratory and pilot plant studies suggested will be a definitive cost study of the process. At this point it appears that the combined hydrolysis-fermentation process for the production of yeast has the potential to become a factor in the future economy. An actual study is needed to determine if in fact a viable industry can grow on urban refuse.

ECONOMIC CONSIDERATIONS OF SOLID WASTE RAW MATERIAL

A. Urban Wastes

THE NATION SPENDS three billion dollars annually [1,2,p132] to dispose of garbage and refuse. Total urban waste loads for the U.S. have been reported by investigators at 152 to 167 million tons per year. [1,3] Indirect costs and economic losses due to poor waste handling add another measure to the mounting bill. Items such as environmental pollution, depreciated property values, fire and rodent damage and attendant medical bills are included in these hidden costs. And yet, these costs may actually be a small fraction of the total which is represented by the current preoccupation of "wasting" the vital resources that are represented in the heterogeneous mixture termed rubbish. It is time to dedicate engineering and scientific endeavors to the reclamation and utilization of these so-called waste materials.

Composition:

Knowledge of the physical and chemical composition of municipal wastes is surprisingly small. Work to define the composition of refuse has only been conducted over the last decade with the initial work in this area being conducted in Western Europe by the International Research Group on Refuse Disposal.

While the work in Western Europe is of academic interest here, it will not define the municipal waste compositions in the United States. Table I indicates the variation of waste composition on a location basis. Waste composition information for Germany, for example, would not apply to the California situation. Therefore, waste utilization plant designs must be based on realistic current local data.

The value of current waste composition information is pointed up by studies [4,p.24,25] in New York and Chicago in 1939 and 1956 through 1958 respectively. The Chicago data showed garbage contents of 28 percent and ash 44 percent of New Yorks 1939 study while the paper content increased to 250 percent of the earlier figures. Changes in food processing, fuels and packaging are no doubt responsible for these variations along

TABLE I. COMPOSITION OF HOUSEHOLD GARBAGE[5,6]

	Percentage by Weight					
	Germany	England	Holland	Switzerland	California	Montreal
Rags, leather, rubber	1.3	1.8	1.9	2.2	1.6	5.7
Paper, cardboard	4.5	12.6	15.5	22.6	} 68.4	50.1
Bones	0.7	0.5	1.0	} 50.0		
Organic kitchen wastes	18.0	12.5	18.5			10.2
Other organic wastes	10.0	2.2	9.7			8.6
Iron and metals	2.5	3.7	5.3	3.5	10.7	8.6
Glass & glass fragments	3.0	2.8	3.4	3.8	11.7	3.9
Ashes, china, clinker unfit for composting	60.0	63.9	44.7	17.9	7.6	12.9

Note: In the printed table, braces group rows. For Switzerland, 50.0 covers Bones, Organic kitchen wastes and Other organic wastes. For California, 68.4 covers Paper, cardboard through Other organic wastes.

with the increased affluence of the nation. It is not only desirable, but necessary, to develop waste composition measuring tools so that meaningful data can be made available to waste utilization plant design engineers.

Rogus [4,p.17] states that "The development of measuring, sampling, and laboratory technqiues to a common accepted standard is a laborious, costly proposition, requiring a uniform approach to a non-uniform material". He goes on to list the factors that affect the characteristics of municipal wastes as follows [4,p.19-20]:

1. Number and types of industries and degree to which their wastes are self-disposed.
2. Number and types of commercial establishments and degree to which their wastes are self-disposed.
3. Climate -- to illustrate: in the warm belt the output of ashes will be negligible, whereas the amounts of garden trash may be abnormally high.
4. Seasons -- the winter and holiday months will probably produce higher amounts of textiles and wrappings but less of fresh vegetable and fruit wastes.
5. Income level -- residential areas in the high income brackets acquire and waste more per capita.
6. Population density -- the high density apartment house areas will generally put out all the wastes they produce (unless they are equipped with on-site incinerators) while the individual homeowner will tend to dispose of some of his wastes. Conversely, the apartment house districts will put out fewer leaves, tree clippings, and garden wastes.
7. Technological advances -- developments in food processing such as pretrimming of fresh vegetables, quick-freezing of many types of foods, canning of fruit concentrates, etc., have all contributed to reducing the garbage content to about 1/3 of its previous value -- all within one generation. The ever increasing use of non-solid fuels has almost eliminated the former high ash content. The development of many types of synthetic wrappings and the new

systems of pre-packaging of many marketable items have increased the amounts of paper, cartons, and many varieties of synthetic tissue, to a degree where they have more than made up for the reductions in food waste and ashes.

8. Degree of self-disposal -- on-site incineration and garbage grinding does, where used, have a sizeable effect on the amount and character of wastes.
9. Frequency of collection -- where collection schedules are generous the output is untrammeled. Skimpier schedules tend to restrain the average output.
10. Fees -- a charge for collection services, usually in direct proportion to the amount of material put out, will invariably reduce the degree of wastage and encourage some self-disposal.
11. Salvaging -- an attractive market for such salvables as paper, rags, metals, or bottles will induce many householders or janitors to cull out these materials from the waste put out for collection.
12. Cost and availability of fuels -- when the cost of fuels for cooking and/or heating is high and they are difficult to procure, the tendency is to utilize some of the combustible refuse for these purposes either in the cooking range, in the furnace, or in the fireplace.

With this wide variety of factors affecting the composition of municipal wastes it becomes apparent that the development of a "standard method" of sampling and analyzing refuse must be established. Work on this problem was discussed by Professor John Bell in his paper[7] presented at the National Conference on Solid Waste Research in December, 1963. The ultimate value of this study is the development of engineering data for specific municipalities of the type assembled by Mr. Elmer Kaiser [7,p.37] from Professor Bell's results as shown in Table II. Many studies have been performed on municipal waste compositions and are reported in the literature.[4,p24,8,9,10] A summary of nine studies carried out by USPHS, APWA and university personnel is contained in the data in Table III.

TABLE 11. COMPOSITION AND ANALYSIS OF AN AVERAGE MUNICIPAL REFUSE[7,p37]

	Per cent of total refuse	Proximate Analysis* "As received" basis, weight per cent. Moist-ure	Volatile Matter	Fixed Carbon	Non-** Comb.	Ultimate Analysis, Dry basis, weight per cent. Carbon	Total Hydrogen	Available Hydrogen	Oxygen	Nitrogen	Sulfur	Non-** Comb.	Ratio C:(H)	Btu per lb Dry basis	Btu per lb Dry, ash-free basis
Rubbish, 64%															
Paper, mixed	42.0	10.24	75.94	8.44	5.38	43.41	5.82	(0.28)	44.32	0.25	0.20	6.00	155	7572	8055
Wood and bark	2.4	20.00	67.89	11.31	0.80	50.46	5.97	(0.672)	42.37	0.15	0.05	1.00	75	8613	8700
Grass	4.0	65.00	--	--	2.37	43.33	6.04	(0.83)	41.68	2.15	0.05	6.75	52	7693	8250
Brush	1.5	40.00	--	--	5.00	42.52	5.90	(0.75)	41.20	2.00	0.05	8.33	56.7	7900	8600
Greens	1.5	62.00	26.74	6.32	4.94	40.31	5.64	(0.77)	39.00	2.00	0.05	13.00	52.4	7077	8135
Leaves, ripe	5.0	50.00	--	--	4.10	40.50	5.95	(0.31)	45.10	0.20	0.05	8.20	131	7069	7700
Leather	0.3	10.00	68.46	12.44	9.10	60.00	8.00	(6.56)	11.50	10.00	0.40	10.10	9.1	8850	9850
Rubber	0.6	1.20	83.98	4.94	9.88	77.65	10.35	(10.35)	-	-	2.0	10.00	7.5	11330	12600
Plastics	0.7	2.00	--	--	10.00	60.00	7.20	(4.40)	22.60	-	-	10.20	13.6	14368	16000
Oils, paints	0.8	0.00	--	--	16.30	66.85	9.65	(9.00)	5.20	2.00	-	16.30	7.43	13400	16000
Linoleum	0.1	2.10	64.50	6.60	26.80	48.06	5.34	(3.00)	18.70	0.10	0.40	27.40	16	8310	11450
Rags	0.6	10.00	84.34	3.46	2.20	55.00	6.60	(2.70)	31.20	4.62	0.13	2.45	20.4	7652	7844
Sweepings, Street	3.0	20.00	54.00	6.00	20.00	34.70	4.76	(0.36)	35.20	0.14	0.20	25.00	96	6000	8000
Dirt, Household	1.0	3.20	20.54	6.26	70.00	20.62	2.57	(2.07)	4.00	0.50	0.01	72.30	10	3790	13650
Unclassified	0.5	4.00	--	--	60.00	16.60	2.45	(0.166)	18.35	0.05	0.05	62.50	100	3000	8000
Food wastes, 12%															
Garbage	10.0	72.00	20.26	3.26	4.48	44.99	6.43	(2.845)	28.76	3.30	0.52	16.00	15.8	8484	10100
Fats	2.0	0.00	--	--	0	76.70	12.10	(10.70)	11.20	0	0	0	7.2	16700	16700
Noncombustibles, 24%															
Metallics	8.0	3.00	0.5	0.5	96.0	0.76	0.04	(0.02)	0.2	-	-	99.0	51	124	12000
Glass and ceramics	6.0	2.00	0.4	0.4	97.2	0.56	0.03	(0.02)	0.11	-	-	99.3	34	65	8000
Ashes	10.0	10.00	2.68	24.12	63.2	28.0	0.5	(0.40)	0.8	-	0.5	70.2	70	4172	14000
	100.0														

Organic Analysis of Composite

	Per cent
Moisture	= 20.73
Cellulose, sugar, starch	= 46.63
Lipids (fats, oils, waxes	= 4.50
Protein, 6.25N	= 2.06
Other organic (plastics)	= 1.15
Ashes, metal, glass, etc.	= 24.93
	100.00

Analysis of Composite Refuse, As Received Basis

Moisture	Carbon	Total Hydrogen	Available Hydrogen	Oxygen	Nitrogen	Sulfur	Non-Comb.	Ratio C:(H)	Btu per lb
20.73	28.00	3.50	(0.71)	22.35	0.33	0.16	24.93	39.4	4917

Btu, dry 6203
Btu, M and AF 9048

*Based on ASTM methods of analysis of coal and coke, as adapted for refuse.

**Non-combustibles-- ash, metal, glass and ceramics.

TABLE III: PHYSICAL BREAKDOWN - MUNICIPAL REFUSE[3]

Type	Percent of Total by Weight	
	Wet	Dry
Paper	48.0	35.0
Leaves	9.0	5.0
Wood	2.0	1.5
Synthetic	2.0	2.0
Cloth	1.0	0.5
Combustibles	62.0	44.0
Garbage	16.0	8.0
Glass	6.0	6.0
Metal	8.0	8.0
Ashes, stone, dust, etc.	8.0	6.0
Non-combustibles	22.0	20.0
Total moisture content		28.0

The tabulation offered by Mr. Kaiser will be very useful to engineering studies on waste utilization. The fact that an average municipal refuse contains 46.63 percent cellulose, sugar and starch on a dry basis makes it a useful raw material commodity for a hydrolysis-fermentation plant. However, the actual supply of this carbohydrate fraction considering seasonal variation will be the design parameter of ultimate importance.

Collection Methods:

The method used in collecting and transporting the waste commodity to a treatment plant will have a significant influence on the overall economics of the waste disposal-utilization complex. The location of plant sites and waste segregation methods are important ancillary considerations attached to the collection scheme.

Reports [2,p249,3,12] dealing with refuse collection and disposal show collection costs to be an extremely large component of the total. Where incineration is used as the disposal means, collection costs represent 60 to 70 percent of the total bill. In the case of landfill operations 80 to 95 percent of the cost is in collection and transportation. Data for municipal disposal for the city of Philadelphia show collection costs at nine dollars per ton.[2,p249]

With the collection factor in mind it is simple to agree that solid wastes delivered to a treatment plant site do have a value. The value added to refuse by virtue of its collection may then, on an extremely conservative basis, represent the raw material cost to a waste utilization plant. The actual assignment of this cost by a municipality to a processor seems unrealistic, however, since the alternatives are rather unappealing. Current practice [16,p26] for converting refuse to compost indicates the willingness of municipalities to assign negative values to refuse in the form of a "dumping fee" paid to the treatment plant.

The important point to consider is the fact that the collection costs are an integral part of all refuse utilization systems and should not be excluded from the economics. If this point is accepted, the design of the collection method becomes an important factor in system economics.

Bowerman stated [13,p 77]:"Most solid waste transportation systems utilize automotive vehicles exclusively; it is safe to say that the one major change in solid waste collection in the last 100 years has been the conversion from horse-drawn wagons to gasoline-powered trucks. ... but some glimmer of hope lies in the present day usage of garbage disposers ... our present technology suggests that grinding at each individual home may not be practical ... It does appear that some merit exists in grinding rubbish to the sewers at transfer stations where the solid waste unsuited for carriage in the sewer (cans, bottles, tree limbs, etc.) would be hauled away for disposal elsewhere. With such a system, the sewer serves as an "endless belt" type of conveyor to deliver the ground refuse at nominal cost to sewage treatment plants ... "

The feasibility of transporting organic refuse by grinding to a trunk sewer was demonstrated by Bowerman in Los Angeles where 7 tons of refuse was ground (particle size 3 to 4 inches) to the sewer in 30 minutes with no apparent transport problems.

Systems of the type envisioned by Bowerman would reduce refuse hauls to a neighborhood basis with some extended runs to landfills for disposal of the can and bottle fraction separated at the transfer station.

An interesting concept of a neighborhood waste collection system has been employed for 5 years in a hospital at Solleftea, Sweden and is currently being installed at a housing estate at Sandeberg to service an estimated 2,770 family units.[14] Refuse is transported by a pneumatic system to a central collection silo from which the waste is transferred to the ultimate disposal system (on-site incinerators in Sweden). The system as described by Mr. Marchant is "the most advanced method of refuse conveyance so far achieved". [14,p 21]

It does appear from the foregoing examples that the collection of wastes need no longer be consigned to the gasoline powered wagons that have so long served as the only practical means of transporting refuse. Design alternatives may now be considered with "total system" economics serving as a basis for selection.

Volume:

When considering waste as a raw material or feedstock commodity for a continuous processing plant, the reliability of supply becomes an important factor. It is logical to size a facility on the average quantities available in any yearly cycle of the waste to be used. Storage capabilities can balance short term volume variations and refuse production projections must, of course, be considered for overall plant growth needs.

Projected refuse production volumes are shown in Figures 1 and 2. The monthly variation in refuse composition for New York City in 1939 is shown in Table IV. Although the latter reference does not represent refuse compositions based on typical wastes of today, the point of seasonal variation in composition is well illustrated. Monthly tonnage volumes over a similar time period vary only fifteen percent. [4,p 23] The refuse production in the U. S. is currently increasing at a rate of 2 percent per capita per year.[2,p182] This coupled with a 2 percent annual population increase results in an overall refuse production increase of 4 percent per year.

The availability of a large and increasing supply of refuse in the U.S. appears to be assured. The availability of individual constituents in the waste, however, must be analyzed on a whole year basis for each location considered.

Preparation Requirements:

The condition of the delivered waste, the economics of the local salvage market and the utilization process requirements all affect the degree of treatment the raw waste is given prior to processing. In general, bulky refuse such as cars, refrigerators, etc. would not be accepted at a utilization plant.

When truck transport of wastes is used, the method of removal of refractory components will be based on the economics of the local salvage market. If economically desirable, a picking belt[9,17] would normally be installed for salvage operations. If salvage is uneconomic other techniques, used by composters,[9,17,18] waste paper processors[19,p302] and in some cases mining operators, may be employed. They include:

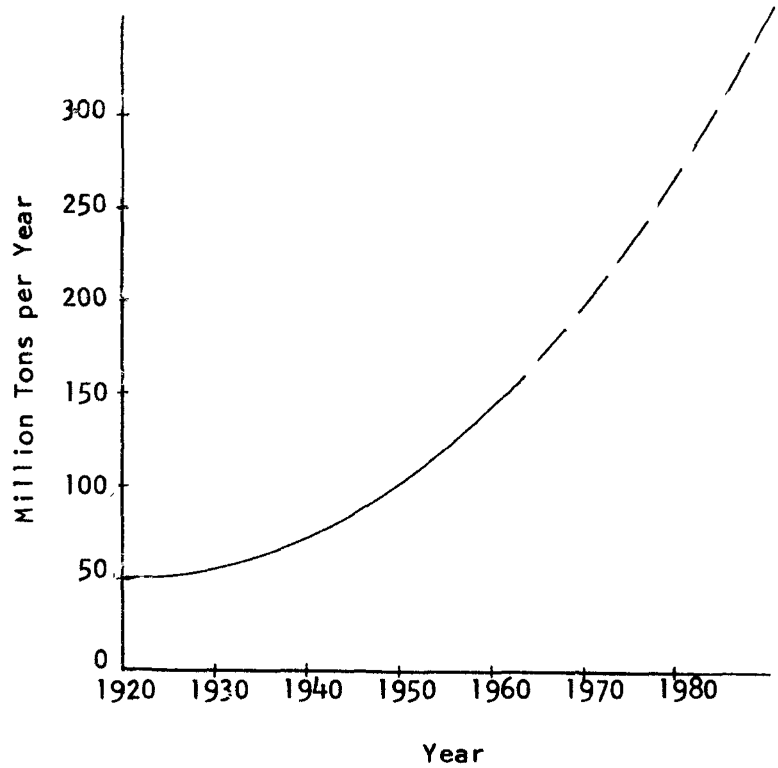

FIGURE 1. TOTAL REFUSE PRODUCTION IN THE U.S.[2,p.133,15]

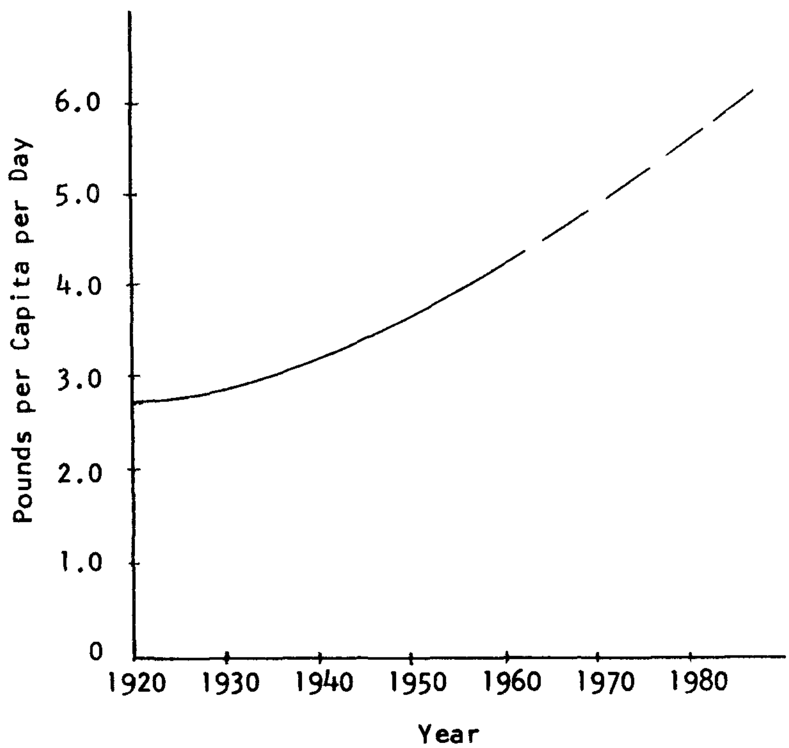

FIGURE 2. PER CAPITA REFUSE PRODUCTION[2,p.133,15]

TABLE IV: MONTHLY DISTRIBUTION BY WEIGHT OF ORGANIC AND INORGANIC REFUSE DISPOSED OF IN NEW YORK CITY, 1939[4,p.24]

	Per Cent by Weight								
	Organic					Inorganic			
Month	Garbage	Misc.	Paper	Wood	Total	Metal	Glass	Ashes	Total
January	5.7	1.0	12.4	0.3	19.4	4.3	4.0	72.3	80.6
February	9.0	1.7	12.6	0.7	24.0	6.6	4.9	64.5	76.0
March	9.7	2.1	20.6	0.3	32.7	7.4	7.3	52.6	67.3
April	18.1	2.8	21.6	2.0	44.5	7.4	6.9	41.2	55.5
May	26.7	3.3	23.0	3.1	56.1	7.1	6.8	30.0	43.9
June	35.1	3.8	24.3	4.6	67.8	6.4	6.8	19.0	32.2
July	43.8	4.1	25.5	5.9	79.3	6.6	6.3	7.8	20.7
August	23.1	7.4	37.6	3.8	71.9	11.6	5.1	11.4	28.1
September	12.6	5.6	26.7	4.9	49.8	8.2	9.1	32.9	50.2
October	10.1	3.8	31.0	2.6	47.5	8.9	4.0	39.6	52.5
November	6.6	1.9	18.0	2.1	28.6	3.8	2.9	64.7	71.4
December	3.5	0.8	9.0	0.8	14.1	3.1	1.9	80.9	85.9
Average	17.0	3.2	21.9	2.6	44.7	6.8	5.5	43.0	55.3

Grinding or Rasping
Magnetic separating
Hydrapulping
or using, Gravitational separators
Ballistic separators
Hammer Mills

Although salvage of metal components is possible using these techniques, paper and salvageable bottle values are certainly lost.

If waste is segregated at the source, homes, commercial establishments, etc. virtually no separation problems need exist at the utilization plant and only valuable salvage operations would be considered. This general comment would also apply to the unique system where wastes are segregated prior to grinding and transmission by sewer line or other pipe line systems.

In overall process economics, the trade-off between in plant preparation vs: collection method costs will be the factor to consider.

Current Disposal Methods:

The dollar value of solid waste raw materials as a feed commodity in a utilization plant must of course be considered in context with competing process uses or disposal methods.

At the present time the large volume of wastes produced by the U. S. population have no positive market value. In reality they are a municipal liability that can be directly measured in part by current disposal costs. Typical costs are summarized below:

TABLE V: Costs for Solid Waste Disposal[2,p196]

	Capital Cost (land excluded) Dollars per ton per day	Operating Cost Dollars per ton disposed
Sanitary Landfill	1000-2000	$1.25-2.25
Central Incineration	3500-7000	3.50-5.00
Composting	1500-10,000	2.00-7.00

Maintenance and operation of open dumps is estimated at 5 to 25 cents per ton.[3]

The use of the sanitary landfill procedure for organic refuse, while the least expensive of the acceptable alternatives presented, appears to present a problem to municipalities when new locations are required. Public acceptance of landfills is difficult due to the wrongs and abuses of open dumps. When sites are found, they are generally at an undesirable distance from the city resulting in increased hauling costs.

Incineration is finding increased favor in spite of the relatively adverse economics. Incineration techniques, while improving, are a cause for concern by air pollution agencies.[20] Acceptable stack effluents will require additional capital investment and operating expenses resulting in increased process costs. Present day cost figures should be minimum values.

Composting, while having the right philosophical basis, has not become popular in the U.S. to this time. The delay in the establishment of salvage and product markets has hindered progress and has resulted in the requirement of basing plant economics on a numicipal dumping fee only.[16,17] The fact that this is an acceptable basis to some municipalities[22] is demonstrated by the City of Houston's commitment[17,p26] to pay $3.47 per ton of refuse delivered to the Houston Compost Plant.

It must be concluded from the above that mixed refuse from municipalities has a negative asset value. Based on the Houston example, it is logical to assume that this value will approach the cost of incineration. John R. Snell states [21] that "If salvage and compost sales are neglected, the [compositing] plant can be maintained, operated and amortized for a dumping fee of approximately fifty cents to a dollar less than a comparable sized incinerator ...".

Using this range and the incineration of operating costs noted in Table V, the dollar liability of mixed refuse for municipalities can be conservatively established in the 2.50 to 4.50 dollars per ton range. This "dumping fee" should be collectable by any process utilizing municipal wastes.

B. Agricultural Wastes

There are two broad groups of organic agricultural wastes that require better disposal systems. They are: animal wastes and plant wastes.

The first category described by Taiganides [23, p39] as the "more vexing" will not be discussed here since our major concern is with cellulosic waste materials. The second category, plant wastes, can also be subdivided into two groups; canning wastes and crop residues.

Utilization of the wastes generated by the fruit and vegetable canning industry, and the fraction of feed and grain crops remaining as residues has challenged the abilities of many researchers in public and private endeavors for many years. A variety of successful products have evolved from these efforts, but their effect on reducing the tremendous volume of wastes available annually from agricultural sources has been minimal. The following discussion summarizes the problems and some of the utilization efforts reported to date. No attempt has been made here to be complete since the volume of work done in this field is large and varied.

Canning Wastes:

The volume of canning wastes in California's Central Valley was discussed by Mr. Walter Mercer, [24,p53] at the National Conference in Solid Waste Research in December, 1963. He stated: "Each year 700,000 to 800,000 tons of tree fruits are grown in California's Central Valley ... Between 12 and 14 percent of this raw tonnage becomes a waste material consisting of pits, peels, green fruit, and defective pieces not suitable for canning.

Of the 3,150,000 tons of tomatoes .... 7 to 10 percent of the tonnage must be handled as waste product. ... All together, it is estimated that each year during the three to four months of canning, between 500,000 and 600,000 tons of wet wastes are produced and must be disposed of by some method."

Volumes of produce and their associated waste loads are available in the literature. [25,26,27,29] Table VI is one example.

TABLE VI: FRUIT AND VEGETABLES: CANNING INDUSTRY DATA[28]

Product	Apples	Berries	Peaches	Pears	Asparagus	Beets	Corn	Peas
Average Season (weeks)	13	6	4	8	6	8	6	6
Tons Raw Material Rec'd:								
Per Plant-Avg. Year	3137	845	1249	6059	859	4772	5349	5108
Per Plant-Max. Day	46	47	85	139	35	126	253	213
Tons Solid Waste Produced:								
Per Plant-Avg. Year	1462	45	132	2765	260	1831	3845	389
Per Plant-Max. Day	19	4	20	55	12	42	178	16
Avg. Tons Waste/Raw Ton	0.47	0.05	0.11	0.46	0.30	0.38	0.72	0.08

The problems associated with the utilization of the wastes generated at canning plants have been tabulated and repeated by many.[25,28,29] The difficulties include the following:

- Seasonal nature of the wastes
- Perishable nature of the wastes
- Pesticide residues in the wastes
- Added responsibility for food processors at their busiest time
- Minimal economic return on waste oriented by-products

Although these problems are real, the alternative difficulties of disposal of these wastes is always increasing and of tremendous magnitude.[24] Therefore, a continuing economic pressure will be exerted on the canneries to find ways of using waste commodities in an efficient manner.

Utilization efforts have centered largely around animal feed applications in the past with wet waste feeding, dried waste feeding and storage and mixed waste ensilage experiments being of major interest.[24,28,30] The current use of pesticides which are concentrated in fruit and vegetable skins reduces the desirability of using those wastes as animal feeds.

California canners are jointly financing a utilization scheme that converts peach pits to charcoal briquets.[24,p56] This process appears to have economic promise.

Other developments include the use of pits as a metal cleaning medium used by blasting techniques and the conversion of pear wastes to alcohol by fermentation.[28] The latter case was a short run success which was eventually abandoned.

The short season and large volume of perishable material makes utilization of canning wastes an extremely difficult and challenging problem.

Crop Residues:

Utilization of crop residues has been traced to 170 BC when the Romans were separating starch from a type of corn.[31] Residues for the purpose of this discussion include cornstalks and cobs, straws, stems, bagasse, hulls, and other woody wastes not generally associated with canning type operations.

The U.S. Dept. of Agriculture estimated [31] a 200 million ton per year production of this type waste of which less than one percent is used.

The large bulk of the crop residues are left in the field[33] at the time of harvest. With the advent of combine harvesters, corn pickers and shellers and other field processing equipment the era of the straw pile is gone. The main problem and raw material cost for utilization of most crop residue wastes is that of material collection and transportation. Although it has been estimated that the annual amount of wasted straw is sufficient to satisfy all of the annual U.S. cellulose demand,[31] it is not utilized for economic reasons.

Current applications of this classification of materials include their use in the manufacture of:

- building board (various types)
- paper
- soil conditioners
- animal feeds
- litter for poultry houses
- furfural
- alcohol
- sugar solutions
- yeast
- packing materials
- sweeping compounds

A selected bibliography[32] covering "unconventional" uses for crop residue waste materials has been published and includes more than 300 references dating from 1942.

Where collection costs and long transportation hauls can be avoided, crop residue wastes should find increasing use as process raw materials. The fact that they can be stored for significant periods without gross degradation allows continuous year long operation of a processing plant thus putting capital investments on a continuous use basis.

C. Wastepaper

The purchase of organic waste raw material from an established secondary materials commodity market for feed to the hydrolysis-fermentation system can be well illustrated by the wastepaper field. The advantage in this approach is the segregation of raw material and hence the relatively uniform feed composition presented to the treatment plant. The disadvantage over mixed organic refuse is cost.

Paper waste is collected on a local basis by secondary materials dealers for resale as paper stock to manufacturers of paperboard, insulation board and, where sufficiently segregated for reuse, in higher grade paper production. The Paper Stock Institute of America in their Circular PS-66[34] define 45 grades of paper for reuse.

The annual tonnage of all grades of paper stock consumed by industry is in excess of ten million tons.[35] Total production of all grades of paper and paperboard exceeded four times this figure in 1966 at about forty six and a half million tons. Normally, paper stock moves from collector to consumer within a single metropolitan area with the normal distance of transport not exceeding fifty miles.

A price history for the No. 1 mixed paper grade of wastepaper in the Boston area is shown in Figure 3, with national area variations for six grades for 1951 displayed in Table VII.

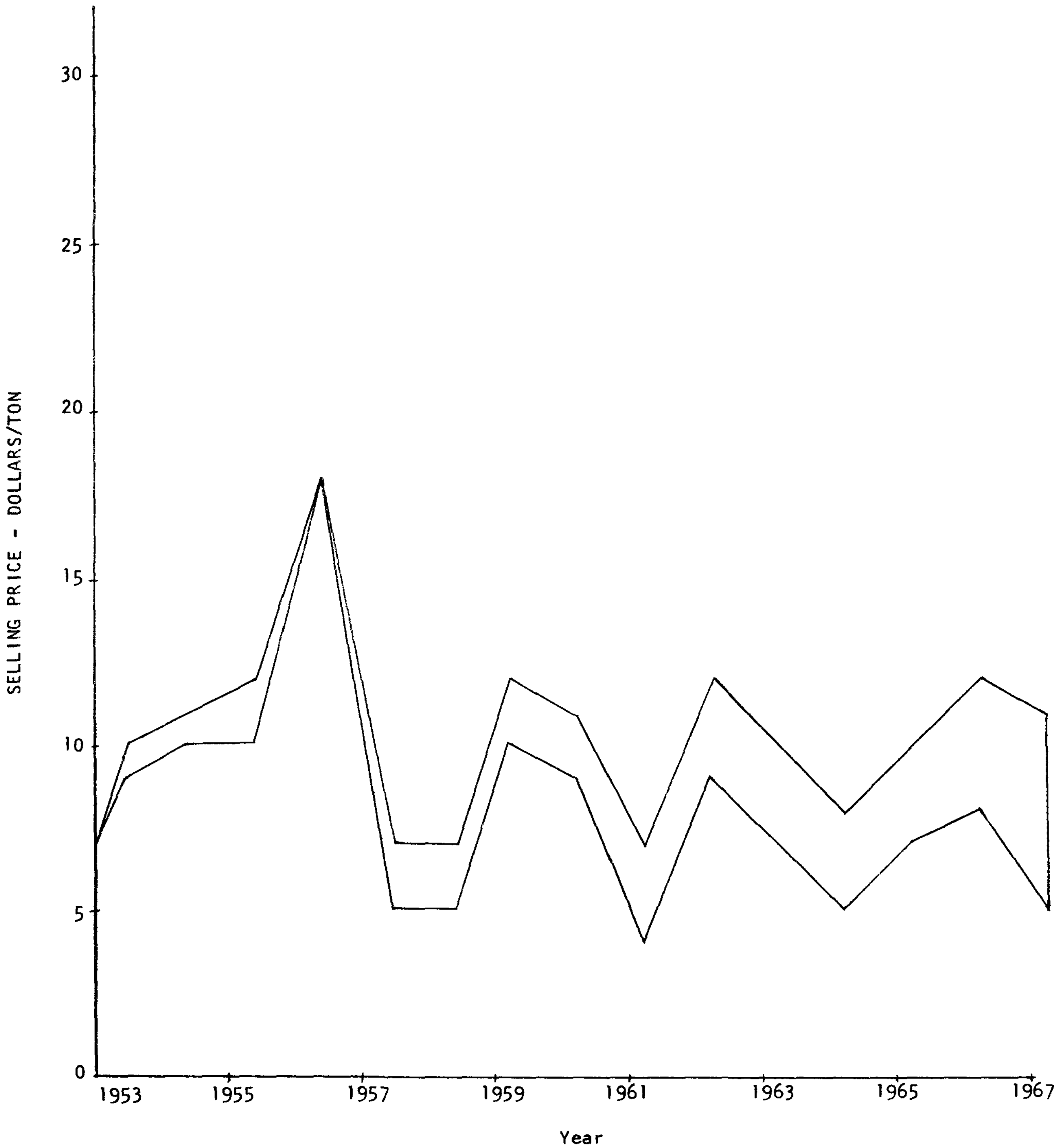

FIGURE 3: WASTEPAPER PRICE TREND 1953-1967[36]
NO. 1 MIXED GRADE

TABLE VII: WASTEPAPER PRICES - 1951[36,39]
(Dollar Range per Ton)

	New York	Philadelphia	Boston	Chicago
Hard white envelope	200/245	225	200/235	190
White ledger	130/140	125/130	125/140	125
Corrugated	64/70	55/62	40/61	52
Over issue news	40/45	40	33/45	41
No. 1 News	37/41	33/40	28/31	35
No. 1 mixed paper	32/35	32/35	29/32	27

Paper stock experiences fluctuations in availability that is certainly influenced by price. The higher the price, the greater the incentive on collection agencies such as the Boy Scouts and church groups to pick up wastepaper, particularly old news. Seasonal variations are also experienced with the highest quantities available during Spring and Fall house cleaning periods.[35]

Availability of paper waste is a function of other factors too. The type of municipal waste collection service and disposal means employed in a community[3] plus local laws on backyard incinerators can have a marked effect on the total paper load collectable within a community. Increases in waste collections of 35 to 100 per cent have been recorded in controlled experiments where backyard burning was banned.[7,p53]

Table VIII shows the daily volume of paper stock sold by commercial wholesalers in various metropolitan areas in the U.S. in 1963. Using Rogus' data [4,p23] for New York City and applying the average municipal paper percentage from Table III, we have an average waste load of 14,000 tons per day times 48 percent paper equals 6,700 tons per day of paper actually disposed of by the populace but uncollected by the wholesalers.

Coincidently this number for uncollected waste paper in New York City just equals the amount of wastepaper collected by wholesalers in the consolidated New York and Northeast New Jersey area. From this it is possible to conclude that sufficient paper wastes are available in this area to double the present wholesale collections. The effect of increased demand on the price structure of the waste commodity is impossible to estimate however since it is collection costs and market demands that will fix the price and not mere availability figures.

TABLE VIII: WASTEPAPER SOLD BY WHOLESALERS BY URBAN AREA[38]

New York & NE New Jersey Consolidated Area	6,700 Tons/Day
Chicago & NW Indiana Consolidated Area	3,800
Philadelphia	2,400
Boston	1,500
Detroit	1,150
Los Angeles & Long Beach	1,140
San Francisco & Oakland	820
Cleveland	725
St. Louis	500
Kansas City	325
Memphis	270
Dallas	230
Houston	180

At the present time the availability of new pulp for paper manufacture has reached record highs while demand has not kept pace. The effect on the waste paper market has been to reduce prices to the historical low ranges with the result of increased closing of paper stock wholesalers.[37] Current outlooks for the wastepaper market look dim. With pulp selling at $85 per ton, high grade wastes that traditionally sold in the $125 per ton range must now reduce to the eighty dollar range to compete.[37]

It would appear reasonable that prices for wastepaper feed stock based on a ten year range can be applied to a new waste utilization process. The price range on this basis for No. 1 mixed paper is $4 to 12 per ton. The volumes available at these prices should be somewhat greater, say a ten to twenty percent increase over the figures in Table VII, than the current collection rate if a market were available. A significant increase in collectable mixed paper should be experienced if air pollution laws are instituted that forbid backyard burners.

The price-demand relationship for wastepaper is tied to a large degree to the productivity-demand cycle of pulp. As long as pulp productivity remains high relative to demand, the demand and hence the price for wastepaper will remain low.

Utilization of Wastepaper as Process Feed:

Paper waste as a feed for the hydrolysis-fermentation plant appears to have desirable qualities for this study. Early work on the kinetics of hydrolysis was conducted on wood chips.[40,41] The rough analysis of various types of paper[19] and wood are shown in Table IX. The similarity of the two materials allows the use of the kinetic data developed for wood to be applied to paper wastes with some degree of confidence. It is expected that the rate data for wood will be conservative when applied to paper stock since permeation of the cellulose fibers by the hydrolyzing acid should be more rapid and complete for the loose paper fibers than the consolidated wood chips.

TABLE IX: COMPOSITION OF WOOD, PAPERS[19] AND BAGASSE[42,43]

	Cellulose		Lignin	Extractives And Ash
	Hemi	Alpha		
Wood	20-26%	44-50%	17-30%	3-8%
Groundwood	20-26%	44-50%	17-30%	3-8%
Sulfite	-	90%+	2-5%	Bal.
Sulfate Paper	80% +		7-12%	Bal.
Bagasse	50-53%		11-25%	Bal.

D. Bagasse

The utilization of crop residues has been discussed briefly in an earlier section. The main economic problem anticipated is that of collection of the waste material. In the case of bagasse this problem does not exist.

Sugar cane is transported to a central processing plant where it is crushed, sugars extracted and the remaining fibrous waste (bagasse) stacked on a waste pile. The normal application of this waste is as fuel for the processing plant. The material's poor fuel characteristics[44] indicate that this utilization technique is more nearly a waste disposal method. Current trends in air pollution abatement indicate that this use of bagasse will be undesirable.

The abundance of bagasse as a raw material has been estimated at 20 million tons annual world production[45] with a U.S. total including Hawaii and Puerto Rico at 9.6 million tons.[46] Of more interest is the amount available at a single location for processing. A typical mill will produce 42,000 tons of bagasse per year while a high efficiency mill will produce twice this figure.

Bagasse wastes have been used to make a variety of products[50] including hardboard,[45,47] cellotex,[44,48] paper,[44,49] plastics,[47,51] chemicals[52] and charcoal. It has been utilized at the sugar central as a fuel, spread on the land as a mulch and fertilizer and fed to livestock. In spite of the many applications there appears to be no problem of availability.

A conservative estimate of raw material costs associated with bagasse would be equivalent to its value as a fuel plus transportation and handling costs.

Raw material costs on this basis were estimated as follows[42]:

Raw material at sugar central (fuel value)	0.25 cents/pound
Baling for shipment	0.25
Transportation to processor (within 50 mile radius) -	0.25
Total Cost	0.75 cents/pound

Sugar mills generally operate on a 70 day grinding season. During this period the 42 to 84 thousand tons of bagasse are generated and stacked. The utilization of this waste, however, can be spread over a longer operating period since techniques allowing storage for up to twelve months have been developed that minimize deterioration problems.[42,44]

With the short primary product season of 70 days for a sugar mill, it would seem logical that a waste utilization plant be installed at the sugar central providing a second product. This would allow a year round application of the labor force at the sugar central and a reduced cost of secondary raw material due to the elimination of baling and transportation costs for the bagasse. Other advantages may accrue from such a combined operation by the utilization of liquid waste streams from the sugar operation in the fermentation process.

Preparation of the bagasse raw material for a hydrolysis operation should be minimal and result largely in a materials handling operation.

E. Comments and Conclusions

Three major sources of wastes have been explored as potential raw materials for a combined hydrolysis-fermentation process. The availability, or rather, over abundance of mixed municipal organic wastes and bagasse make them logical candidates for processing. The use of wastepaper, while desirable from a predictable composition basis, may be a less suitable material due to fluctuating price and availability.

Urban waste utilization will present a purposeful alternative to current disposal practices with their associated problems. The complexity of urban waste economics leads one to the conclusion that "total system" concepts consisting of waste collection, separation, utilization and disposal must be considered for logical municipal planning to take place. The variations in waste due to geographic location, season, local affluence, etc. dictate local studies in the pre-planning stage for any community contemplating a new system. National averages will not be useful for plant designs.

THE HYDROLYSIS PROCESS

A. Introduction

THE HYDROLYSIS OF CELLULOSE to produce fermentable sugars was investigated and utilized in Germany during the periods of World War I and II. A report summarizing the German industry following World War II is available from the United States Department of Commerce.[41] Several processes and their commercial applications are discussed.

Two general processes evolved from the German work: 1) The strong acid or Bergius Process, and 2) the weak acid or Scholler Process.[41,53] The economics of the processes when applied to the saccharification of wood wastes were evaluated. The Bergius Process showed extremely high capital costs, which along with high labor and raw material costs on the U.S. market eliminated its usefulness here. The Scholler Process while uneconomic in the United States in its original form was considered for further technical development.

Work on the weak acid hydrolysis of cellulose was performed at the U.S. Forest Products Laboratory at Madison, Wisconsin during and following World War II. The resulting Madison Wood Sugar Process[53,54] was superior to the German process on the basis of the productivity rates and product yields achieved. Pilot and commercial plant operations using various modifications of the process based on raw materials and final products were established at Madison, Wisconsin, Springfield, Oregon[53,54] and Wilson Dam, Alabama.[55]

B. Chemistry and Kinetics of the Process

In designing the plants for hydrolysis of waste paper the kinetic data for wood hydrolysis was used. The data was compiled by J.F. Saeman of the U.S. Forest Products Laboratory in Madison, Wisconsin.[40]

Kinetically speaking, the hydrolysis of wood to sugar is a series reaction, since in the dilute acid process, the sugars decompose at reaction conditions.

The reaction is:

Wood cellulose → Sugars → Decomposition Products

(A) → (R) (S)

Let us consider each of the above constituents in order.

The chemical ingredients of wood can be classified as outlined in Table X. Aside from extraneous materials such as volatile oils, natural dyestuffs, tannins, etc., wood is composed of a carbohydrate fraction and a lignin fraction. Lignin is a complicated high polymeric non-carbohydrate. It is composed largely of aromatic units and makes up 20 to 30 percent of the weight of wood. Lignin resists hydrolysis in both the dilute-acid and strong-acid processes and remains as an insoluble residue after hydrolysis.

TABLE X. QUALITATIVE OUTLINE OF THE COMPOSITION OF WOOD [53]

I. Main components of the cell wall
  A. Total carbohydrate fraction
    1. Alphacellulose
    2. Hemicellulose
      a. Pentosans
        1. Xylans
        2. Arabans
      b. Hexosans
        1. Mannans
        2. Glucosans
        3. Galactans
      c. Uronic acids
  B. Lignin
II. Extransous materials
  A. Volatile oils and resin acids; volatile acids
  B. Fixed oils (fatty oils)
  C. Natural dyestuffs and precursors
  D. Tannins
  E. Polysaccharides and glycosides
  F. Ash (mineral salts)
  G. Organic nitrogen compounds
  H. Other organic ingredients, like resins, phytosterols, etc.

The carbohydrate portion of wood accounts for 70 to 80 percent of the dry wood substance (D.W.S.) and is composed of alphacellulose and hemicellulose as shown in Table X. Alphacellulose or true cellulose is a high-polymer substance, composed of multiple glucose units with the chemical formula $(C_6H_{10}O_5)n$. When complete hydrolysis takes place, the bonds between glucose units are broken and a molecule of water is added to each unit to give the sugar glucose. The acid acts only as a catalyst.

$$\underset{\text{alphacellulose}}{(C_6H_{10}O_5)n} + nH_2O \xrightarrow{\text{Acid}} \underset{\text{glucose}}{nC_6H_{12}O_6}$$

Table XI gives the percentage composition of various woods. As shown, alphacellulose accounts for 45 to 50 percent of the D.W.S. and hemicellulose accounts for 20 to 30 percent D.W.S. Hemicellulose, in addition to alphacellulose is part of the carbohydrate fraction of wood and is hydrolyzable to sugars. The distinction between alphacellullose and hemicellulose is not at all a clear one. Ideally, alphacellulose is that part of the total carbohydrate that hydrolyzes to glucose whereas hemicellulose hydrolyzes largely to pentose sugars and hexose sugars other than glucose. In practice, however, hemicellulose has been defined as "the easily hydrolyzed portion of the wood". This definition is the most useful and is the one on which most data is based. Hemicellulose hydrolysis gives a much larger percentage of pentose sugars than alphacellulose and its hydrolysis rate is at least an order of magnitude faster.

There are six sugars obtainable from the hydrolysis of wood. These are glucose, mannose,galactose, fructose, xylose, and arabinose. Table XII gives the percent of each of these sugars obtained in the hydrolyzate of various woods. Glucose, mannose, galactose, and fructose are all hexoses (six carbon sugars) of molecular weight 180. Xylose and arabinose are pentoses (five carbon sugars) of molecular weight 150. The four hexoses each have the chemical formula $C_6H_{10}O_6$ and differ only in structure whereas the two pentoses have the formula $C_5H_{10}O_5$ and also differ in structure. Sugars are classified two ways: 1) According to their ability to reduce

Fehling's or Tollen's reagent, and 2) according to their fermentability by Saccharomyces cerevisiae yeast. All monosaccharides and most disaccharides reduce Fehling's or Tollen's reagent and are thus reducing sugars. Since all sugars obtained by wood hydrolysis are monosaccharides the reducing power of the hydrolyzate is a measure of the total sugar content. On the other hand, fermentability is a measure of only the hexose sugars since S. cerevisiae, traditionally used in brewing, cannot ferment pentose sugars. However, other yeast strains can utilize a considerable portion of the pentose sugars. Table XIII gives the potential reducing sugar and potential fermentable sugar obtainable from various woods.

TABLE XI. THE PERCENTAGE COMPOSITION OF CERTAIN WOODS [53]

	Lignin	Holo-cellu-lose	Alpha-cellu-lose	Hemi-cellu-lose	Pento-sans	Uronic acid anhy-dride	Acetyl	Methoxyl in carbohy-drate
White spruce	26.6	73.3	49.5	23.8	10.9	2.68	2.35	0.70
Red spruce	26.6	72.9	48.3	24.6	11.6	3.20	2.50	0.92
Eastern hemlock	31.5	68.5	48.2	20.3	10.0	3.40	1.87	0.84
Balsam fir	30.1	69.9	44.0	25.9	10.3	3.08	2.24	0.41
Jack pine	27.2	72.5	49.5	23.0	12.8	2.92	1.92	0.75
Aspen	17.3	82.5	50.7	31.8	23.5	4.28	4.65	0.93
Willow	22.0	78.3						
Maple	23.5	76.3	50.0	26.3				
White oak	24.1	75.4	49.5	25.9				

TABLE XII. COMPOSITION OF THE TOTAL HYDROLYZATE OF WOOD [53]

	Birch %	Jack pine %	Spruce and pine %
Glucose	67.7	67.6	61.9
Mannose	1.8	14.1	24.7
Galactose	0.0	6.2	4.0
Fructose	--	--	1.4
Xylose	30.1	8.9	8.0
Arabinose	0.4	3.2	--
Total	100.0	100.0	100.0

TABLE XIII: YIELD OF POTENTIAL REDUCING SUGARS AND FERMENTABLE SUGARS FROM SAMPLES OF REPRESENTATIVE HARDWOODS AND SOFTWOODS [53]

Species	Potential reducing sugars %	Ferment-ability %	Potential fermentable sugars %
Hardwoods			
American beech	70.1	75.1	52.6
Aspen	75.1	76.3	57.3
Birch	69.9	67.8	47.4
Maple	68.2	71.0	48.4
Red oak	63.6	63.0	40.2
Sweetgum	66.4	73.8	49.0
Yellow poplar	70.9	76.1	54.0
Softwoods			
Douglas Fir	66.6	86.2	57.4
Eastern white pine	66.5	86.3	57.4
Hemlock	66.1	88.2	58.3
Ponderosa pine	68.0	82.2	55.9
Redwood	52.4	77.1	40.4
Sitka spruce	70.1	85.3	59.8
Southern yellow pine	64.8	82.0	53.2
Sugar pine	64.3	82.4	53.0

Unfortunately, the reaction conditions that favor wood hydrolysis also favor sugar decomposition. Qualitively the decomposition reactions are as follows:

1) $C_5H_{10}O_5 \rightarrow C_5H_4O_2 + 3H_2O$
Pentoses Furfural

2) $C_6H_{12}O_6 \rightarrow C_6H_6O_3 + 3H_2O$
Hexoses Hydroxymethylfurfural

3) $C_6H_{12}O_6 \rightarrow C_5H_8O_3 + HCOOH + H_2O$
Hexoses Levulinic acid Formic acid

4) $C_6H_{12}O_6$ or $C_5H_{10}O_5 \rightarrow$ Humic Substances
Hexoses Pentoses Sludge

The humic substances formed in reaction 4 are high molecular weight condensation products. Very little qualitative information is available on the relative rates of the above reactions and therefore the by-product production of the plant is somewhat uncertain.

Discussion of Kinetic Data:

Saeman[40] did his kinetic studies on the hydrolysis of Douglas fir wood chips using dilute sulfuric acid. The hydrolysis rate of Douglas fir is compared to several other woods in Figure 4 and is found to be fairly representative. The kinetic data for Douglas fir was therefore used as a basis for the plant design. Figure 5 shows the variation of hydrolysis rate with particle size. As may be expected the reaction rate increases as the wood chips become smaller or as the exposed surface area becomes larger. In applying these results to the hydrolysis of waste paper one would expect the pulped paper to have a larger exposed surface area than an equal weight of wood chips and therefore a greater hydrolysis rate. By using the kinetic data for wood chips the calculations are expected to be somewhat conservative.

In addition to the type of wood used and the particle size of the wood chips, other process variables of importance are: 1) Liquid to solid ratio (L/S), 2) acid concentration, 3) temperature, and 4) time. Saeman studied Douglas fir chips smaller than 30 mesh using the following range of variables: 1) Liquid to solid ratios from 5:1 to 20:1, 2) acid concentrations from 0.4 percent (by weight) to 1.6 percent, 3) temperatures from 170°C to 190°C, and 4) times from 0 to 400 minutes. Figure 6 shows the variation of hydrolysis rate with liquid to solid ratio at 180°C and 0.8 percent sulfuric acid. The hydrolysis rate increases with increasing L/S ratio. Figure 7 gives the hydrolysis rate for various acid concentrations and temperatures. The L/S ratio is 10:1. Figures 4 through 7 show consistently that the hydrolysis of wood is a first order reaction of the form.

5) $$r_A = \frac{dC_A}{dt} = k_1 C_A$$

where r = reaction rate

c = concentration

k = first-order reaction rate constant

t = time

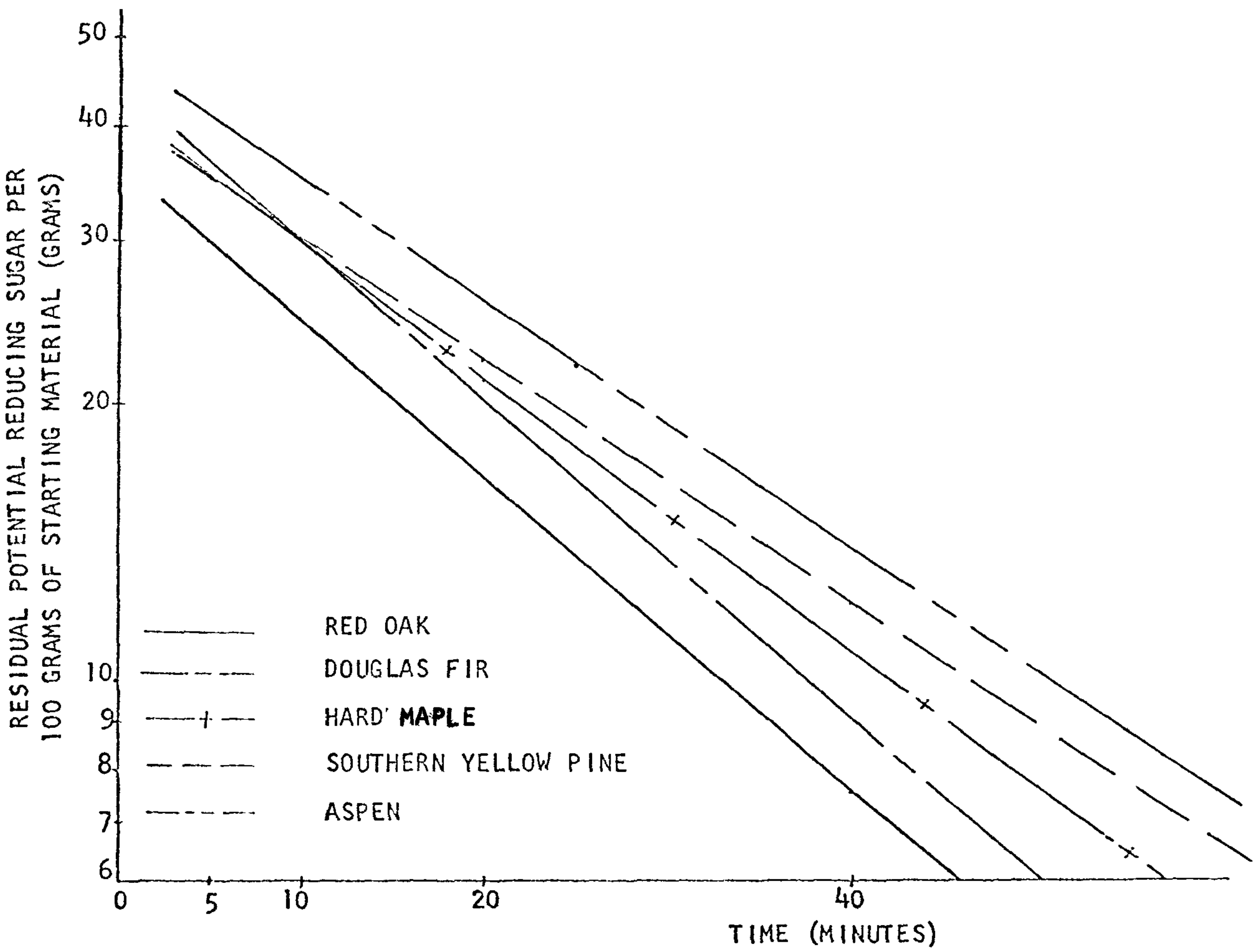

Figure 4 Comparative Rates of Hydrolysis of Various Species of Wood [40]

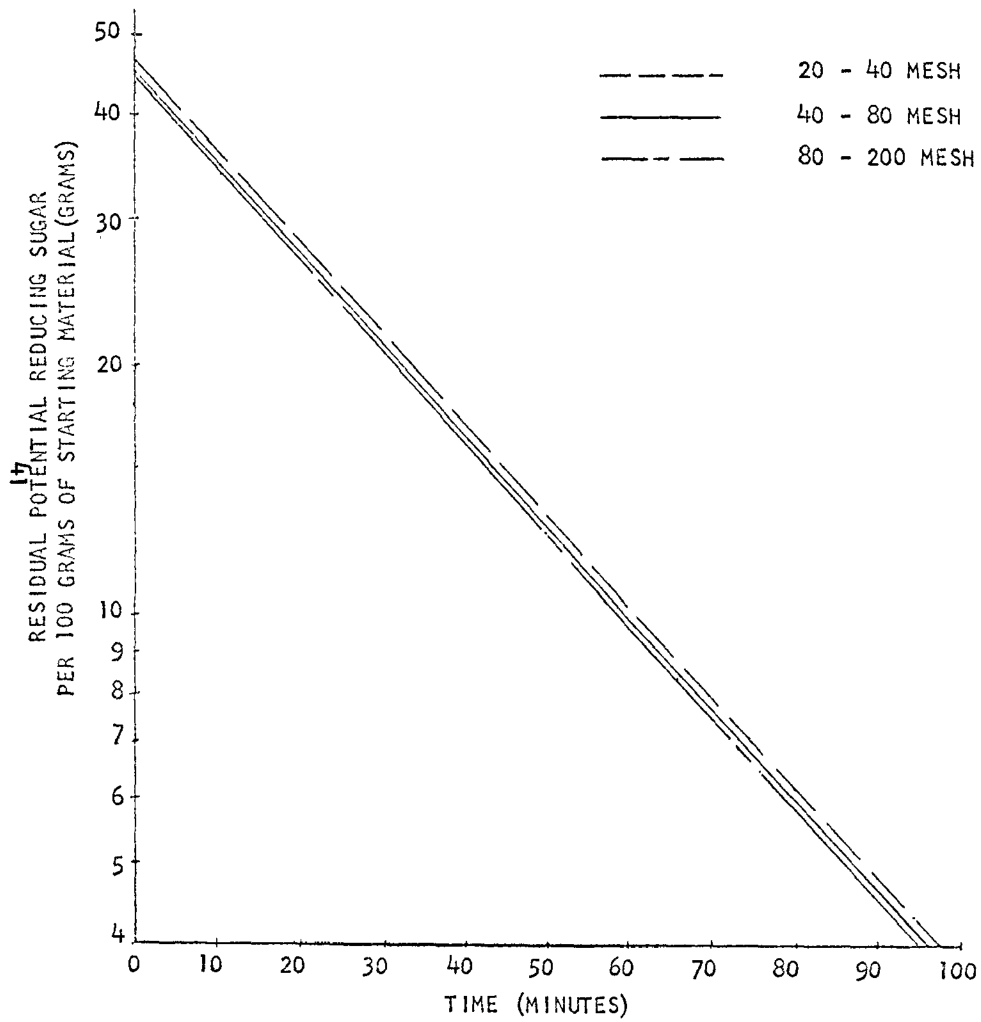

Figure 5 Hydrolysis of Douglas Fir of Various Particle Sizes [40]

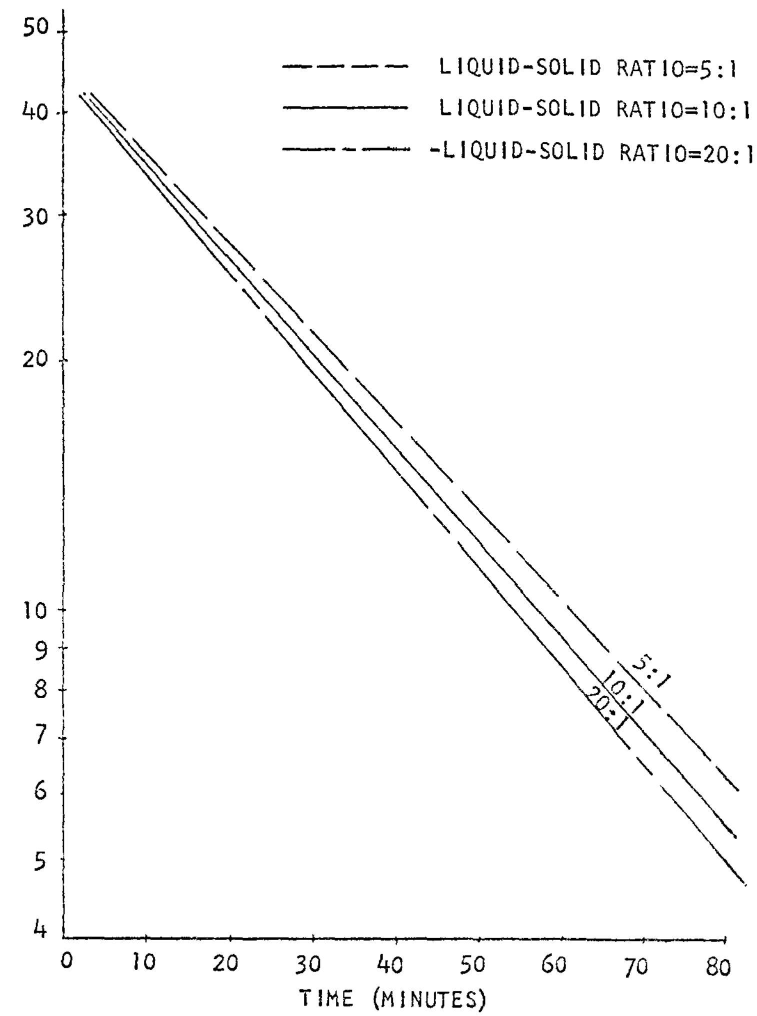

Figure 6 Hydrolysis of Douglas Fir at Various Liquid-Solid Ratios [40]

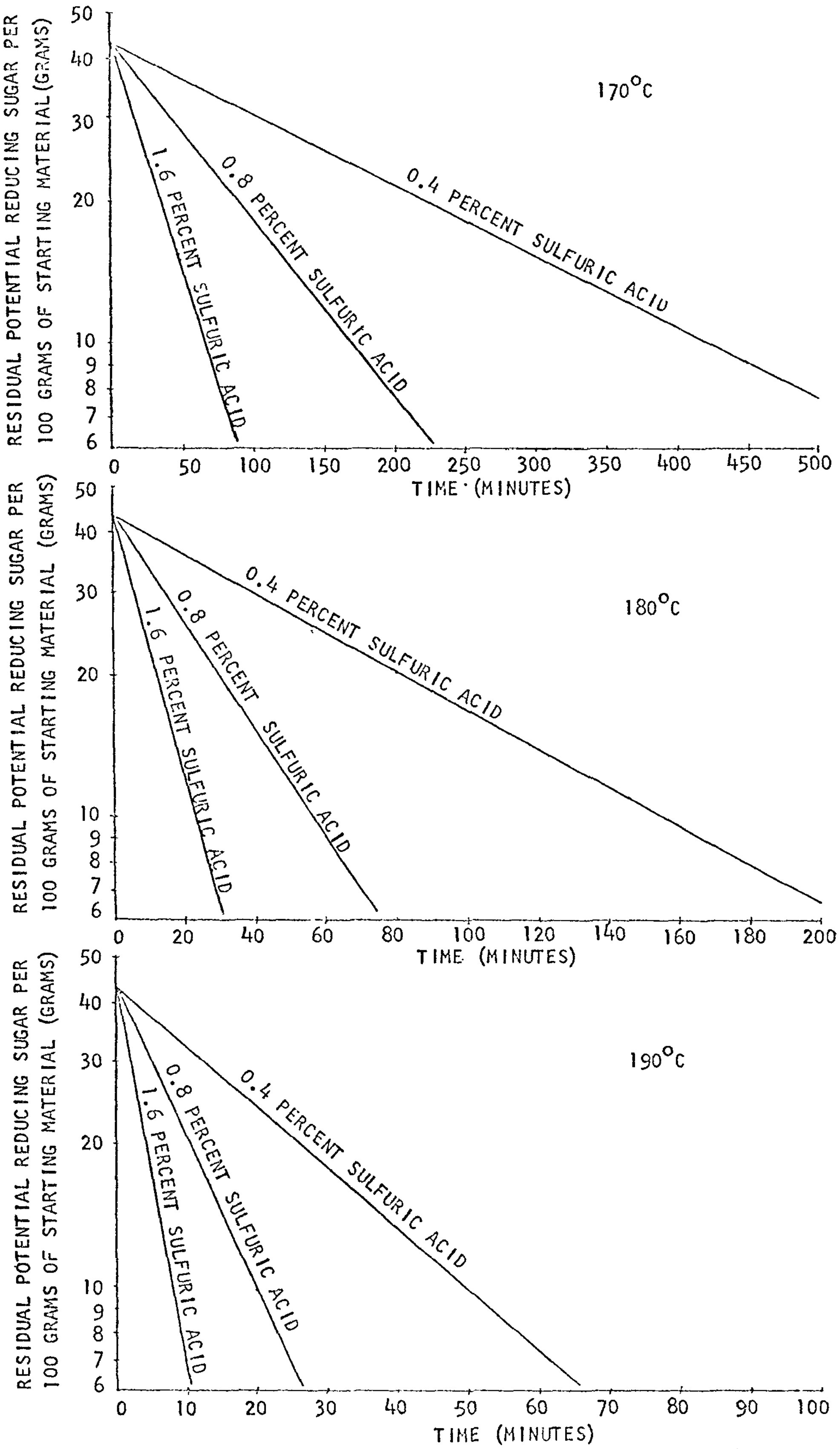

Figure 7 Hydrolysis of Douglas Fir at 170°C. 180° and 190°

Saeman also presents data on the decomposition rates of sugars. Figure 8 compares the decomposition rates of various sugars formed by wood hydrolysis. It is seen that the pentose sugars decompose more rapidly, particularly xylose, and glucose is the most stable. Figure 9 shows the decomposition rate of glucose as a function of acid concentration and temperature. From these figures it is clear that all the sugars decompose by a first order reaction since a plot of the logarithm of concentration against time is a straight line. Figures 10 and 11 show the variation of the first order reaction rate constant (k_2) for glucose with acid concentration and temperature. From these lots one can make the following correlation for glucose.

8) $k_2 = 1.86 \times 10^{14} C_s^{\ 1.02} e^{\frac{-32,700}{RT}}$ min^{-1} (Based on loss of reducing power).

To be completely accurate the decomposition rate of the sugar in the hydrolyzate should be a weighted average of the decomposition rates for the individual sugars. Thus k_2 will change during the reaction from a relatively large value initially (due to the higher concentration of pentose which are easily decomposed) to a lower value finally when glucose is substantially the only sugar formed. Determining what weighted average to use as a function of time would require considerable specification. Since these kinetics deal only with alphacellulose hydrolysis and since much more glucose is formed than any other sugar in this type of hydrolysis, the kinetic data for glucose was used to determine the decomposition rate of the sugars in the hydrolyzate.

The yield of sugar increases as the acid concentration increases and as the temperature increases. In addition, the yield increases as the liquid to solid ratio increases. Since high acid concentrations are undesirable from the stand point of corrosion it would probably be more profitable to increase yield by increasing the reaction temperature. In addition use of high concentrations of acid and high liquid to solid ratios would substantially increase raw material costs unless some means of acid recovery was employed, and sulfuric acid is difficult to recover. It is unfortunate that Saeman did not investigate a wider range of variables, particularly temperature. For the design of the continuous reactors the data was extrapolated to 200°C, 10°C above the experimental range.

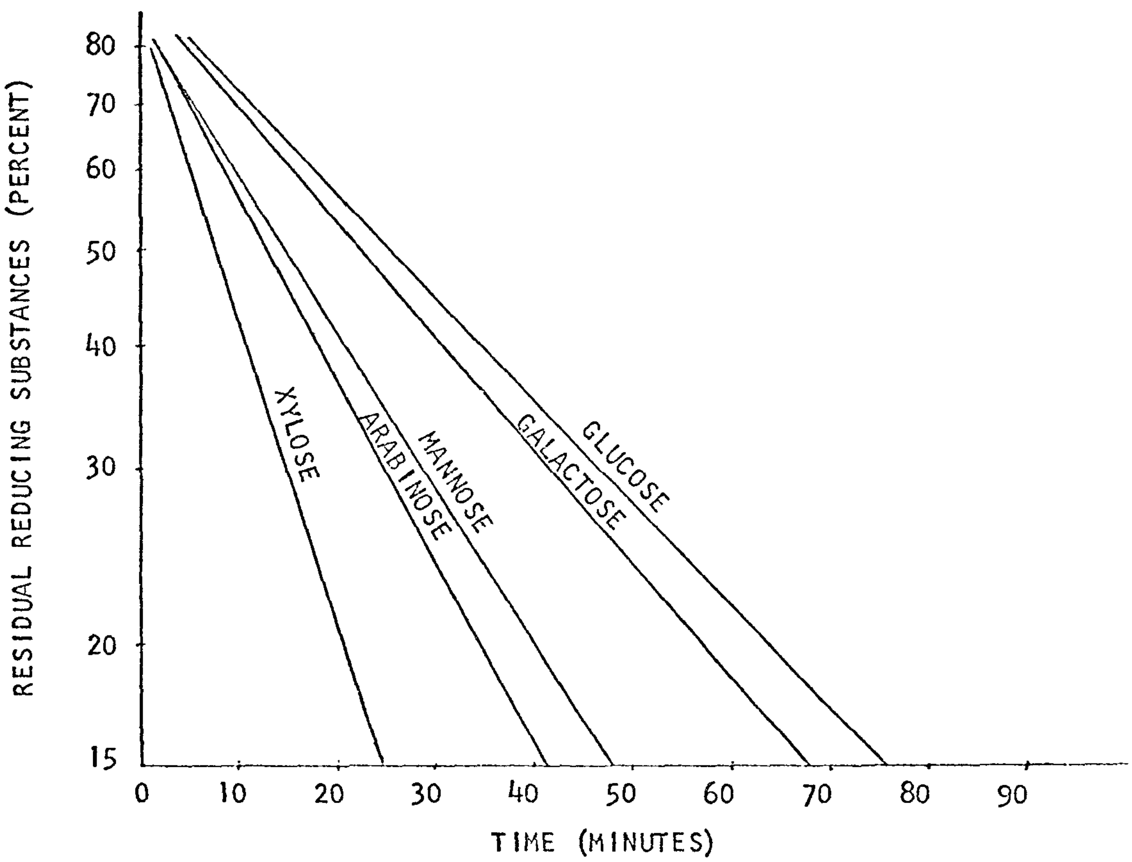

Figure 8 Decomposition of Sugars at 180°C. in 0.8% Sulfuric Acid [40]

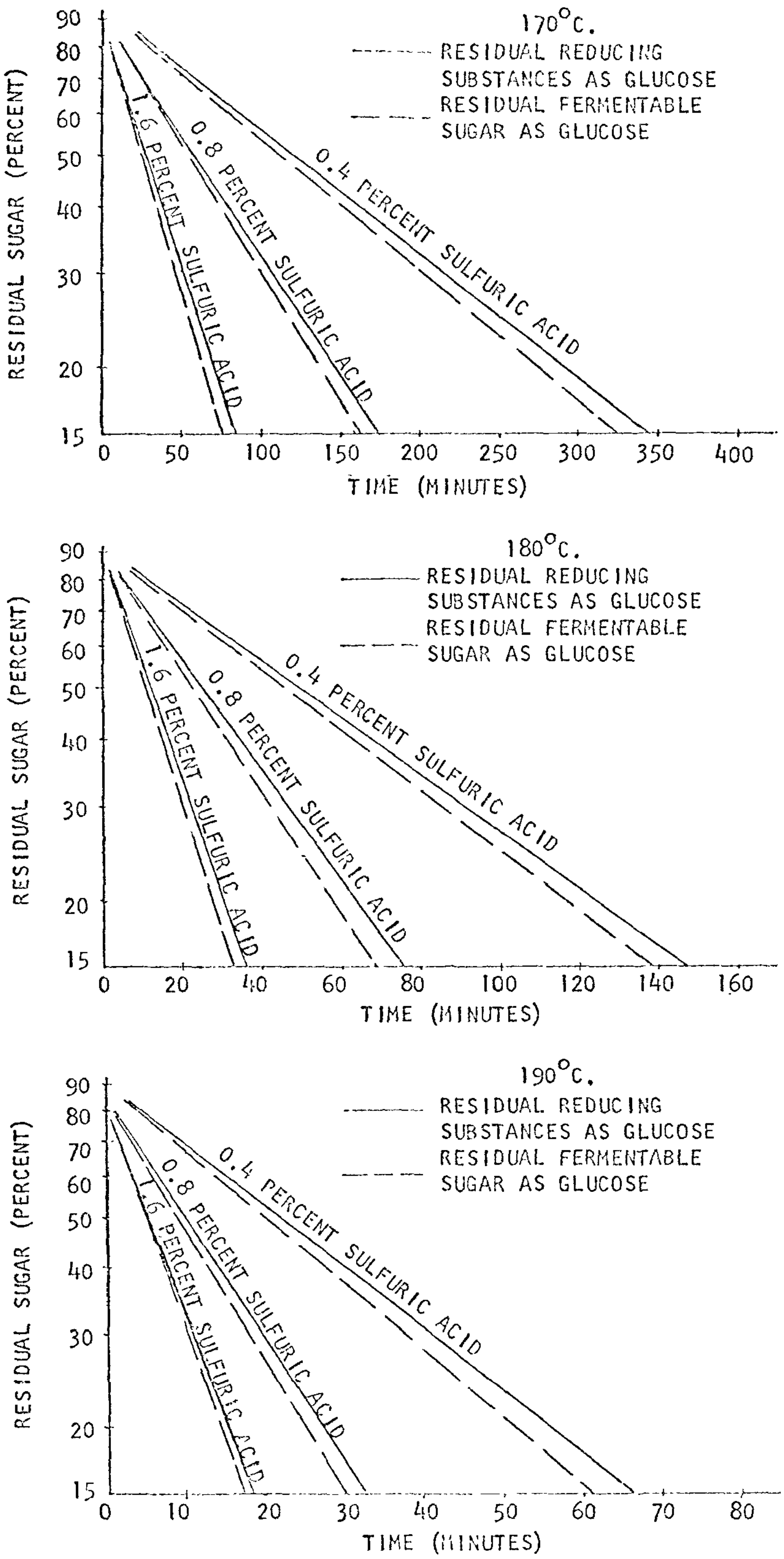

Figure 9 Decomposition of Glucose in Dilute Sulfuric Acid at 170°, 180°, and 190°C.[40]

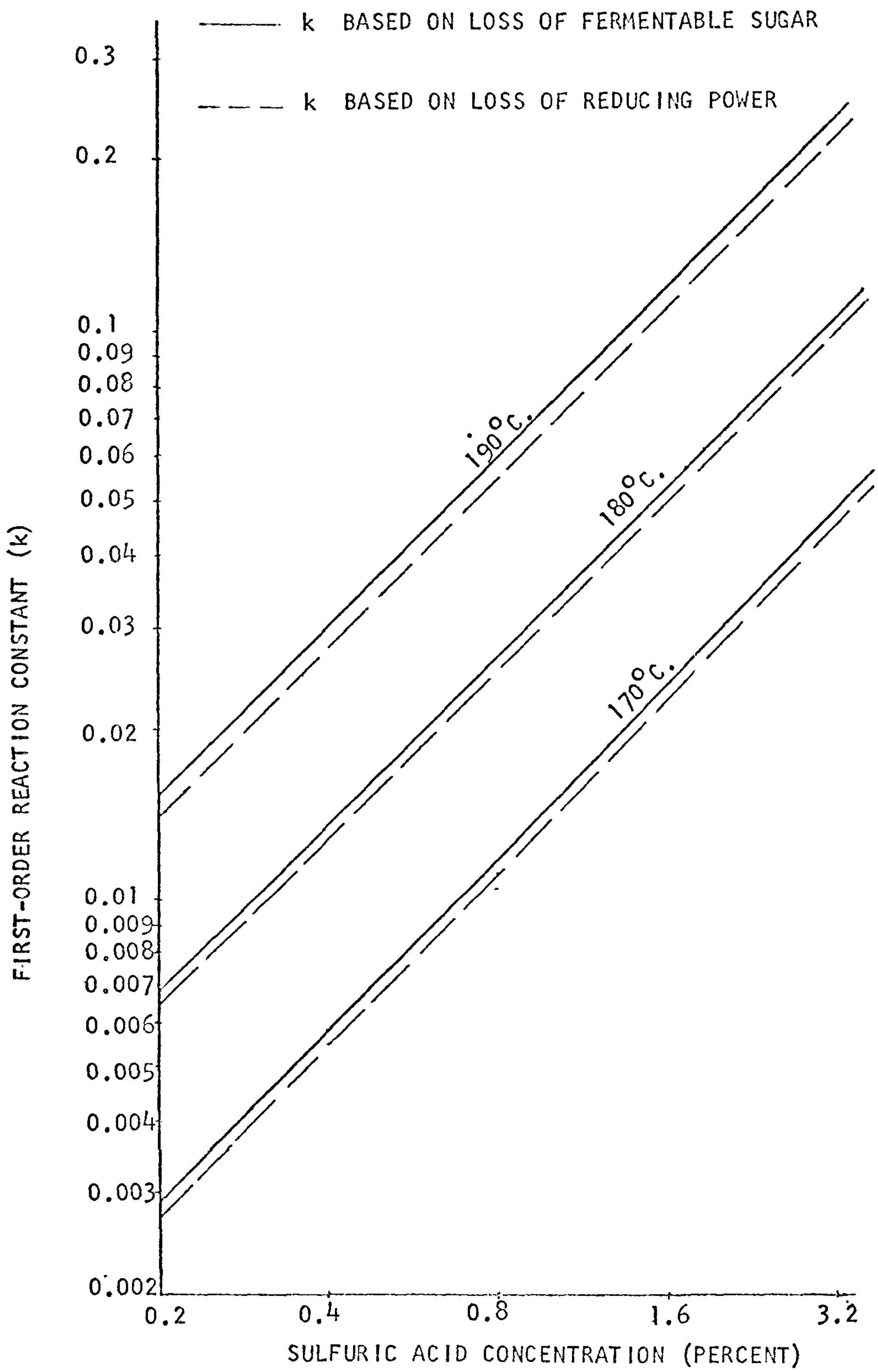

Figure 10 Relation of First-Order Reaction Constant k to Acid Concentration in Decomposition of Glucose at Various Temperatures [40]

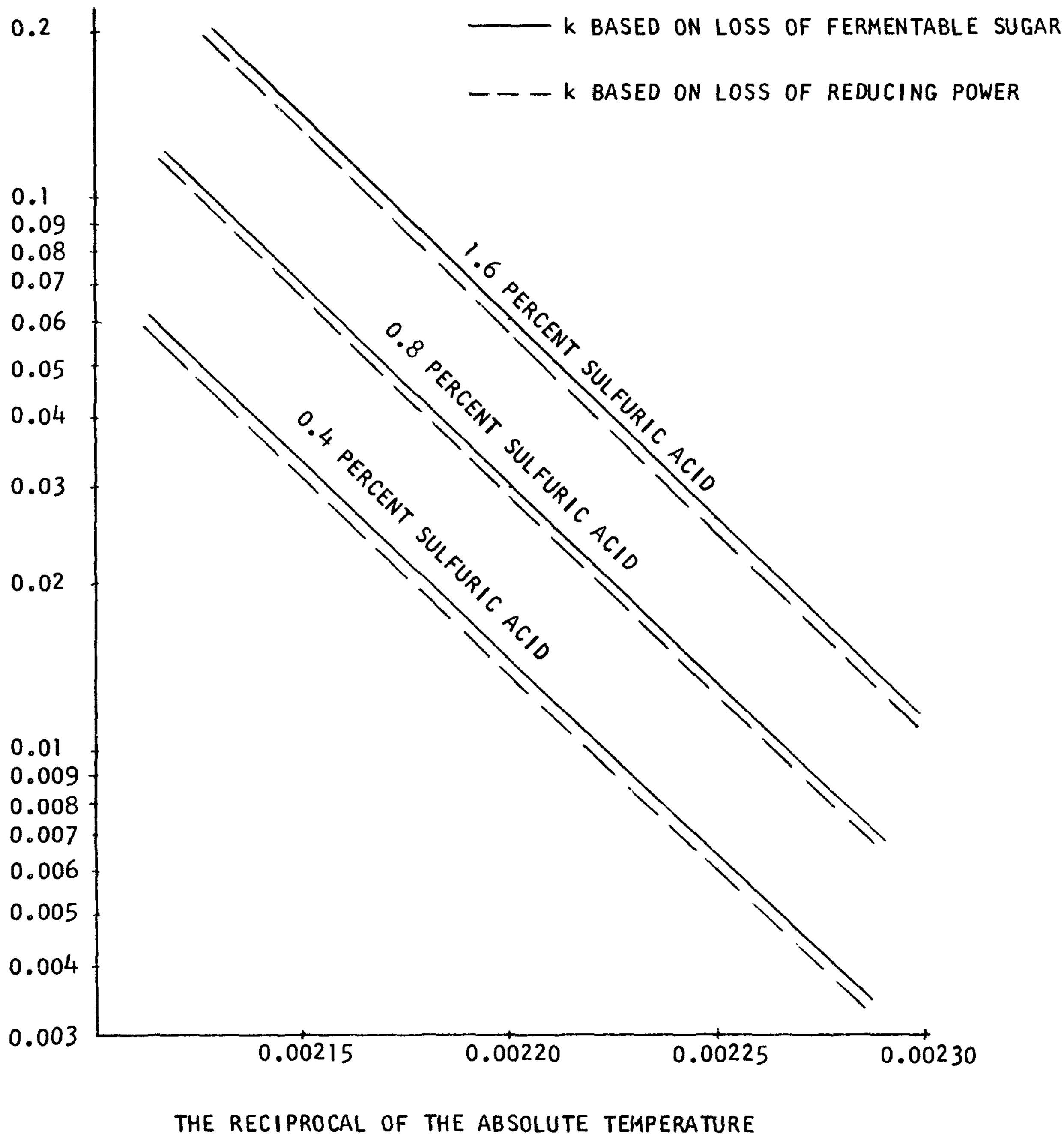

Figure 11 Relation of First-Order Reaction Constant k to Temperature in Decomposition of Glucose with Sulfuric Acid of Various Strengths [40]

C. The Batch Process

The U.S. Forest Products Laboratory of Madison, Wisconsin did considerable work on wood saccharification during World War II.[54] The work was authorized by the War Production Board to find a commercially practical method of obtaining sugar from wood and subsequently fermenting the sugar to alcohol. The process recommended by the Forest Products Laboratory was called the Madison Wood Sugar Process and used semi-batch digestors or percolators for reactors. These are simply towers or pressure tanks into which a batch of wood chips is charged. The liquid phase (0.5 percent sulfuric acid solution) is then introduced continuously, allowed to flow down over the wood chips, and withdrawn continuously during the percolation period. When the sugar in the hydrolyzate leaving the reactor falls below 1 percent, the liquid is drained from the spent wood chips which are subsequently discharged.

The Forest Products Laboratory also investigated a reaction scheme similar to one patented by Scholler in Germany.[56] This scheme consisted of charging wood chips to a digester and then introducing a given amount of dilute acid, allowing the reaction to occur for a specific time, and draining off the hydrolyzate. This is followed by the introduction of fresh acid solution and the cycle is repeated until the sugar in the hydrolyzate drops below a predetermined value. Although the Forest Products Laboratory reaction scheme was similar to the German Scholler process, reaction conditions were quite different and the American process gave better yields in less time.

The following is a comparison by the Forest Products Laboratory of the Madison Wood Sugar Process, the German Scholler process, and the American modified Scholler process.[54]

> "A process, known as the Madison wood sugar process, has been developed for hydrolyzing mixtures of wood waste with 0.5 percent to 0.6 percent sulfuric acid at 150°C to 180°C by allowing the dilute acid to flow continuously through the charge of wood. Compared to the German Scholler process, hydrolysis was accomplished in less time because the sugars produced were removed more rapidly. Decomposition was less because the sugars were in contact with the acid for a shorter period of time and consequently, yields of sugar and alcohol were higher. Fewer by-products inhibitory to fermentation were produced, so that fermentations

were more rapid. The sugar produced in 2.8 hours from a ton of dry, bark-free, Douglas fir wood waste yielded 64.5 gallons of 95 percent alcohol as compared to 3.2 hours for 58 gallons by the rapid cycle method developed earlier, (American modified process) and 13 to 20 hours for 55 gallons by the Scholler process as carried out in Germany."

The Madison wood sugar process was clearly superior to all other batch processes and a plant using the Madison process was constructed at Springfield, Oregon. A description of this plant has been given by several authors.[53,54] The plant was a 78 fold scale up of the Forest Products pilot plant. Several difficulties were encountered in its operation and consequently the Tennessee Valley Authority at Wilson Dam, Alabama undertook a study of the process on a scale intermediate between the Forest Products Laboratory and the Springfield plant. The T.V.A. made several simplifying recommendations and improvements.[55] Their pilot plant was designed to hydrolyze wood chips to sugar and then concentrate the sugar solution to 50 percent molasses for use in animal fodder. The commercial plant proposed as a result of T.V.A. pilot plant work is shown in Figure 12. In general, the wood hydrolysis portion of the plant (excluding evaporation and concentration) is quite similar to the Madison wood sugar process. The TVA modification of the Madison process was followed quite closely in the design of our batch hydrolysis plant. Unfortunately, neither the Springfield plant nor the proposed TVA plant had economic data which allowed one to estimate the cost of the hydrolysis portion of these plants.

Batch Process Description:

The flow sheet for the proposed batch process is given in Figure 13. Using one 2000 cubic foot digestor, based on the maximum size of the Springfield, Oregon plant, plant capacity and operating procedures were determined.

The total operating time per batch is 4.75 hours. It is possible to run five batches per day using this time schedule, and since each batch uses 16 tons of dry wood substance the plant will handle 80 tons of raw material per day.

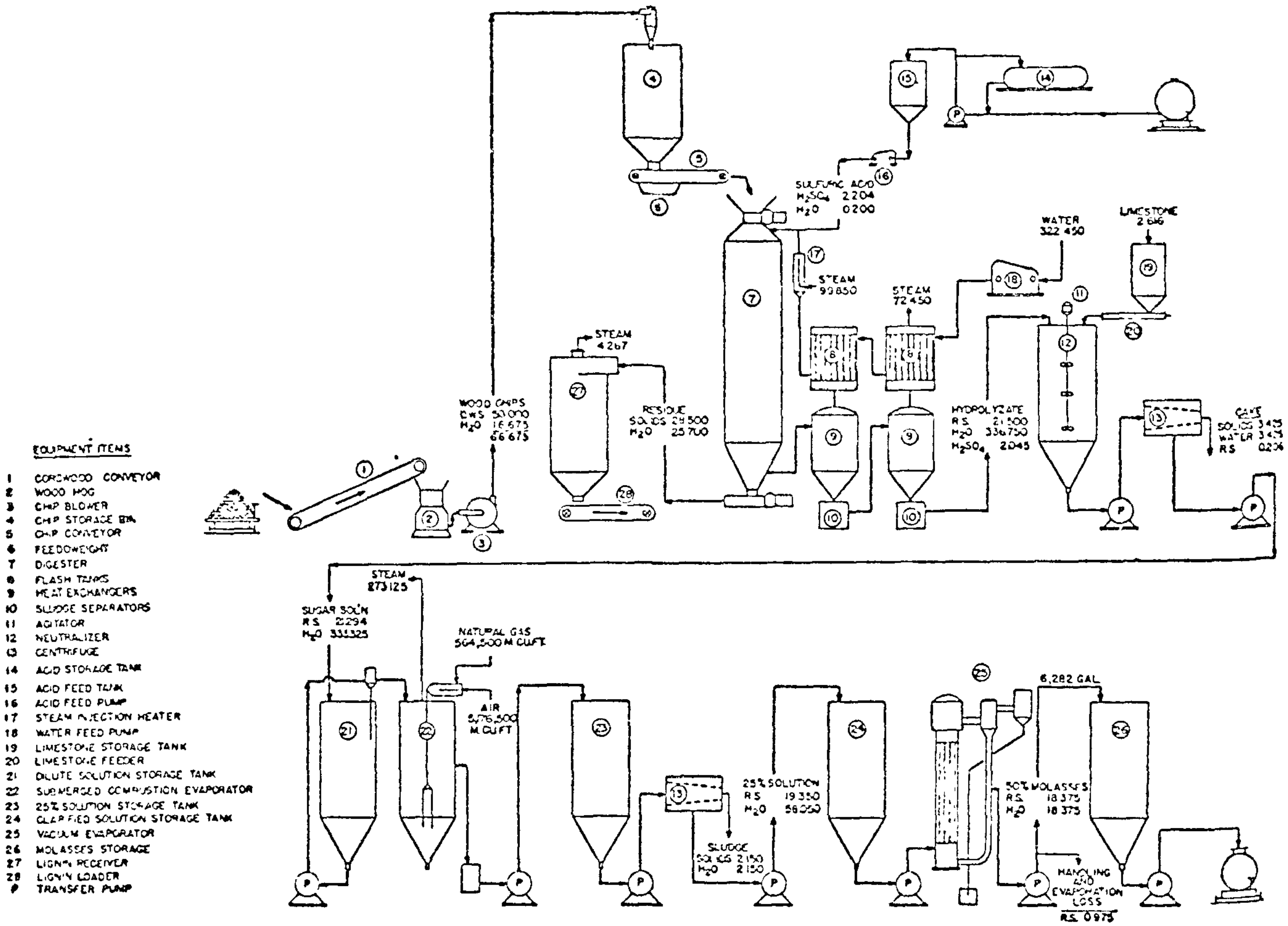

FIGURE 12: Flow Sheet of Wood Hydrolysis Plant Using 50 Tons of Dry-Wood Substance per Day [55]

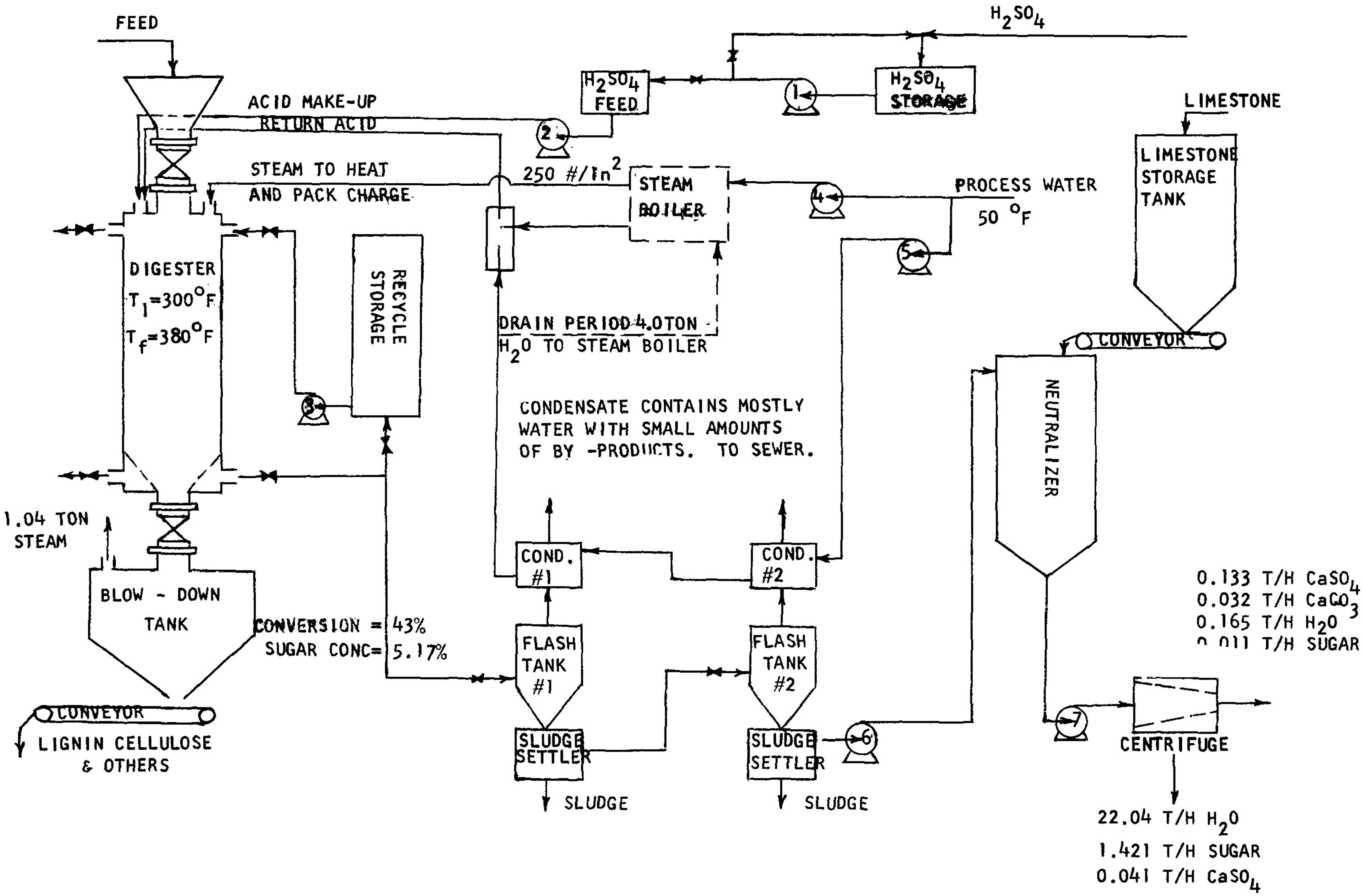

FIGURE 13: BATCH PROCESS - FLOW SHEET

The Processing of a Single Batch:

1. The digester is filled with wood chips (or paper pulp), packed with a sudden steam blast, and refilled. The charge is heated with live steam, to an initial temperature of 300°F (pressure = 67 psia); the condensate remains in the digester. This requires about 4 tons of steam.

2. Hydrolyzate collected during the drain period of the previous batch is introduced as rapidly as possible. The 17.2 tons of recycled solution is composed of 1 percent reducing sugars, 0.43 percent sulfuric acid, and the remainder largely water with some decomposition products.

3. As the recycled hydrolyzate is being introduced sulfuric acid must also be introduced in a quantity of 0.101 tons of 77.7 percent (60° Baumé) sulfuric acid per batch. This make-up acid is required for two reasons: The acid concentration in the recycled hydrolyzate is below 0.5 percent due to the fact that some sulfuric acid combines chemically with lignin, and the steam condensed during packing and heating must be brought up to a 0.5 percent acid concentration.

4. The digester contents are held at 300°F for 15 minutes during which the hemicellulose hydrolyzes. The liquid to solid ratio is 2 to 1.

5. At the end of this period the hydrolyzate line at the bottom of the digester is opened and the hydrolyzate is drained at a rate of 200 gal/min. At the same time, dilute acid is introduced into the top of the digester at 200 gal/min. The temperature of the dilute acid used for percolation is controlled by the injection of 250 psi steam.

6. The temperature of the dilute acid being introduced is raised from an initial temperature of 300°F to a final temperature of 380°F.

The rate of temperature rise is 5°F/minute taking a total of 16 minutes. Dilute acid at 380°F is introduced at 200 gal/min. for the remainder of the percolation period (134 minutes). Hydrolyzate is continuously withdrawn during the same period.

7. The hydrolyzate is flashed to atmospheric pressure in a series of 2 flash tanks. The first tank operates at 65 psia and the second at atmospheric pressure. The first hydrolyzate to be withdrawn from the digester is at a temperature of 300°F (67 psia) and thus very little is vaporized in the first flash tank. As the hydrolyzate temperature increases, the fraction vaporized in the first flash tank increases to 0.0943. The fraction vaporized in the second flash tank is constant at 0.0902.

8. By the end of the percolation period the sugar content of the hydrolyzate has dropped below 1 percent. The liquid in the digester is then drained. About 25 percent of the drained hydrolyzate is flashed while the remainder is sent to a hold-up tank and subsequently recycled to the next batch of fresh wood chips for the hemicellulose hydrolysis.

9. After the draining period, the spent wood chips (mostly lignin) are blown down to atmospheric pressure through a quick opening valve in the bottom of the digester.

10. The vapors produced in the flashing process are condensed by counter-current heat exchange with water to be used in the digester. This considerably reduces the steam required for heating the dilute acid stream.

11. Humic substance formed as a result of sugar decomposition separates out in the flash tanks as a thick insoluble sludge.

12. The hydrolyzate, still containing about 0.5 percent sulfuric acid is then neutralized with calcium carbonate to form a calcium sulfate precipitate. Since the solubility of calcium sulfate decreases as the solution temperature increases it is desirable to maintain the hydrolyzate at a high temperature. The neutralizer

serves two purposes: a) to contact the hydrolyzate with limestone and b) to provide a hold-up in the process so that the slurry may be removed continuously.

13. Calcium sulfate and excess calcium carbonate are removed from the system by centrifugation. The hydrolyzate leaving the centrifuge contains about 6 percent reducing sugar. Thus the plant will take 80 tons per day of dry wood substance and convert it to 34.1 tons of sugar.

The conversion of wood to sugar (based on the DWS charged to the reactor) is 43 percent. This number was taken from the TVA proposed plant and is based on their pilot plant work. Even though it is theoretically possible to calculate the conversion from Saeman's kinetics, the complexity of the system requires several questionable assumptions and the resulting differential equations are quite complex. Therefore the experimental conversion was used.

Economic Analysis:

The required process equipment together with description, material of construction, and costs is listed in Table XIV. Further specifications in addition to assumptions made in the design of the equipment are included with the calculations in the addendum report on hydrolysis. The cost indicated for a piece of equipment in this table is the arithmetic average of the costs from various references.[57,58,59,60,61,62,63,64,65,66,67,68] All costs are corrected to a Chemical Engineering Plant Cost index (CE) of 100 (1957-1959 = 100)[69] and are on an installed basis. Where installation costs were not given a value of 43 percent of the purchased equipment cost was used. This value is recommended by various authors.[58,60,70] The total installed equipment cost (CE = 100) is $332,400. From January through June, 1967, the Chemical Engineering Plant Cost Index has remained approximately constant at 109. Correcting to an index of 109, then, the installed equipment cost is $362,000. Table XV is an estimate of the required total capital investment. An explanation of the various items included in this estimate immediately follows Table XV. The total

TABLE XIV: AVERAGE EQUIPMENT COSTS

	Item	Size	Material of Construction	Installed Cost C.E. Index = 100
1)	H_2SO_4 Storage Tank	19,000 Gal.	Monel-Clad Steel	23,300
2)	H_2SO_4 Feed Tank	625 Gal.	Monel-Clad Steel	3,600
3)	Limestone Storage Tank	21,000 Gal.	Steel	8,200
4)	Neutralizer	21,000 Gal.	Steel (Agitated Tank)	20,700
5)	2-Condensers	200 ft^2 each	Steel Shell-Stainless Steel	13,500
6)	2-Flash Tanks	500 Gal each	Stainless-Clad	15,800
7)	Blow-Down Tank	11,200 Gal.	Monel-Clad Steel	15,800
8)	Recycle Storage Tank	4,860 Gal.	Stainless-Clad	26,600
9)	Digester	2000 ft^3	316 Stainless	133,000
10)	Centrifuge	30 in. Bowl Dia.	Steel	31,700
11)	Pump + Drive #1	40 GPM	Stainless	1,600
12)	Pump + Drive #2	0.73 GPM	Stainless	1,400
13)	Pump + Drive #3	144 GPM	Stainless	2,100
14)	Pump + Drive #4	16 GPM	Iron	1,400
15)	Pump + Drive #5	158 GPM	Iron	4,000
16)	Pump + Drive #6	200 GPM	Stainless	2,500
17)	Pump + Drive #7	200 GPM	Iron	1,700
18)	Lignin Conveyor	200 ft long	Open Belt	12,600
19)	Limestone Conveyor	200 ft long	Open Belt	12,900
		Total Equipment Cost	(Installed 1957-1959)	332,400

The Chemical Engineering Plant Cost Index for 1967 from January through June has remained approximately constant at 109.

Total Installed Equipment Cost (CE = 109) = $362,000

TABLE XV: ESTIMATE OF TOTAL CAPITAL INVESTMENT - BATCH PROCESS

	ITEM & BASIS OF ESTIMATE	COST (CE = 109)
1.	Purchased Equipment - Delivered (P.E.C.)	253,000
2.	Equipment Installation (Including Instrumentation and Insulation) - 43% P.E.C.	109,000
	Installed Equipment Cost	362,000
3.	Piping (Including Insulation) 36% P.E.C.	91,000
4.	Electrical Installations 15% P.E.C.	38,000
5.	Buildings Including Services 35% P.E.C.	88,500
6.	Yard Improvements 10% P.E.C.	25,300
7.	Service Facilities 35% P.E.C.	88,500
8.	Land 6% P.E.C.	15,200
	Total Physical Plant Cost	718,500
9.	Engineering and Construction 40% P.E.C.	101,200
	Direct Plant Cost (D.P.C.)	819,700
10.	Contractor's Fee 7% D.P.C.	57,500
11.	Contingency 15% D.P.C.	123,000
	Fixed Capital Investment (F.C.I.)	1,000,200
12.	Working Capital (Total Operating Cost for 30 Days)	94,000
	Total Capital Investment	1,094,200

physical plant cost was estimated to be $718,500. The fixed capital investment was $94,000 to give a total capital investment of $1,094,000.

For the sake of comparison the TVA work claimed that the installed equipment cost of the hydrolysis section (excluding neutralization and centrifugation) was $114,200 for a 50 ton per day plant at an Engineering News Record Index of 542. Correcting this to an 80 ton per day plant using the six-tenths factor[71] gives $151,500. At a Chemical Engineering Index of 109 the cost is $232,000. The cost of the neutralizer and centrifuge (CE Index = 109) is $57,200, for an estimated cost of $289,200 for the installed equipment, compared to $362,000 as estimated in this paper.

Explanation of Total Capital Investment Estimate - Table XV:

Item 1 - Purchased equipment costs were obtained from various references.[57,58,59,60,61,62,63,64,65,66,67,68] Since some references listed the cost of installed equipment all costs were put on an installed basis. The arithmetic average of the costs from the various references was taken as the equipment cost. All costs were corrected to a Chemical Engineering Plant Cost Index of 100 and these are summarized in Table XIV. The total installed equipment cost was then corrected to the present (June, 1967) CE Index of 109 and the purchased equipment cost was obtained from this by assuming an installation cost of 43 percent of the purchased equipment cost.

Item 2 - Lang[71] reports a study based on the design of 14 different chemical plants. This study indicates that about 70 percent of the installed equipment cost is spent for the equipment while about 30 percent is spent on installation. Thus on the basis of purchased equipment costs installation is $\frac{30}{70}$ or about 43 percent. This value includes instrumentation, insulation, foundations, supports, platforms, and erection of the equipment.

Item 3 - Piping costs for plants handling both solids and liquids are estimated at 36 percent of the purchased equipment cost.[58, p 96] This includes both material (21%) and labor (15%).

Item 4 - In ordinary chemical plants the cost of electrical installations amounts to 10 to 15 percent of the value of all purchased equipment.[58, p 97] "Electrical installations" consist primarily of material and installation labor for power and lighting.

Item 5 - "Buildings including Services" consists of expenses for labor, materials, and supplies involved in the erection of all buildings connected with the plant in addition to such building services as plumbing, heating, lighting, and ventilating. The cost of this item depends largely on whether a large portion of the major equipment is located indoors or outdoors. Assuming largely outdoor construction a value of about 35 percent of the purchased equipment cost is applicable.[58, p 101]

Item 6 - "Yard improvements" includes costs for fencing, grading, roads, sidewalks, railroad sidings, landscaping, and similar items. For chemical plants this item is usually 10 to 15 percent to the purchased equipment cost.[58 p 98]

Item 7 - Service facilities include utilities for supplying steam, water, power, compressed air and fuel in addition to waste disposal, fire protection, and miscellaneous service items such as shop, first-aid, and cafeteria equipment and facilities. The service facilities vary widely depending on the particular plant requirements. The cost of service facilities usually ranges from 20 to 70 percent of the purchased-equipment cost.[58, p 99] For a solid-fluid-processing plant a value of 35 percent was considered applicable.[58 p 101] Since this plant uses a considerable amount of steam, steam utilities costs are included in the steam cost. In addition, since electrical usage is relatively small it was decided to purchase power from an outside source rather than installing utilities for self-generation. No fuel or compressed air is required in this plant which leaves water-supply as the only remaining utility. In this case then, a value of 35 percent of the purchased equipment cost is probably a conservative estimate.

Item 8 - Land costs may vary from \$300 per acre in some rural districts to \$5000 per acre in industrialized areas. Land costs generally average about 1 to 2 percent of the total capital investment or about 6 percent of the purchased equipment cost.[58,p99]

Item 9 - "Engineering and Construction" includes the costs for construction design and engineeeing, field offices, field supervision, insurance, temporary construction, inspection, and general construction overhead. This cost generally ranges from 10 to 20 percent of the total physical plant cost or an average of about 40 percent of the purchased equipment cost.[58,p99]

Item 10 - The contractors fee varies with the complexity of the plant but is ordinarily in the range of 4 to 10 percent of the direct plant cost.[58,p99] An average value of 7 percent was chosen.

Item 11 - A contingency factor is usually included in a capital investment estimate to account for such unforeseen expenses as storms, floods, strikes, price changes, small design changes, errors in estimation, and so forth. Contingency factors usually range from 10 to 20 percent of the direct plant cost.[58,p99] An average value of 15 percent was used.

Item 12 - Working capital consists of money invested in the following: 1) raw materials and supplies carried in stock, 2) finished products and semifinished products in stock, 3) accounts receivable, and 4) cash which must be kept on hand for monthly payment of operating expenses such as salaries, wages, and raw material purchases. The raw-material inventory usually amounts to a 1-month supply.[58p19] No finished or semi-finished products are stocked in any appreciable amount in this section of the plant. No product is sold to a customer which eliminates accounts receivable. In this case, then, the working capital consists of 1 and 4 above. A good approximation for working capital would be the total production cost for 1 months operation. Working capital is usually about 10 to 20 percent of the total capital investment.[58,p19]

Manufacturing Costs:

The estimated manufacturing cost for hydrolyzate sugar from a plant utilizing wastepaper as feedstock is given in Table XVI. The daily manufacturing cost was estimated to be $3,133. No allowance was made for the value of the calcium sulfate which is a product of the neutralization reaction. About 3.19 tons per day of calcium sulfate are produced but the solid product contains impurities as well as an equal weight of water. In order to sell the produce, provisions would have to be made for drying, storing, and shipping.

The daily output of sugar from this hydrolysis plant is 68,300 pounds. This number must be modified however to allow down-time for maintenance work, unforseen work stopages, etc. Assuming an on-stream factor of 0.9 or 328 days of full capacity operation per year, the average daily production is 61,500 pounds of sugar. The cost per pound of sugar is then 5.1 cents.

Explanation of Estimated Manufacturing Cost - Table XVI:

Item A-1 - The f.o.b. costs, freight rates, and assumptions made in the calculation of raw material costs are given in the addendum report on hydrolysis.

Item A-2 - The calculation of utility costs and the assumptions made in these calculations are given in the addendum report.

Item A-3 - The operating labor force of 4 men/shift was based on the following expected requirements.

1) Two men to operate the digester
2) One man to attend the flash tanks, condensers, and sludge separators.
3) One man to operate the neutralizer and centrifuge. It is doubtful that the plant operation will fully occupy the 4 men. Therefore, in their spare time these men can run control tests.

TABLE XVI: ESTIMATED MANUFACTURING COST - BATCH PROCESS

ITEM	UNITS/DAY	COST	DAILY COST
A. Direct Production Costs			
1. Raw Materials			
H_2SO_4 (60° Baume = 77.7%)	4.38 Ton	$26.00/Ton	125.60
Limestone (Crushed - 100 Mesh)	3.83 Ton	12.40/Ton	47.50
Wastepaper (Mixed)	80.0 Ton	13.00/Ton	1,040.00
2. Utilities			
Electricity (125% of Process Demand)	2580 kw-hr	$ 0.014/kw-hr	36.10
Steam (125% of Process Demand)	144/Ton	0.75 Ton	216.00
Process Water	162.5 M-Gal	0.25/M-Gal	40.60
3. Operating Labor 4 Men/Shift at $3.00/Hr.	96 Man-Hrs.	$ 3.00/M-Hr.	288.00
4. Supervisor 1 Man - Day Shift at $3.50/Hr.	8 Man-Hrs.	$ 3.50/M-Hr.	28.00
5. Fringe Benefits 15% of Operating Labor + Supervision			47.50
6. Operating Supplies, 10% of Labor			28.80
7. Maintenance and Repairs, 10% F.C.I.			
Labor (per year) = 5% F.C.I.			137.00
Overhead & Supplies (per year) = 5% F.C.I.			137.00
Direct Production Cost			2,172.10
B. Fixed Charges			
1. Depreciation - 12 Year Plant Life - Zero Salvage Value = 8 1/3 % F.C.I. per year			228.00
2. Local Taxes 2% F.C.I. per year			54.80
3. Insurance 1% F.C.I. per year			27.40
Fixed Charges			310.20
C. Plant Overhead - 70% of Operating + Maintenance Labor + Supervision = (.70) (440)			308.00
D. General Expenses			
1. Administrative Costs - 15% of Operating + Maintenance Labor + Supervision = (.15) (440)			66.00
2. Distribution and Selling Cost - (Not Applicable)			-
3. Research and Development Cost - 5% Total Product Cost			157.00
4. Financing Interest 4% of Total Cap. Invest. Per Year			119.00
General Expenses			343.00
Total Production Cost (A + B + C + D) =			3,133.30

Assuming an On-Stream factor of 0.9 to allow down-time for maintenance and other unforseeable work stoppages the average daily output is 61,500#Sugar

Total Product Cost $= \frac{\$3,133}{61,500\#}$ = 5.1¢/#Sugar

Item A-5 - Generally, fringe benefits range from 10 to 25 percent of the straight hourly wage.[61, p 26-30] An average value of 15 percent was assumed.

Item A-6 - Operating supplies include such miscellaneous expenses as gloves, stationery, flashlights, wiping rags, etc. This item varies from about 5 to 20 percent of the operating labor and an average value of 10 percent is usually applicable.[72]

Item A-7 - Maintenance and repairs usually range from 4 to 8 percent of the fixed capital investment per year. For a plant handling corrosive materials this may go as high as 12 percent.[72] A value of 10 percent was chosen. Fifty to sixty-five percent of the total maintenance can be attributed to maintenance labor.[72] A value of 50 percent was taken.

Item B-1 - Depreciation was calculated on the basis of a 12 year plant life with zero salvage value to give 8-1/3 percent per year. Interest on the investment was taken into account in item D-4. Eight and one-third represents a fairly typical depreciation allowance.[72,73]

Items B-2 and B-3 - Local taxes range from 1 to 4 percent of the fixed capital investment per year while insurance varies from 0.4 to 1 percent per year.[58, p 108] Respective values of 2 and 1 percent were selected.

Item C - Plant overhead is usually in the range of 50 to 70 percent of the cost for operating labor, supervision, and maintenance labor.[58, p 109] Another source[72] indicates 50 to 100 percent of the productive payroll. Therefore a value of 70 percent was chosen. Plant overhead includes the following: general plant upkeep, payroll overhead, packaging, medical services, safety and protection, restaurants, recreation, salvage, laboratories and storage facilities.

Item D-1 - Administrative Costs includes costs for executive salaries, clerical wages, legal fees, office supplies, and communications. The cost amounts to about 15 percent of the operating labor, supervision, and maintenance labor.

Item D-2 - This item was not considered applicable since no product was being sold or distributed.

Item D-3 - Two to five percent of every sales dollar goes toward financing research and development or approximately 5 percent of the total product cost.[58, p 109] Although this item is questionable in this application it remains in the analysis as a second contingency factor in keeping with the conservative approach to estimating operating costs.

Item D-4 - Some factor should be applied to take into account the time-value of money. The money borrowed for the fixed capital investment is paid back gradually over the life of the plant by depreciation allowances. The investment made on the working capital is not regained until the plant is shut down. The financing interest takes into account the interest paid on the money borrowed for both the fixed capital and working capital investments. It is approximately 4 percent per year of the total capital investment. The actual interest payments of course, will be greater than this in the early years of the plant life and smaller in the later years.

D. The Continuous Process

The flow sheet for the continuous process is shown in Figure 14. In general this process is similar to the batch process and requires the same processing steps: hydrolysis, flash vaporization, neutralization, and centrifugation. The basic difference is in the reactor. The continuous reactor system is a series of individual reactor tubes with a screw press after each unit. Paper pulp and dilute acid are conveyed co-currently through each reactor tube by means of a screw conveyor. Paper pulp containing 50 percent moisture from pre-hydrolysis processing is fed to reactor number 1. A hot dilute solution of sulfuric acid mixes with the paper pulp at the inlet of the reactor and heats the charge. The first reactor is designed to hydrolyze only the hemicellulose portion of the charge and should therefore be operated at lower temperatures and shorter residence times than the other reactors to minimize the decomposition of the sugars. An initial liquid to solid ratio of 4 was used. From reactor number one the paper pulp-dilute acid mixture passes through a screw press that squeezes most of the hydrolyzate from the paper pulp thus removing from the reaction system most of the sugars formed in the first reactor and preventing their decomposition: The paper pulp from the screw press containing about 50 percent, moisture is mixed again with fresh, hot, dilute acid at the inlet of reactor number 2. The temperature of reactor two is maintained at 200°C since this and all remaining reactors are designed to hydrolyze the alpha cellulose portion of the charge. The residence time is longer, about 10 minutes, and corresponds to the residence time at which conversion of alpha cellulose to sugar is a maximum. Hydrolyzate is again removed by a screw press after reactor two to prevent further decomposition of sugars. This scheme of mixing the charge with fresh acid, reacting and removing the hydrolyzate may be continued for as many stages as economics justifies.

The reactor system described above is commercially available from The Black Clawson Company of Middletown, Ohio.[74] Black Clawson was consulted for information on costs, operating labor and power requirements, for their systems used in this plant design.[75]

Reactor one operates at a lower temperature than the other reactors therefore the hydrolyzate removed from screw press one will be under a lower pressure.

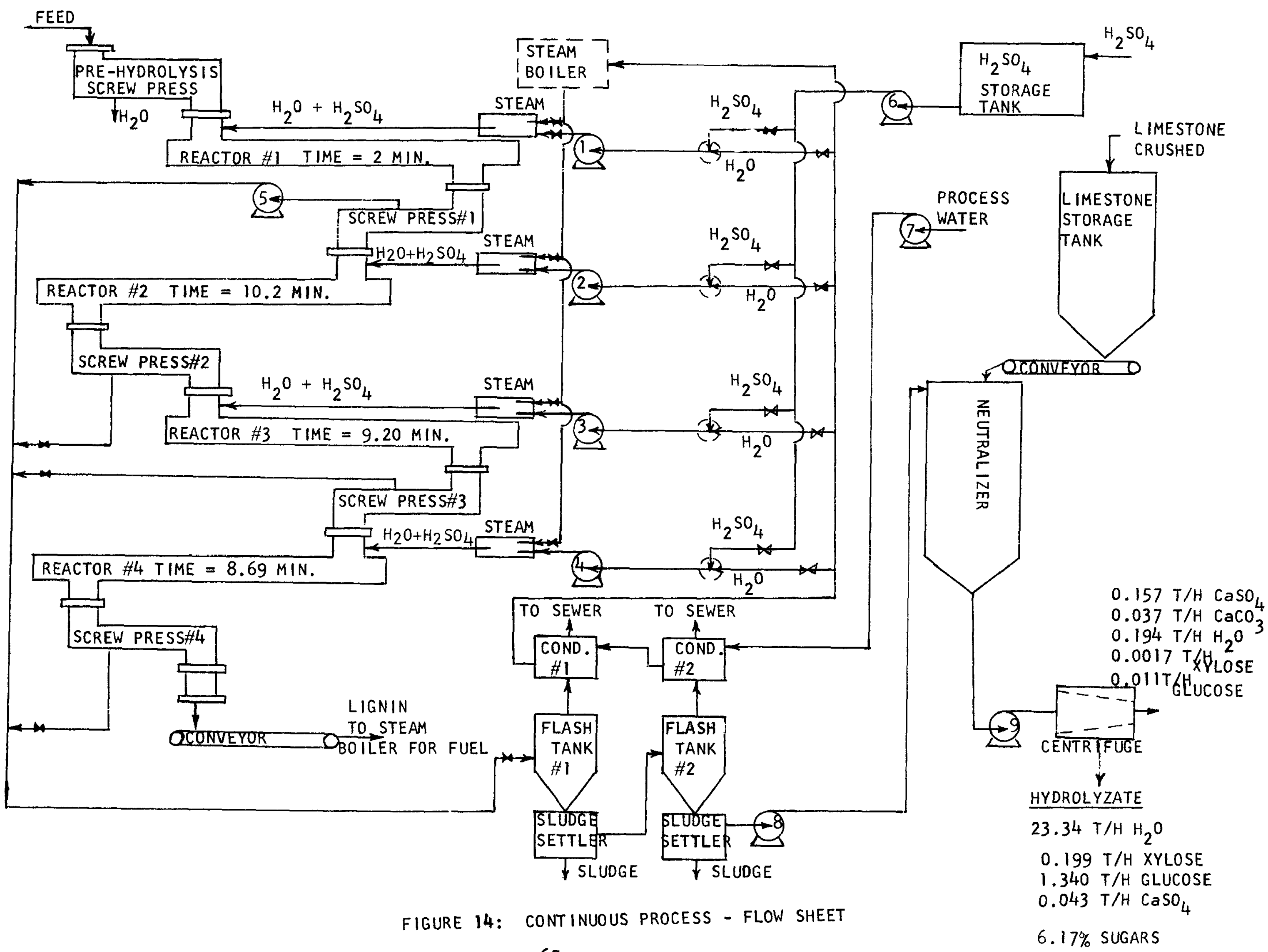

FIGURE 14: CONTINUOUS PROCESS - FLOW SHEET

Thus the hydrolyzate from screw press one must be pumped to a higher pressure before mixing with the hydrolyzates from the other screw presses, resulting in an additional operation.

Other flow sheet changes were made simply to facilitate continuous addition of hot, dilute, sulfuric acid to each reactor. Aside from the above mentioned modifications the process description for the batch plant is generally applicable.

Continuous Process - Discussion of Process Variables:

The important process variables are: 1) residence time 2) temperature 3) Liquid to solid ratio and 4) acid concentration. Residence time is not an independent variable. That is, given a temperature, a liquid to solid ratio, and an acid concentration, one can calculate the residence time at which conversion of cellulose to sugar is a maximum. The equation for the residence time at which maximum conversion is realized is a function of initial concentrations and k_1 and k_2, the specific reaction rate constants for wood hydrolysis and sugar decomposition respectively. The values of k_1 and k_2 are in turn, functions of temperature, acid concentration, and liquid to solid ratio. Therefore the optimum residence time is dependent on these three variables.

The conversion of wood cellulose to sugar increases as the ratio of k_1 to k_2 increases. This ratio can be increased by increasing either temperature, liquid to solid ratio, or acid concentration. The reaction temperature can easily be increased by using more steam. However, it is necessary to keep the dilute acid in the liquid phase; so the pressure within the reactor must also be increased to correspond with the vapor pressure of water at the temperature in question. Since vapor pressure increases exponentially with temperature, operation at high temperature may lead to excessive pressures. From Figure 15 the vapor pressure of water at 200°C is 225 psia but at 210°C the pressure is 276 psia. The Black Clawson Chemipulpers are produced in 2 pressure series: 175 psia and 275 psia. Operation at or above 210°C would require specially fabricated equipment. Allowing a 10°C safety margin, one could operate at 200°C and remain within the pressure limitations of the system. Another

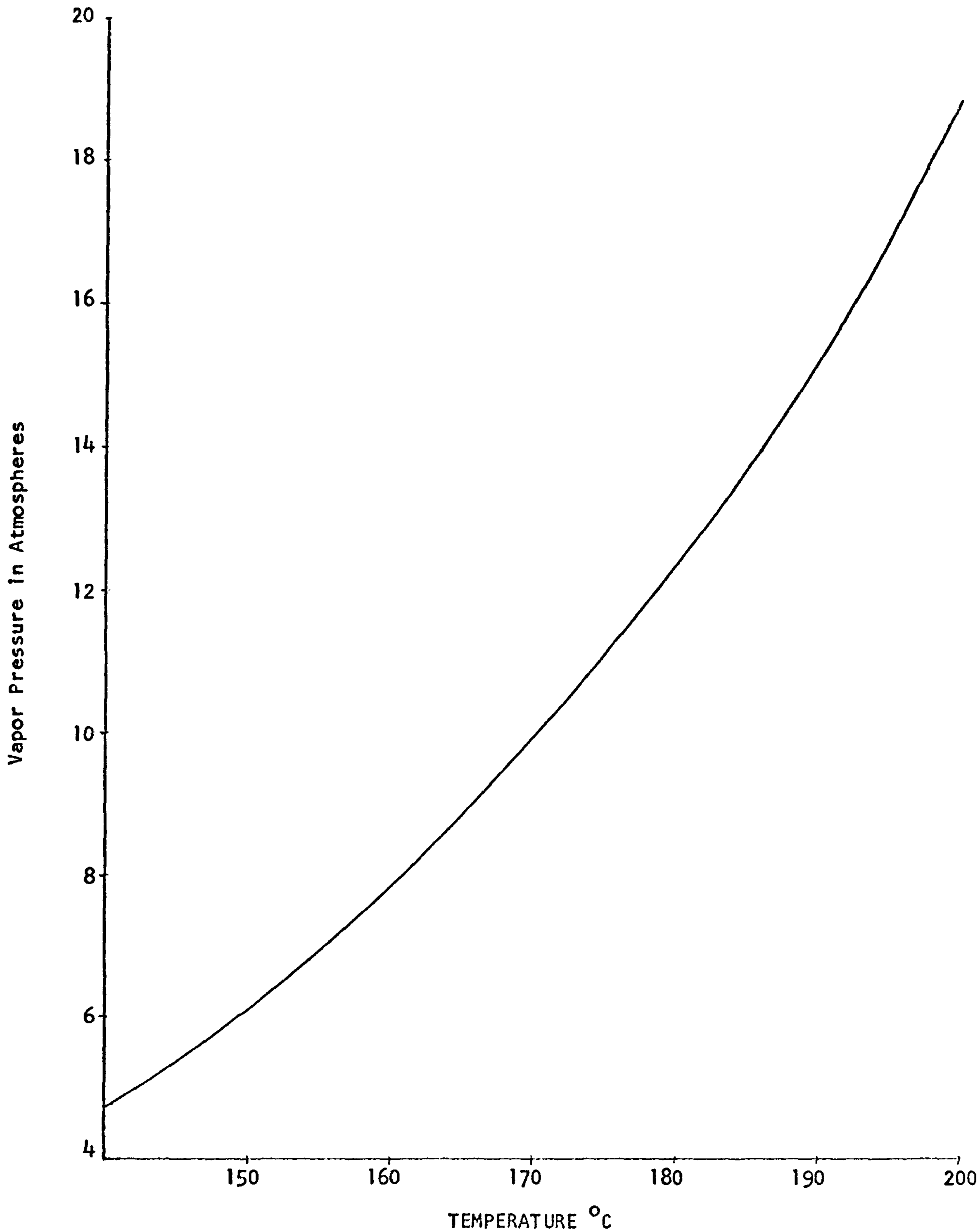

FIGURE 15 Vapor Pressure vs. Temperature - Water

consideration that supports the choice of 200°C as the maximum operating temperature is the fact that the maximum temperature used to obtain the kinetic data was 190°C.[40] It is never a good idea to extrapolate kinetic data too far from the experimental range. At temperatures below 200°C both conversion and reaction rate decrease. Reaction rate is quite dependent on temperature. In the range of 170°C to 190°C an increase of 10°C in the reaction temperature increases the rate of hydrolysis by 186 percent. Thus as one decreases the operating temperature from 200°C the required reactor volume increases quite rapidly. For example, the residence time at which conversion of alphacellulose to sugar is a maximum for acid concentrations of 0.5 percent and liquid to solid ratios of 10 is as follows:

$$T = 200^{\circ}C \qquad t\ max = 11.7\ min.$$
$$T = 170^{\circ}C \qquad t\ max = 175\ min.$$

This time is directly proportional to reactor volume for a given feed rate.

Total steam costs account for only 4.5 percent of the total manufacturing cost at an operating temperature of 200°C. The cost of the small amount of steam required to increase the reaction temperature from 170°C to 200°C will be more than compensated for by a smaller and less expensive reactor system and an increase in sugar yield. Therefore, the temperature for alphacellulose hydrolysis was set as 200°C.

Liquid to solid ratio has no effect on k_2 (sugar decomposition) and only a slight effect on k_1 (alphacellulose hydrolysis). However, it has a considerable effect on the final sugar concentration, the sugar yield, and the amounts of acid, water, and steam required for the hydrolysis. Thus the L/S ratio is quite important. From the standpoint of limiting acid, water and steam usage the L/S ratio should be small. However from the standpoint of yield the L/S ratio should be large. This is due to the fact that a certain amount of liquid is entrained with the solids and does not get removed in the screw press. The higher the L/S ratio, the less concentrated the entrained liquid is, and there is less loss of sugar and therefore a greater yeild. The factor that determines the lower limit of the L/S ratio is the ability of the screw press to remove the liquid. A single stage screw press can accept consistencies of 15 to 25 percent solids and thicken up to 50 percent solids.[74] Thus the lower limit on the L/S ratio is 1.0 (50 percent liquid, 50 percent solids). If the system were operated at this minimum no product would be obtained. Therefore, higher ratios must be employed. The ratios are determined by an economic balance of sugar yield against acid, steam, water, and limestone usage. It should also be pointed out that as the L/S ratio increases the size of all the process equipment (except the pre-hydrolysis operations) must also increase. This factor must also be considered. The optimum L/S ratio probably lies somewhere between 2 and 6. A value of 4 was chosen for this preliminary estimate and the plant was designed on that basis.

The influence of acid concentration on product cost is summarized in the following examples. Calculations for this comparison are included in the addendum report.

A four-stage reactor system using 0.5 percent sulfuric acid converted 100 pounds of dry feed to 46.57 pounds of sugar whereas the same reactor system using 1.5 percent sulfuric acid converted the same feed to 49.30 pounds of sugar. Neglecting the small additional investment for the 1.5 percent sulfuric acid (for larger storage tanks), the optimum acid concentration is the concentration at which the daily profits are a maximum. On the basis of an 80 ton per day plant, the additional sugar produced by using 1.5 percent sulfuric acid is 0.091 tons per hour or, assuming an on-stream factor of 0.9, 3,930 pounds per/day. From Table XIX the 0.5 percent acid process requires 4.65 tons of acid per day at a cost of \$121. The 1.5 percent acid process would require 3.95 tons of acid per day at a cost of \$363 per day. Also, the 0.5 percent acid process requires 4.42 tons per day of limestone at a cost of \$54.80 per day whereas the 1.5 percent acid process would require 13.26 tons per day of limestone at a cost of \$164.40. Therefore, the cost of the sugars produced by increasing the acid concentration from 0.5 to 1.5 percent is:

$$\frac{\$(363 + 164.40) - \$(121 + 54.80)}{3{,}930 \text{ pounds sugar}} = \frac{8.95 \text{ cents}}{\text{pound sugar}}$$

From Table XIX, the manufacturing cost using 0.5 percent sulfuric acid is 5.7 cents per pound sugar. Obviously, then, one should not increase the acid concentration. The total manufacturing cost using an acid concentration of 1.5 percent turns out to be 5.90 cents per pound sugar. There may be some economic advantage in decreasing the acid concentration below 0.5 percent but at these low concentrations acid costs are not a major factor in the manufacturing cost. For example, at 0.5 percent, the acid cost is only 3.2 percent of the manufacturing cost when a four-stage reactor system is used. For this reason no lower acid concentrations were investigated and the plant was designed on the basis of 0.5 percent sulfuric acid.

Having chosen the important process variables: T = 200°C, L/S = 4, and acid concentration = 0.5 percent the plant design and economics can proceed. Actual plant calculations, necessary assumptions and equipment selections are detailed in the addendum report.

Continuous Process - Economic Analysis:

The equipment costs as found in various references[57,58,59,60,61,62,63,65,66,67,68,75,76] are summarized in Table XVII. The total installed equipment cost is $697,000 computed at a Chemical Engineering Plant Cost Index (CE) of 109 (first half, 1967). The reactor system was by far the most expensive item; its installed cost at CE of 109 was $500,000. The estimated total capital investment is itemized in Table XVIII. The items included in this table are defined in the text following Table XV. Several things should be pointed out concerning this estimate: 1) Many of the items of this table are based on a percentage of the purchased equipment. Since much of the plant is constructed of exotic materials (Carpentor 20 for the reactor system for example) the purchased equipment cost will be much higher than for the "ordinary chemical plant" on which the estimates are based. That is, "buildings and services" are estimated at 35 percent of the purchased equipment cost whether the equipment is constructed of carbon steel or stainless. This leads one to the conclusion that buildings and services are a function of the material of construction of the process equipment. This is, of course, not the case. The 35 percent is based on averages throughout the chemical process industries and applies strictly only to the "average chemical plant". To minimize this effect, the installed equipment cost was calculated and, assuming an installation cost of

TABLE XVII: AVERAGE EQUIPMENT COSTS FOR CONTINUOUS PROCESS USING A FOUR-STAGE REACTOR SYSTEM

	Item	Size	Material of Construction	Installed Cost C.E. Index = 100
1)	Reactor System		Carpenter #20 Steel	459,000
2)	4-Reactor Tube Motors	10 H.P. Each	A.C. - Enclosed	5,200
3)	Pre-Hydrolysis Press Motor	261 H.P.	A.C. - Enclosed	10,000
4)	Screw Press #1 Motor	202 H.P.	A.C. - Enclosed	7,500
5)	Screw Press #2 Motor	132 H.P.	A.C. - Enclosed	4,400
6)	Screw Press #3 Motor	105 H.P.	A.C. - Enclosed	3,500
7)	Screw Press #4 Motor	98 H.P.	A.C. - Enclosed	3,400
8)	H_2SO_4 Storage Tank	20,500 Gal.	Monel-Clad Steel	24,000
9)	Limestone Storage Tank	24,500 Gal.	Steel	8,900
10)	Neutralizer	10,800 Gal.	Steel (Agitated Tank)	13,800
11)	2-Condensers	100 Ft^2 Each	Steel Shell-Stainless Tubes	9,100
12)	2-Flash Tanks	300 Gal. Each	Stainless Clad	16,400
13)	Centrifuge	30 in. Bowl Dia.	Steel	31,700
14)	Lignin Conveyor	200 Ft. Long	Open Belt	12,600
15)	Limestone Conveyor	200 Ft. Long	Open Belt	12,900
16)	Pump + Drive #1	31 GPM	Stainless-Centrifugal	1,800
17)	Pump + Drive #2	26 GPM	Stainless-Centrifugal	1,800
18)	Pump + Drive #3	17 GPM	Stainless-Gear	1,700
19)	Pump + Drive #4	14 GPM	Stainless-Gear	1,600
20)	Pump + Drive #5	46 GPM	Stainless-Centrifugal	1,900
21)	Pump + Drive #6	> 1 GPM	Stainless-Gear	1,400
22)	Pump + Drive #7	107 GPM	Iron-Centrifugal	3,500
23)	Pump + Drive #8	97 GPM	Stainless-Centrifugal	1,900
24)	Pump + Drive #9	97 GPM	Iron-Centrifugal	1,400

Total Equipment Cost - Installed (1957-1959) = 639,400

For the first half of 1967 a Chemical Engineering Plant Cost Index of 109 is applicable.

Total Equipment Cost - Installed = 697,000

TABLE XVIII: ESTIMATE OF TOTAL CAPITAL INVESTMENT FOR CONTINUOUS PROCESS USING A FOUR-STAGE REACTOR SYSTEM

Item & Basis of Estimation	Cost (CE = 109)
1. Purchased Equipment - Delivered (P.E.C.)	487,000
2. Equipment Installation (Including Instrumentation and Insulation) - 43% P.E.C.	210,000
Installed Equipment Cost	697,000
3. Piping (Including Insulation) - 36% P.E.C.	175,000
4. Electrical Installations - 15% P.E.C.	73,000
5. Buildings Including Services - 35% P.E.C.	170,000
6. Yard Improvements - 10% P.E.C.	48,700
7. Service Facilities - 35% P.E.C.	170,000
8. Land - 4% P.E.C.	19,500
Total Physical Plant Cost	1,353,200
9. Engineering and Construction 40% P.E.C.	195,000
Direct Plant Cost (D.P.C.)	1,548,200
10. Contractors Fee 7% D.P.C.	108,200
11. Contingency 15% D.P.C.	232,000
Fixed Capital Investment	1,888,400
12. Working Capital (Total Operating Cost for 30 Days)	113,800
Total Capital Investment	2,002,200

43 percent of the purchased equipment cost (again based on the "ordinary chemical plant") the purchased equipment cost was calculated. This purchased equipment cost would be more in line with what one would expect for the "ordinary chemical plant" given the above calculated purchased equipment cost, and the sum of the two is the installed equipment cost for this particular plant. 2) It is rather doubtful that there should be any significant difference in the land required for the batch and the continuous processes. Therefore, the land cost (as a percent of the purchased equipment cost) was adjusted to give a value of 15,000 to $20,000.

The fixed capital investment for the 4-stage continuous plant using 0.5 percent sulfuric acid was estimated to be $1,888,000 and the total capital investment was estimated at $2,002,000.

The estimated manufacturing cost for hydrolyzate sugar using a wastepaper feed is itemized in Table XIX. An explanation of the various items included in this table is given in the text following Table XVI. The daily operating cost was estimated to be $3,786. The largest single item in this estimate is the cost of the wastepaper which amounts to 27.5 percent of the manufacturing cost. To determine the cost per pound of sugar produced, some on stream factor should be assumed since it is doubtful that the plant will operate at full capacity for 365 days per year. A factor of 0.9 was chosen and the daily sugar output was then multiplied by this factor. At full capacity (80 tons dry feed per day) the plant output is 73,900 pounds of sugar. With an on-stream factor of 0.9 the average daily output of sugar is 66,500 pounds. Theoretically the on-stream factor should also be applied to the usage of raw materials and utilities. However, when the reactor system is shut down, the reacting material is converted all the way to decomposition products and there is a net loss of raw material over and above the corresponding loss in sugar production. When the system is restarted, very little sugar will be obtainable from the material held in the reactor system during shut-down. Therefore a factor somewhat greater than 0.9 should be applied to raw materials and utilities depending on the frequency with which shut-downs will occur. Since the choice of 0.9 is somewhat arbitrary, no on-stream

TABLE XIX: ESTIMATED MANUFACTURING COST FOR CONTINUOUS PROCESS USING A FOUR - STAGE REACTOR SYSTEM

ITEM	UNITS/DAY	COST	DAILY COST
A. Direct Production Cost			
1. Raw Materials			
H_2SO_4 (60° Baume - 77.7%)	4.65 Ton	$26.00/Ton	$ 121.00
Limestone (Crushed - 100 Mesh)	4.42 Ton	12.40/Ton	54.80
Wastepaper (Mixed)	80.0 Ton	13.00/Ton	1,040.00
2. Utilities			
Electricity	17.600 kw-hr	0.007/kw-hr	123.20
Steam (125% of Process Demand)	325,500 #	0.52/1000 #	169.20
Process Water	172,000 Gal	0.25/1000 Gal	43.00
3. Operating Labor 3 Men/Shift	72 Man-Hrs.	3.00/Man-Hr.	216.00
4. Supervisor 1 Man - Day Shift	8 Man-Hrs.	3.50/Man-Hr.	28.00
5. Fringe Benefits - 15% Hourly Wage			36.60
6. Operating Supplies - 10% of Labor			21.60
7. Maintenance and Repairs - 10% F.C.I.			
Labor (Per Year) = 5% F.C.I.			258.00
Overhead and Supplies (Per Year = 5% F.C.I.			258.00
Direct Production Cost			2,369.40
B. Fixed Charges			
1. Depreciation - 12 Year Plant Life - Zero Salvage Value = 8 1/3% F.C.I. Per Year			426.00
2. Local Taxes - 2% FCI Per Year			103.50
3. Insurance - 1% FCI Per Year			51.70
Fixed Charges			581.20
C. Plant Overhead - 70% of Operating Labor, Supervision & Maintenance Labor			351.50
D. General Expenses			
1. Administrative Costs - 15% of Operating Labor, Supervision & Maintenance Labor			75.30
2. Distribution and Selling Cost - (Not Applicable)			-
3. Research and Development Cost - 5% Total Prod. Cost.			190.00
4. Financing Interest 4% of Total Cap. Investment Per Year			219.00
General Expenses			484.30
Total Production Cost (A + B + C + D)			3,786.40

Total Product Cost = $\frac{¢3,786.40}{66,500\#}$ = 5.7¢/#Sugar factor was applied to the raw materials and utilities. Thus the cost per pound of sugar is determined by dividing the daily cost at full capacity by nine-tenths times the daily full capacity output. The manufacturing cost obtained in this way is 5.7 cents per pound of sugar. If one assumed an on-stream factor of 0.9 and applied it not only to sugar production but to raw materials and utilities as well, the cost would be 5.45 cents per pound.

Continuous Process - Optimum number of stages:

Since the reactor system accounts for over seventy percent of the installed equipment cost the optimization of the plant with respect to the number of reactor stages is quite important. A four stage system was assumed as a starting point to get some estimate of the manufacturing cost. By using some approximations, the total capital investment for a plant using a three stage reactor can be estimated. Also, the daily operating cost and the daily sugar production can easily be obtained from the four stage design. The calculations and assumptions made in revising the various costs of the four stage system are given in the text following Table XXI. The revised installed equipment cost is $582,000. Table XX gives the itemized total capital investment for the continuous process using a three stage reactor. The fixed capital investment is $1,583,000 compared to $1,888,000 for the four stage process. The estimated manufacturing cost for the three stage plant is given in Table XXI. The daily product cost is $3,466 but the plant capacity, at an on-stream factor of 0.9, drops from 66,500 to 62,500 pounds per day. Thus, the manufacturing cost for the three stage plant is 5.55 cents per pound of sugar as compared to 5.7 cents per pound of sugar for the four stage process. The four stage process should be compared to the three stage process to see if the return on the additional investment for another stage is worthwhile. This comparison is made following Table XXI.

TABLE XX: ESTIMATE OF TOTAL CAPITAL INVESTMENT FOR CONTINUOUS PROCESS USING A THREE-STAGE REACTOR SYSTEM

	ITEM & BASIS OF ESTIMATION	COST (CE = 109)
1.	Purchased Equipment - Delivered (P.E.C.)	407,000
2.	Equipment Installation (Including Instrumentation and Insulation) - 43% (P.E.C.)	175,000
	Installed Equipment Cost	582,000
3.	Piping (Including Insulation - 36% P.E.C.	146,700
4.	Electrical Installations - 15% P.E.C.	61,000
5.	Buildings Including Services - 35% P.E.C.	142,600
6.	Yard Improvements - 10% P.E.C.	40,700
7.	Service Facilities - 35% P.E.C.	142,600
8.	Land - 4.8% P.E.C.	19,500
	Total Physical Plant Cost	1,135,100
9.	Engineering and Construction - 40% PEC	162,900
	Direct Plant Cost (D.P.C.)	1,298,000
10.	Contractors Fee - 7% D.P.C.	90,900
11.	Contingency - 15% D.P.C.	194,600
	Fixed Capital Investment (F.C.I.)	1,583,500
12.	Working Capital (Total Operating Cost for 30 Days)	104,000
	Total Capital Investment	1,687,500

TABLE XXI: ESTIMATED MANUFACTURING COST FOR CONTINUOUS PROCESS USING A THREE - STAGE REACTOR SYSTEM

ITEM	UNITS/DAY	COST	DAILY COST
A. Direct Production Cost			
1. Raw Materials			
H_2SO_4 (60° Baume - 77.7%)	4.02 Tons	$26.00/Ton	104.60
Limestone (Crushed - 100 Mesh)	3.78 Tons	12.40/Ton	46.90
Wastepaper (Mixed)	80.0 Tons	13/Ton	1,040.00
2. Utilities			
Electricity	15.630 kw-hr.	0.007/kw-hr.	109.50
Steam (125% of Process Demand)	285,500 #	0.52/1000#	148.30
Process Water	172,000 Gal	0.25/1000 Gal	43.00
3. Operating Labor 3 Men/Shift	72 Man-Hrs.	3.00/Man-Hr.	216.00
4. Supervisor 1 Man - Day Shift	8 Man-Hrs.	3.50/Man-Hr.	28.00
5. Fringe Benefits - 15% Hourly Wage			36.60
6. Operating Supplies - 10% of Labor			21.60
7. Maintenance and Repairs - 10% F.C.I.			
Labor (Per Year) = 5% FCI			217.00
Overhead & Supplies (Per Year) = 5% F.C.I.			217.00
Direct Production Cost			2,228.50
B. Fixed Charges			
1. Depreciation - 12 Year Plant Life - Zero Salvage Value = 8 1/3% FCI per Year			357.00
2. Local Taxes - 2% FCI Per Year			86.70
3. Insurance - 1% FCI Per Year			43.50
Fixed Charges			487.20
C. Plant Overhead - 70% of Operating Labor, Supervision & Maintenance Labor			323.00
D. General Expenses			
1. Administrative Costs - 15% of Operating Labor Supervision & Maintenance Labor			69.10
2. Distribution and Selling Cost (Not Applicable)			-
3. Research and Development Cost - 5% Product Cost			173.00
4. Financing Interest 4% of Total Capital Investment Per Year			185.00
General Expenses			427.10
Total Production Cost Excluding Income Tax (A + B + C + D)			3,466.00

With on-stream factor = 0.9 the daily sugar production is 62,500#

Total Product Cost = $\frac{\$3,466.00}{62,500\#}$ = 5.55¢/# Sugar

Modification of Calculations for Three-Stage Reactor System:

Reactor System:

Average cost of one reactor tube = \$33,400

Average cost of one screw press = \$55,000

Approximate installation cost = \$20,000

Savings in equipment cost (installed) = \$108,400 (CE=109)

Other Equipment:

By eliminating the 4th reactor, the amount of material that must be handled by the other equipment (flash tanks, condensers, neutralizer, centrifuge, and storage tanks) is less. The flow to the 1st flash tank is decreased by about 14 percent. The equipment could be re-sized for the smaller flow. However, since this will have only a minor effect on the total cost, it is assumed here that the size and cost of all other equipment remains unchanged.

The other equipment that may be eliminated from the process is:

1) Pump number 4 at a cost of \$1,600
2) Reactor tube number 4 motor at \$1,300
3) Screw Press number 4 motor at \$3,400

Utilities:

Electric power usage decreases from 17,600 kw-hr per day for the four-stage process to 15,630 kw-hr per day for the three-stage process by eliminating the above three pieces of electrical equipment.

Based on 125 percent of the process demand the steam usage decreases from 6.78 tons per hour to 5.95 tons per hour. The daily steam usage is 285,000 pounds.

Water usage should remain the same if the final concentration and losses in centrifugation are to remain the same.

The revised utility costs are:

Electricity - (15,630 kw-hr)(\$0.007/kw-hr) = \$109.50

Steam - (285,500#)(\$0.52/1000#) = \$148.30

Raw Materials:

Waste paper requirements remain the same. Sulfuric acid requirements decrease by 0.0261 tons per hour to a daily usage of 4.02 tons. The revised sulfuric acid cost is (4.02)($26.00) = $104.60.

The limestone must now provide for the neutralization of 0.1444 - 0.0208 = 0.1236 tons/hr of sulfuric acid. Making the same assumptions as in the previous calculation the required limestone usage is 0.1575 tons per hour or 3.78 tons per day. The revised limestone cost is (3.78)($12.40) = $46.90.

Sugar Production:

Assuming sugar losses at the centrifuge are the same, the rate of sugar production with a three-stage reactor system is 1.539 ton/hr - 0.0906 ton/hr = production is 62,500 pounds.

Installed Equipment Cost:

Total saved on installed equipment (CE = 109) = $115,300 total installed equipment cost for three reactor system (CE=109) = 697,000 - 115,300 = $581,700.

Comparison of Three-Stage and Four-Stage Reactor Systems:

Three-Stage System:

Basis for profit estimation - 25 percent of total capital investment per year[58, p 75 & 76] before taxes.

Total capital investment = $1,687,000

Yearly profit (before taxes) = (0.25)($1,687,000) = $422,000

Profit per pound of product (before taxes) $= \frac{\$422,000}{(365)(62,500)} = 1.85$ cents/pound sugar

Fictitious selling price $= \frac{5.55¢}{\#Sugar} + \frac{1.85¢}{\#Sugar} = \frac{7.40¢}{\#Sugar}$

Four-Stage System:

Total capital investment = #2,002,000

Total yearly income at 7.40 cents pound sugar = ($0.074)(66,500)(365) = $1,798,000

Total yearly expenses = (3,786)(365) = $1,382,000

Total yearly profit = $1,798,000 - $1,382,000 = $416,000 "six-tenths factor":

$$\left[\frac{\text{(Capacity of Unit B)}}{\text{(Capacity of Unit A)}}\right]^{0.6} = \frac{\text{(Cost of Unit B)}}{\text{(Cost of Unit A)}} \qquad \text{(Ref. 57)}$$

In general, most of the log-log plots of costs vs. capacity have a slope of 0.6. Pump costs were not adjusted since the installed cost for electric motors varies very little with motor size[66] and the motor cost is usually a sizeable percentage of the total installed pump cost. The conveyors were not adjusted either due to the lack of cost data on the small size of conveyors required.

To maintain a product comparable with the four-stage system and to eliminate greater sugar losses during centrifugation (due to centrifugation of a more concentrated solution) the hydrolyzate should be diluted before centrifugation. Therefore the centrifuge will be required to handle about the same flow rate and its cost should not change significantly.

The following table may be prepared by revising previous calculations.

Item	Capacity for 4-Stage React	Capacity for 2-Stage React	Slope (Ref 10)	Cost 4-Stage CE = 109	Cost 2-Stage CE = 109
H_2SO_4 Storage Tank	20,500 Gal.	14,500 Gal.	0.55	26,200	21,700
Limestone Storage Tank	24,500 Gal.	17,600 Gal.	0.51	9,200	8,200
Neutralizer	10,800	7,500 Gal.	0.51	15,000	12,500
2 Condensers	100 Ft^2 Each	70 Ft^2 Each	0.60	9,900	8,000
2 Flash Tanks	300 Gal. Each	200 Gal. Each	0.53	17,900	14,500
Total Cost				78,700	64,900

Savings by capacity reduction (Installed, CE109) = 13,800

Other equipment that may be eliminated for the process is:

1)	Pump #4	$1,600	(CE = 100)
2)	Pump #3	$1,700	
3)	Reactor tube #4 motor	$1,300	
4)	Reactor tube #3 motor	$1,300	
5)	Screw press #4 motor	$3,400	
6)	Screw press #3 motor	$3,500	
		$12,800	(CE = 100)

Comparing Profits:

Three-Stage = \$422,000

Four-Stage = \$416,000

Therefore the additional investment for the four-stage system should not be made since there would be a negative return for the additional investment.

The next logical step is to compare a three-stage reactor to a two-stage reactor to determine if the additional investment for the third stage is worthwhile. The assumptions and calculations for the various costs of the two-stage process are given in the text following Table XXII. The installed equipment cost is found to be \$451,000 compared to \$582,000 for the three-stage process. The estimated total capital investment for the two-stage process is \$1,232,000 compared to \$1,583,000 for the three-stage process. Table XXIII lists the various manufacturing costs for the two-stage reactor sustem. The daily cost is \$3,096, but the sugar production has dropped from 62,500 pounds per day to 52,900 pounds per day so that the manufacturing cost per pound of sugar increases from 5.55 cents per pound for the three-stage plant to 5.85 cents per pound. An economic comparison of the three-stage plant to the two stage plant is noted below. It is seen that the increase in profit divided by the increase in investment is 36.2 percent. This is above the assumed minimum acceptable return of 25 percent and therefore places the optimum number of reactor stages at three.

Reactor System:

Average cost of two reactor tubes = 68,600

Average cost of two screw presses = 110,000

Approximate installation cost = 40,000

Savings in reactor system (installed) = 218,600 (CE = 109)

Other Equipment:

By using only the two reactors the flow to the flash tanks is decreased by 32.5 percent. Therefore some adjustment should be made for smaller equipment in the rest of the plant. This can be done by the so-called

TABLE XXII: ESTIMATE OF TOTAL CAPITAL INVESTMENT FOR CONTINUOUS PROCESS USING A TWO - STAGE REACTOR SYSTEM

	ITEM & BASIS OF ESTIMATION	COST (CE= 109)
1.	Purchased Equipment - Delivered (P.E.C.)	315,500
2.	Equipment Installation (Including Instrumentation and Insulation) - 43% P.E.C.	135,500
	Installed Equipment Cost	451,000
3.	Piping (Including Insulation) - 36% P.E.C.	113,700
4.	Electrical Installations - 15% P.E.C.	47,300
5.	Buildings Including Services - 35% P.E.C.	110,500
6.	Yard Improvements - 10% P.E.C.	31,500
7.	Service Facilities - 35% P.E.C.	110,500
8.	Land - 6.18% P.E.C.	19,500
	Total Physical Plant Cost	884,000
9.	Engineering and Construction - 40% P.E.C.	126,100
	Direct Plant Cost (D.P.C.)	1,010,100
10.	Contractors Fee - 7% D.P.C.	70,700
11.	Contingency - 15% D.P.C.	151,500
	Fixed Capital Investment	1,232,300
12.	Working Capital (Total Operating Cost for 30 Days)	92,700
	Total Capital Investment	1,325,000

TABLE XXIII: ESTIMATED MANUFACTURING COST FOR CONTINUOUS PROCESS USING A TWO - STAGE REACTOR SYSTEM

ITEM	UNITS/DAY	COST	DAILY COST
A. Direct Production Cost			
1. Raw Materials			
H_2SO_4 (60° Baume - 77.7%)	3.26 Tons	$26.00/Ton	84.70
Limestone (Crushed - 100 Mesh)	2.97 Tons	12.40/Ton	36.80
Wastepaper (Mixed)	80 Tons	13.00/Ton	1040.00
2. Utilities			
Electricity	13,510 kw-hr	0.007/kw-hr	94.60
Steam (125% of Process Demand)	236,000#	0.52/1000#	122.80
Process Water	172,000 Gal	0.25/1000 Gal	43.00
3. Operating Labor - 3 Men/Shift	72 Man-Hr.	3.00/Man-Hr	216.00
4. Supervisor - 1 Man - Day Shift	8 Man-Hrs.	3.50/Man-Hr	28.00
5. Fringe Benefits - 15% Hourly Wage			36.60
6. Operating Supplies - 10% of Labor			21.60
7. Maintenance and Repairs - 10% F.C.I.			
Labor (Per Year) = 5% F.C.I.			169.00
Overhead & Supplies (Per Year) = 5% F.C.I.			169.00
Direct Production Cost			2062.10
B. Fixed Charges			
1. Depreciation - 12 Year Plant Life - Zero Salvage Value = 8 1/3% F.C.I. Per Year			281.50
2. Local Taxes - 2% FCI Per Year			67.50
3. Insurance - 1% F.C.I. Per Year			33.80
Fixed Charges			382.80
C. Plant Overhead - 70% of Operating Labor, Supervision and Maintenance Labor			289.00
D. General Expenses			
1. Administrative Costs - 15% of Operating Labor, Supervision and Maintenance Labor			62.00
2. Distribution and Selling Cost - (Not Applicable)			-
3. Research and Development Cost - 5% Total Product Cost			155.00
4. Financing Interest - 4% of Total Capital Investment Per Year			145.00
General Expenses			360.00
Total Production Cost			3,096.00

With on-stream factor = 0.9 the daily sugar production is 52,900#

Total Product Cost = $\frac{\$3,096.00}{52,900\#}$ = 5.85¢/#Sugar

Savings from eliminated equipment (Installed CE 109) = $13,900

Utilities:

Electric power usage decreases from 17,600 kw-hr in the four-stage plant to 13,510 kw-hr in the two-stage plant.

Steam usage decreases from 6.78 tons per hour for the four-stage plant to 4.91 tons per hour in the two-stage plant using 125 percent of process demand. Daily steam usage is 236,000 pounds steam.

As mentioned before, water requirements will remain approximately the same due to dilution prior to centrifugation.

The required utility costs are:

Electricity - (13.510 kw-hr) ($0.007/kw-hr) = $94.60

Steam - (236,000 # steam) ($0.52/1000 # st) = $122.80

Raw Materials:

Waste paper usage remains the same. Sulfuric acid requirements decrease from 4.65 tons per day to 3.26 tons per day for a revised cost of 3.26 x $26.00 = $84.70.

The limestone must neutralize only 0.097 ton/hr of sulfuric acid compared to 0.1444 ton/hr with the four-stage plant. Using the same assumptions as previously the required limestone is 0.1238 tons/hr or a daily usage of 2.97 tons. The revised limestone cost is 2.97 x $12.40 = $36.80.

Sugar Production:

Assuming sugar losses at the centrifuge are the same as for the four-stage plant the sugar production rate is 1.539 - 0.317 = 1.222 tons/hr. Assuming an on-stream factor of 0.9 the daily production rate is 52,900 pounds.

Installed Equipment Cost:

Amount saved on reactor system	= 218,600	
Amount saved on capacity reduction	= 13,800	
Amount saved by equipment elimination	= 13,900	
Total saved on two-stage system	= $246,300	(CE = 109)

Installed equipment cost for two-stage plant = $697,000 - $246,000 = $451,000.

Comparison of Two-Stage and Three-Stage Reactor System:

Two-Stage System:

Assume a minimum acceptable return of 25 percent per year before taxes[58 p 75 & 76]

Total capital investment = \$1,325,000

Yearly profit (before taxes) = (0.25) (\$1,325,000 = \$332,000

Profit per pound of product (before taxes) = $\frac{\$332,000}{(365)(52,900)}$ = 1.72¢/# sugar

Total fictitious selling price = $\frac{5.85¢}{\#\ sugar} + \frac{1.72¢}{\#\ sugar} = \frac{7.57¢}{\#\ sugar}$

Three-Stage System:

Total capital investment = \$1,687,000

Gross yearly income at 7.57¢/# = (\$0.0757) (62,500#) (365) = \$1,729,000

Total yearly expenses = (\$3,466) (365) = \$1,266,000

Total yearly profit = \$1,729,000 - \$1,266,000 = \$463,000

Gain in profit = ΔP = 463,000 - 332,000 = \$131,000

Increase in nvestment = ΔI = 1,687,000 - 1,325,000 = \$362,000

$$\frac{\Delta P}{\Delta I} = \frac{\$131,000}{\$362,000} = 0.362$$

The annual return on the investment is 36.2 percent which is greater than 25 percent minimum acceptable return. Therefore, the three-stage reactor system is the most desirable design from an economic standpoint.

Variation of Costs with Capacity:

Having decided on three reactors for optimum operation of the plant, the next logical question is: how does the plant size affect product cost. The largest reactor system produced by The Black Clawson Company could handle 1,570 tons per day of raw waste material compared to the 80 tons per day for which this plant is designed. This leaves considerable room for expansion.

Black Clawson[75] state that the capacity cost exponent for the entire reactor system is 0.6.

Chilton[71] indicates that, in general, entire plant costs as well as equipment costs vary according to the "six-tenths factor". Hackney[77] lists capacity-cost exponents for various processes. Two of the processes are somewhat similar to the one under consideration here. They are:

Soybean extraction: exponent = 0.70

Solvent extraction or treating: exponent = 0.67

Therefore, although some of the other process equipment (other than the reactor system) may also be limited to a lower expansion ratio, the maximum cost exponent of 0.70 was chosen for calculating costs of the larger plants. This will give a more conservative cost picture than the six-tenths factor.

In Table XXIV, fixed capital investment is given for five different capacities. Fixed capital investments at larger capacities were obtained by applying the seven-tenths factor to the 80 ton per day plant and the breakdown of these larger plants is exactly the same as given in Table XX for the 80 ton per day plant.

TABLE XXIV: Fixed Capital Investment vs Plant Size

CAPACITY (TONS FEED PER DAY)	FIXED CAPITAL INVESTMENT (CHEM ENG INDEX = 109)
80	\$ 1,583,000
150	\$ 2,460,000
300	\$ 3,990,000
500	\$ 5,720,000
1000	\$ 9,260,000

In calculating the manufacturing cost per pound of sugar the following points should be kept in mind:

1) If the feed to the plant is doubled the usage of all raw materials is doubled and the production of sugar is also doubled.
2) If the plant capacity is doubled, water and steam usage will double, but, due to the fact that larger pumps and larger motors have higher efficiencies, the electric usage will not quite double. The assumption that electric usage is proportional to capacity should, however, be quite adequate for this analysis. Errors will give conservative results.
3) Operating labor should remain constant as the capacity is increased based on information obtained from The Black Clawson Company.[75]

The itemized operating cost for the three-stage reactor, 80 ton per day plant is given in Table XXI. Table XXV shows the itemized operating costs at various capacities.

Comparison of Batch and Continuous Processes:

As is usually the case batch operation is more economical for small plants than large plants. For the 80 ton per day capacity the manufacturing cost when operating batch-wise is 5.1 cents per pound of sugar compared to 5.55 cents per pound using a three-stage continuous process. The main disadvantage in the batch plant is that there is very little advantage to expansion. As mentioned previously, the 2000 cubic foot digester cannot be scaled up without making unrealistic demands on the system. Thus to go to 160 tons per day, one must build essentially two 80 ton per day plants. Of course certain conservations can be made such as both 80 ton plants using the same storage tanks and possibly the same centrifuge, but the capacity-cost exponent should still be close to 1.0. Assuming that it is 1.0, the economic cross-over from batch to continuous operation takes place at a plant capacity of 125 tons per day when based on manufacturing costs.

Variation of Costs with Raw Material Source:

The cost of the raw waste material utilized as feed to the hydrolysis plant is a significant portion of the total product cost. This factor increases in significance with increasing plant size. The fraction of the product cost attributable to raw material for wastepaper is available from Table XXV and is summarized in Table XXVI.

TABLE XXV: DAILY MANUFACTURING COST FOR CONTINUOUS PLANTS OF VARIOUS CAPACITIES USING THREE-STAGE REACTOR

Item	80 Ton/Day Plant	150 Ton/Day Plant	300 Ton/Day Plant	500 Ton/Day Plant	1000 Ton/Day Plant
A-1 Raw Materials					
H_2SO_4	104.60	196.00	392.00	654.00	1,308.00
Limestone	46.90	88.00	176.00	293.00	586.00
Wastepaper	1,040.00	1,950.00	3,900.00	6,500.00	13,000.00
A-2 Utilities					
Electricity	190.50	357.00	715.00	1,190.00	2,380.00
Steam	148.30	278.00	556.00	927.00	1,854.00
Process Water	43.00	80.60	161.20	269.00	538.00
A-3 Operating Labor	216.00	216.00	216.00	216.00	216.00
A-4 Supervisor	28.00	28.00	28.00	28.00	28.00
A-5 Fringe Benefits	36.60	36.60	36.60	36.60	36.60
A-6 Operating Supplies	21.60	21.60	21.60	21.60	21.60
A-7 Maintenance					
Labor	217.00	337.00	546.00	784.00	1,270.00
Overhead&Supplies	217.00	337.00	546.00	784.00	1,270.00
B-1 Depreciation	357.00	561.00	910.00	1,305.00	2,110.00
B-2 Local Taxes	86.70	134.80	219.00	314.00	507.00
B-3 Insurance	43.50	67.50	109.30	157.00	254.00
C Plant Overhead	323.00	407.00	553.00	720.00	1,060.00
D-1 Administrative Cost	69.10	87.10	118.50	154.00	227.00
D-2 Distribution & Selling Cost	-	-	-	-	-
D-3 Research & Development	173.00	288.00	509.00	792.00	1,462.00
D-4 Financing Interest	185.00	288.00	470.00	679.00	1,111.00
Daily Production Cost	3,466.00	5,759.00	10,183.00	15,824.00	29,239.00
Production Cost Per Pound	5.55¢ / # Sugar	4.91¢ / # Sugar	4.34¢ / # Sugar	4.05¢ / # Sugar	3.65¢ / # Sugar

TABLE XXVI: RAW MATERIAL FRACTION OF PRODUCT COST

Plant Size (Tons/Day)	Product Cost (Cents/Pound)	Waste Feed Fraction (Percent)
80	5.55	30.0
150	4.91	33.8
300	4.34	38.3
500	4.05	41.0
1000	3.65	44.5

The cost ranges for three classes of raw waste materials established in this report are as follows:

Commodity	Price Range
No. 1 mixed paper	\$4 to 12/Ton
Bagasse	\$5 to 15/Ton
Organic urban refuse	\$2.50 to 4.50/Ton Credit

Assuming that the production of sugar per ton of raw feed is about equal for the three materials and that the materials will be utilized within fixed metropolitan areas or within a maximum of fifty miles of the sugar central in the case of bagasse, the above cost figures can be substituted directly in the manufacturing cost summary. The productivity assumption seems reasonable based on present knowledge of commodity compositions as summarized in Tables II and IX.

The direct application of the credit figures for Organic Urban Refuse may not be realistic in some cases. Since these numbers represent costs for disposing of mixed refuse (municipal dumping fees) that will in some cases include non-organic material that can not be used in this process, such as cans and bottles a preparation charge must be established. In cases where refractory components can be removed at a profit or zero cost due to the existence of a salvage market, a charge for preparation of the waste will not apply. Inclusion of a preparation step will result in a fourth alternative in the waste commodity list and will be a function of the local municipal waste collection system.

One method of preparation of mixed urban refuse is the inclusion of a hydropulping operation as a prehydrolysis step. This approach is detailed in the discussion following Table XXVII. The costs of the hydropulping operation vary with plant size and therefore cannot be expressed as a single raw material cost function. Hydropulping costs vary from $394 per day for the 80 ton day continuous plant to $1581 per day for the 1000 ton per day plant. This results in an actual charge to the hydrolysis operation of $2.42 per ton for the Mixed Urban Refuse at the lower dumping fee of $2.50 per ton and on 80 ton per day plant, and a credit to the hydrolysis step of $2.92 per ton for the $4.50 per ton dumping fee at the 1000 ton per day plant. Dumping fee credits balance the additional preparation costs for hydropulping at about the 300 ton per day plant size the $2.50 per ton fee and the 80 ton per day plant for the $4.50 per ton fee.

The variation in product cost in cents per pound of sugar with plant size and raw material are shown graphically in Figure 16. The shaded area represents the cost range expected in each instance. The cost ranges by waste commodity is summarized below:

Commodity	Cost Range Cents/Pound Sugar
No. 1 Mixed Paper	2.59 - 5.42
Bagasse	2.73 - 5.81
Organic Urban Refuse	1.51 - 3.56
Mixed Urban Refuse	1.71 - 4.19

The highest costs are always represented by the smallest plant size and the high end of the commodity price range. The converse is true for the low costs.

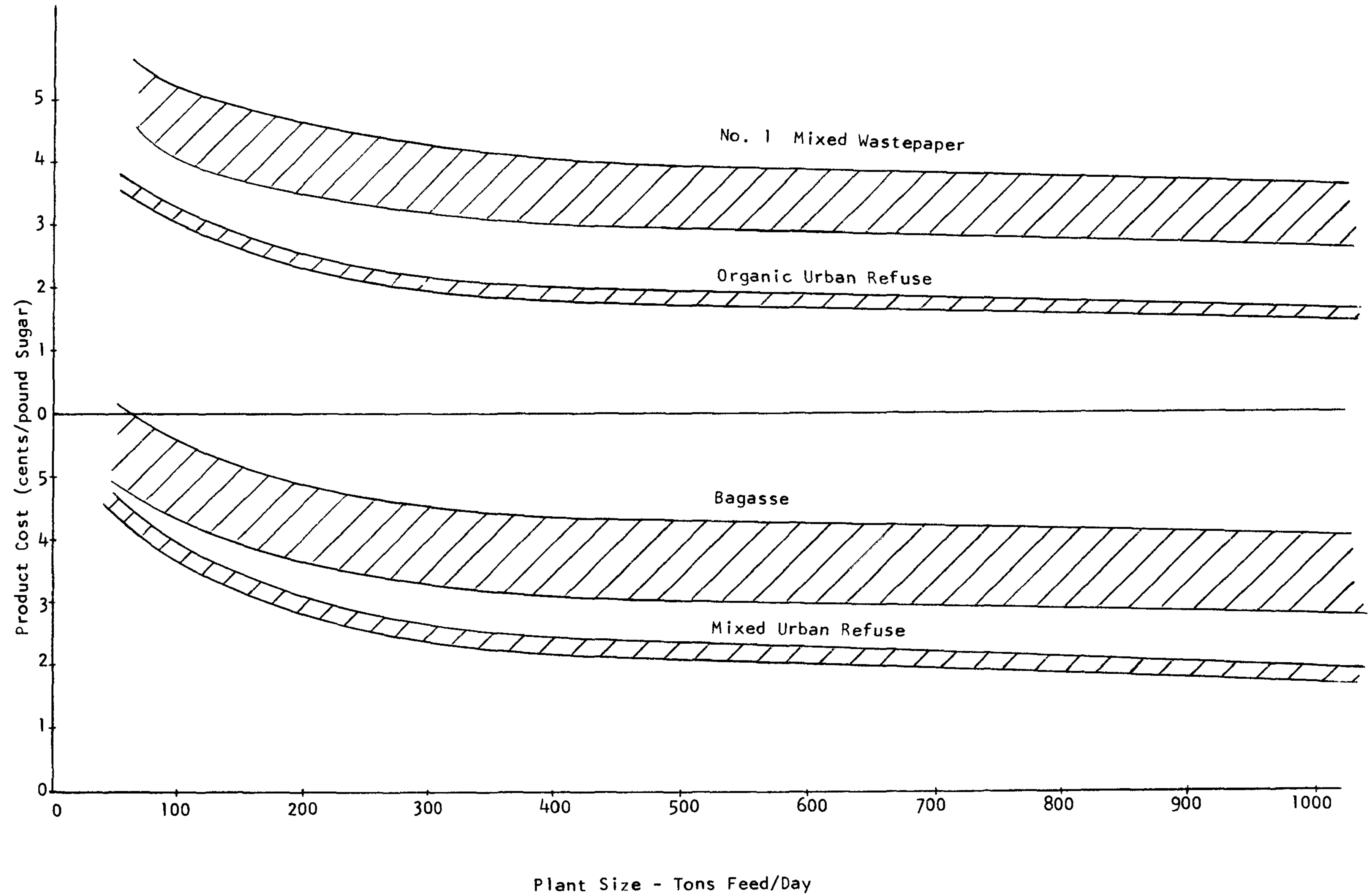

Figure 16: Cost Range Per Pound of Sugar Produced vs Plant Size

TABLE XXVII: PRODUCTION COST IN CENTS PER POUND OF SUGAR FOR VARIOUS RAW WASTE COMMODITIES AND VARIOUS PLANT CAPACITIES (BASIS: THREE STAGE CONTINUOUS PLANT)

RAW MATERIALS		PLANT CAPACITIES				
Type	Price $/Ton	80 Ton/Day Plant	150 Ton/Day Plant	300 Ton/Day Plant	500 Ton/Day Plant	1000 Ton/Day Plant
No. 1 Mixed Wastepaper	4.00	4.39	3.76	3.20	2.91	2.59
	12.00	5.42	4.80	4.22	3.93	3.62
Bagasse	5.00	4.53	3.90	3.33	3.03	2.73
	15.00	5.81	5.18	4.60	4.32	4.01
Organic Urban Refuse	2.50 Cr.	3.56	2.93	2.36	2.07	1.76
	4.50 Cr.	3.30	2.68	2.11	1.81	1.51
Mixed Urban Refuse *	2.50 Cr.	4.19	3.39	2.69	2.34	1.96
	4.50 Cr.	3.94	3.13	2.44	2.08	1.71

* Includes hydropulper operation

Cost of Adding Hydropulping Preparation Step:

Capital equipment costs for an 80 ton per day plant were estimated by The Black Clawson Company, Middletown, Ohio,[75] as $75,000 to $100,000. Since this operation can be performed in mild steel the lower range of $75,000 plus $5,000 for necessary auxilliaries is chosen and the following analysis made:

	ITEM & BASIS OF ESTIMATE	COST (C.E.=109)
1.	Purchased Equipment - Delivered (P.E.C.)	80,000
2.	Equipment Installation (Including Instrumentation and Insulation) = 43% P.E.C.	34,400
	Installed Equipment Cost	114,400
3.	Piping (Including Insulation) 36% P.E.C.	28,800
4.	Electrical Installations 15% P.E.C.	12,000
5.	Buildings Including Services - 35% P.E.C.	28,000
6.	Yard Improvements - 10% P.E.C.	8,000
7.	Service Facilities - 35% P.E.C.	28,000

ITEM & BASIS OF ESTIMATE (Continued)	COST (C.E.=109)
8. Land - 6% P.E.C.	4,800
Total Physical Plant Cost	224,000
9. Engineering and Construction 40% P.E.C.	32,000
Direct Plant Cost (D.P.C.)	256,000
10. Contractors Fee 7% D.P.C.	17,900
11. Contingency 10% D.P.C.	25,600
Fixed Capital Investment (F.C.I.)	229,500

A. Fixed Charges Due to Addition of Hydropulper:

	Daily Cost
1. Depreciation - 12 year plant life - zero salvage Value = 8-1/3% F.C.I. per year	68.50
2. Local Taxes - 2% F.C.I. per year	16.40
3. Insurance - 1% F.C.I. per year	8.20
Fixed Charges	$93.10

Note: A scale-up factor of 0.7 was used in calculating the larger plants.

B. Additional Direct Production Costs:

1. Operating labor 1 man/shift 24 man hrs. @ $3.00	72.00
2. Fringe Benefits - 15% of operating labor	10.80
3. Operating Supplies - 10% of labor	7.20
4. Maintenance & Repairs - 10% F.C.I. per year	82.00
Direct Production Cost	$172.00

C. Overhead and G & A

1. Additional overhead - 70% direct & maintenance labor = 0.70 x 113	79.00
2. Administrative costs - 15% direct & maintenance labor = 0.15 x 113	16.90
3. Financing interest = 4% F.C.I. per year	32.80
	$128.70
Total Daily Production Cost due to Hydropulper addition. A + B + C =	$393.80

The Daily Production Cost due to Hydropulper Addition for Other Plant Sizes is as Follows:

Plant Size	Daily Cost
80	\$394
150	\$531
300	\$768
500	\$1038
1000	\$1581

Typical Calculation for Sugar Production Costs using Mixed Urban Refuse:

Daily production cost 80 ton/day plant (from Table XXV) =	3,466.00
Additional Cost due to hydropulper	394.00
Total Cost	3,860.00
Subtract wastepaper raw material cost (Table XXV)	1,040.00
	2,820.00
Apply mixed refuse dumping fee credit (\$4.50/ton)	360.00
Daily Production Cost	2,460.00

Daily Production = 62,500 pounds sugar.

Production Cost per pound sugar = \$2,460.00/62,500 = 3.94¢/# sugar.

E. COMMENTS AND CONCLUSIONS:

The design of a chemical processing plant based on data not specific to the proposed process is always a questionable approach. Sincere attempts were made in all judgements to justify the necessary assumptions required for plant design and as a result a detailed design effort was made for the hydrolysis plant.

The desireability of the batch reactor plant is questioned due to problems in process control such as porous bed channeling and the attendant variations in raw material utilization, product decomposition and pressure-temperature compensations needed. The Springfield, Oregon plant using digesters of the size proposed in this report was never able to operate at full capacity due to trouble in the digester.

The continuous process approach is logical from both technical and economic considerations. Reductions in product decomposition and better overall process controls due to stage-wise segregation should result in an operation that is capable of close control. Then too, the large plants that have economic potential will require the use of the continuous process.

The economic considerations for this plant have been consistently biased to the conservative side in order to compensate for unknown problems that may exist by converting the process kinetics from wood waste to other cellulosic raw materials. This approach may be excessive in this case since there is some consensus that the waste materials considered as feedstock for this plant will be easier or at least as easy to hydrolyze as wood waste. However, without this specific knowledge the conservative approach to design economics was felt to be justified.

The final verification of the process assumptions must, of course, be made in the laboratory.

THE FERMENTATION PROCESS

A. Introduction

UNDERKOFFLER AND HICKEY[53] introduce the fermentation industries as "the branch of chemical manufacture which yields useful products through the vital activities of microorganisms. Fermentation, in the broad sense in which the term is now generally used, may be defined as a metabolic process in which chemical changes are brought about in an organic substrate through the activities of enzymes secreted by microorganisms."

Two general processes of fermentation are practiced today: 1) The anaerobic process in which atmospheric oxygen is not involved and is represented by the alcohol producers including the wine and beer manufacturers, and 2) the aerobic process in which large quantities of atmospheric oxygen are consumed for the purpose of production of cell materials for example in the production of yeasts. The latter category is of primary interest in this study.

Yeast propogation can take place on many diverse sugar containing substrates. In the case of the hydrolysis sugars, both hexose and pentose types are present in quantity. Therefore, it is desirable to select a microorganism that can utilize both species. One such microorganism is the yeast Candida utilis commonly called Torula. This species was developed for use in plant scale equipment in Germany and has been used extensively as a food and animal feed yeast. Torula exhibits rapid growth rates and has other properties of acid tolerance and the assimilation of inorganic nitrogen that make it useful for consideration in the fermentation of hydrolyzate sugars.

Process equipment design, yeast culture maintenance, contamination problems and product handling systems are all serious considerations of a yeast plant. When continuous cultures are to be maintained, special effort in equipment design and "housekeeping" measures are required. Although some of the latter can be controlled by chemical and thermal conditions conducive to the microorganism of interest, the specificity of process parameters is not an exact science and the threat of contamination and loss exists. Pilot studies of organisms and operating conditions are always recommended.

B. PROCESS CONSIDERATIONS:

The fermentation process in this instance consists of the propogation and recovery of a microorganism. Briefly, this is carried out by growing a yeast on the sugar solution resulting from the hydrolysis steps. In addition to sugars, other nutrients required include a nitrogen source, oxygen, small amounts of phosphate, and other minerals in even smaller amounts. Growth is carried out at temperatures in the range of 20 to 35°C in reactors provided with a means of agitation. This may be a stirrer of various types, or may simply be the introduction of large amounts of air into the fermentor through perforated pipes at the bottom of the vessel.

When the yeast cell concentration is adequate, the broth and suspended cells may be harvested by passage through a centrifuge which since the cells have a density slightly greater than that of the broth and a size of approximately five microns, readily removes them. If the fermentor is operated continuously, a constant feed of fresh medium is pumped into the vessel, while a stream of broth and cells goes to the centrifuge. After centrifugation, the cells may be washed and dried, or may be dried directly.

Nature of the Organism:

The organism which is best suited to the overall process is the yeast Candida utilis. This organism, known also as Torula utilis, has been widely used for production of food and fodder yeast from sulfite liquor and wood hydrolyzates because it has the ability to assimilate a wide variety of carbon sources, particularly the pentoses which comprise an important fraction of the available sugar. Common baker's yeast, which is also a good food and fodder yeast, is unable to assimilate pentoses, and would therefore be unsuitable for the proposed process.

The protein content of the yeast is approximately 50 per cent based on dry weight. In addition yeast is a significant source of B complex vitamins.

While it would be possible to use bacteria as a source of single-cell protein, in this particular application Candida utilis yeast is to be preferred because of its known value as a source of protein for animal feeding, its frequent usage as a vitamin source in human foods, and the fact that since it is larger than bacterial cells the costs of centrifugation will be lower than if bacteria were being used. It is well-suited to the substrate available, and hence no advantage is to be expected from using bacteria in this particular application.

Nutrients Required:

The basic feedstock (product of the continuous hydrolysis process) consists of 24.92 tons of solution per hour containing 1.340 tons of glucose and 0.199 tons of xylose, and hence has a sugar concentration of 6.17 per cent. In order to calculate the other nutrients required, the information needed is:

a. composition of cells

b. yield based on sugars

c. yield based on oxygen

Typical yeast cells analyze as follows[78]: Carbon, 44.6 per cent; nitrogen, 8.5 per cent; phosphorous, 1.1 per cent; potassium, 2.2 per cent; and sulfur, 0.6 per cent. A yield of dry cell mass of 50 per cent based on sugar consumed will be used; this will vary from 45 to 55 per cent depending on operating conditions which must be determined experimentally.[79] An oxygen requirement of 1.05 pounds of oxygen per pound of dry cell mass is a typical oxygen requirement[78] for a well operated process and will be used for purposes of calculation.

Hence, the rate of dry yeast production per hour must be (1.539)(0.5) = 0.77 tons of 1540 pounds dry yeast per hour. This will require the consumption of the following chemicals in pounds per hour:

Ammonia (.085)(1540)(17/14)	= 159
Phosphoric Acid (.011)(1540)(98/31)	= 52.5
Potassium Chloride (.022)(1540)(74.5/39)	= 64.6
Oxygen (1.05)(1540)	= 1615

The requirement for sulfur will be met either from the addition of potassium sulfate, if that proves the cheapest form of potassium, or by the dissolved calcium sulfate present in the feedstock. The potassium may also be added as the hydroxide if it is necessary to raise the pH of the feedstock to the region of pH 3 to 5 required for growth of this organism. Addition of small amounts of magnesium and iron may be needed if there is insufficient present in the limestone or water, but these represent insignificant costs, and will be neglected here.

Productivity:

The productivity of the fermentor system will be limited by the rate of oxygen transfer from the air to the fermentation broth. Industrial experience with yeast production indicates that a rate of 120 millimoles of oxygen absorbed per liter-hour is an economic rate, in terms of power consumption.[79] This rate of oxygen transfer corresponds to 3.84 grams of oxygen per liter-hour or (3.84)(100/105)=3.66 grams of yeast per liter-hour.

The productivity is equal to the product of the cell concentration times the dilution rate, where dilution rate is defined as the ratio of media feed rate to fermentor volume. Thus, (dilution rate)(cell concentration) = 3.66 grams per liter-hour. The maximum cell concentration would be attained with undiluted feedstock, and would be 30.85 grams per liter. For this concentration of cells, the dilution rate would be (3.66/30.85) = 0.118 hr^{-1}.

If it were desired to operate with a somewhat more dilute solution, as is sometimes the case, the feedstock could be diluted to yield a concentration of sugars of 4 per cent and a yeast concentration of 20 grams per liter. At this concentration, the maximum dilution rate for the accepted productivity would be (3.66/20) = 0.183 hr^{-1}. The effect of this dilution will be considered later under centrifuge calculations, where it will be seen that the major effect will be to require somewhat greater centrifuge capacity.

The fermentation volume required during steady-state continuous operation is (1540)(454)/(3.66) = 190,000 liters of actual liquid volume. To provide for an expansion of volume because of gassing with air and to provide some freeboard for foaming, this will be increased by 200 per cent, so that the nominal fermentation capacity must be 570,000 liters.

Fermentor:

The fermentor will be essentially a cylinder whose ratio of height to diameter is 3 to 1. This is not a very important variable, and satisfactory fermentors can be had with height to diameter ratios varying from 1 to 1 to 4 to 1. The bottom will be standard dished, and the approximate dimensions to hold 570,000 liters will be 20.6 feet in diameter and 62 feet in height. The material of construction will be carbon steel. The possibility of using wood is considered as an economic alternate in Case 2 presented in Tables XXXII through XXXV.

While the use of wood fermentors is not "modern", it is believed to be a reasonable approach because the fermentation can be carried out at low pH making asepsis unnecessary. Furthermore, at a low pH no pathogens can develop, so that there will be no hazard because of the inability to sterilize. The wood can be painted with epoxy paint making sanitizing convenient. It would be desirable to evaluate on a small scale first, the use of epoxy-painted redwood or cypress fermentors to see what maintenance problems develop. If it should be possible to use them, and this is a good probability, the savings in capital costs are substantial.

Air Requirements:

While the stoichiometric amount of oxygen required was calculated to be 1615 pounds per hour, usual experience in yeast production[79,80] indicates that the efficiency of oxygen absorbtion is typically only 15 per cent. Thus, the amount of air required is (1615)(.15)(.21) = 51,200 pounds per hour, or at 68^{o}F and 1 atm 690,000 cubic feet of air per hour.

This quantity of air must be supplied at a higher pressure to provide for the hydrostatic head in the fermentor, pressure drop through the lines, and pressure drop through the perforations. The hydrostatic head contributes 10.3 psig and the other pressure drops are estimated to be approximately 10 psig. Therefore, the air supply should be at a pressure of 20 psig.

In this application, the agitation will be entirely in the form of air dispersed from tubes at the bottom of the fermentor. Frequently, Waldhof-type fermentors are used in which a considerable fraction of the power is supplied by an agitator. However, the capital costs are considerably higher and the electric power costs are only slightly lower. Mixer type fermentors are often used in Europe, while in this country many fermentors of the air-agitated type are used. The total operating costs are not greatly different, and it is suggested that an air-agitated type be used in this application.

Heat Production and Cooling:

As a result of fermentation, the heat production is estimated to be 15.6 x 10^6 BTU per ton of yeast produced.[78] For this process, therefore, $(15.6 \times 10^6)(1540/2000) = 12 \times 10^6$ BTU per hour must be removed from the fermentor. In order to do this, fermentation broth at 90°F will be pumped to an external refrigeration system, and will be returned to the fermentor at 85°F. This slight drop in temperature will not affect the growth of the organisms.

The external refrigeration system in turn will be cooled by water from a cooling tower.

As the accompanying comparisons for Case 1 and Case 2 show, if the fermentation plant can be located in a part of the country in which cool surface water(below 65 to 70°F) is available, a very large savings is possible because mechanical refrigeration and a cooling tower is not required. Such locations, using for instance sea water, might be: Boston, Seattle, San Francisco, or New York; cool fresh water might be available on a year round basis at Chicago, Detroit or Minneapolis.

Cell Recovery:

The yeast concentration in the effluent from the fermentor will be either 20 or 30.85 grams of dry solid per liter of solution. In order to obtain a dried product, initial concentration of the effluent stream is necessary. There are several methods which, in theory, are applicable in concentrating solid suspensions. These are gravitational settling, filtration and centrifugation. A brief summary is presented below to show the rationale in the selection of the method of concentration.

Yeast cells such as Candida utilis are approximately 3.5 by 7 microns[81] and other species such as Saccharomyces cerevisiae have mean diameters of approximately 5.5 microns.[82] The density of yeast (S. cerevisiae) in aqueous solution is approximately 1.08 gram per cubic centimeter.[82] Suspensions of yeast will settle according to the modified Stoke's law for hindered settling:

$$U_h = \left[\frac{1}{1 + \alpha c^{1/3}}\right]\left[\frac{g_c d_p^{\,2}(\rho_p - \rho_L)}{18\mu}\right] \quad (1)$$

where:

U_h = hindered settling velocity

α = constant

c = volume fraction of solids

g_c = gravitational constant

d_p = diameter of particle

ρ_p = density of particle

ρ_L = density of liquid

μ = viscosity of liquid

It is therefore possible to use gravitational settling tanks to concentrate suspensions such as yeast. However, the settling area required is quite large and renders this unpractical. For example, using a mean particle diameter of 6 microns, the hindered settling velocity is calculated to be on the order of 1.1×10^{-5} centimeters per second. At this rate, the settling area required for the production of 1540 pounds of yeast per hour is approximately 15,000 square meters.

Alternatively, filtration is possible as a method of recovery provided that the resistance of the yeast cake during filtration is low enough so that a sufficient rate can be achieved. This method, however, has not been successful on an industrial scale due to the nature of the cake formed during filtration. It has been found that the yeast cake "binds" easily and the rate of filtration becomes exceedingly small and thus renders this approach unpractical.[83]

In view of these facts, the method most commonly used for the recovery of yeast on an industrial scale is by the centrifugal separator.[84,85] The throughput of a centrifugal separator can be shown to be expressed in the following equation:

$$Q = \frac{Kd_p^2 (\rho_p - \rho_L)}{\mu} \frac{r_e w^2 V}{g_c S_e} \qquad (2)$$

where:

Q = Flow rate through centrifuge

K = constant

d_p = diameter of the particle

ρ_p = density of the particle

ρ_L = density of the liquid

r_e = equivalent diameter of the centrifuge

w = rotational speed of the centrifuge

μ = viscosity of the liquid

V = volume holdup of the liquid in centrifuge

S_e = equivalent sedimentation distance of the particle

It can be seen from equation 2 that one reason for selecting yeasts instead of other unicellular organisms such as bacteria as a product is the relative ease of recovery of the yeast. Theory predicts the throughput of a centrifuge is proportional to the square of the particle diameter. In this case to separate a yeast having a mean diameter of 6 microns in comparison to a bacterium of 1.5 micron, the centrifuge throughput for the yeast is nearly sixteen times greater than that for the bacterium. Considering necessary capital investment costs as well as operating costs, the selection of yeast as the organism has a positive economic basis.

It is envisioned that the yeast from the fermentor is fed directly to continuous sludge discharge type of centrifuges. This type of machine is commercially available and has been used successfully in industrial yeast production.[83,84,86,87] A battery of three 6000 gallons per hour, 20 horsepower continuous sludge discharge separators will be required. Yeast from the fermentor will be concentrated from approximately two hundred grams per liter after one pass through the centrifuge. It will be necessary to wash the concentrated paste to remove undesirable tastes and odor. Counter-current washing using in-line mixers is proposed in order to minimize the water consumption. This procedure is commonly employed in the industrial yeast manufacturing. The effluents from the first and second stage centrifugation can be recycled to the hydrolyzer for reuse. The solid paste from the last centrifuge is refrigerated to prevent contamination and pumped to the drum dryer. The solids from the last centrifugation stage will have undergone an approximate ten fold concentration factor and will contain approximately twenty percent dry solids.

Drying:

The concentrated paste from the third centrifuge will be dried by means of a double drum atmospheric dryer. It has been shown by Inskeep et al[86] that yeast grown on sulfite waste liquor can be drum dried using 85 psig steam to produce a non-viable product of adequate nutritional value for animal feed supplements. In addition, drum dryers require a lower capital investment as well as lower operating and maintenance costs per pound of water removed. The moisture content of the feed to the drum dryer will range from 80 to 85 percent. For the production of 1540 pounds of dry yeast per hour, the drum dryer must evaporate 12,350 pounds of water per hour. A representative average product rate for a double drum dryer was reported by Perry[61] to be on the order of 3.5 pounds of product per hour per square foot of drum surface. Therefore a drum dryer having approximately 440 square feet of drying area will be required. The product from the dryer will contain 2 to 10 per cent moisture.

After drying, the lumpy product will be processed through a hammer mill, be screened and finally pass into a storage hopper capable of holding one day's production. The product in the hopper will discharge to a chute permitting bags or drums to be filled for shipment.

C. Economic Analysis

The flow sheet for the fermentation process is shown in Figure 17. The required process equipment together with materials of construction and costs are noted in Tables XXVIII and XXXII for two alternate plant designs. Costs indicated for various items of equipment are taken from Bauman.[88]

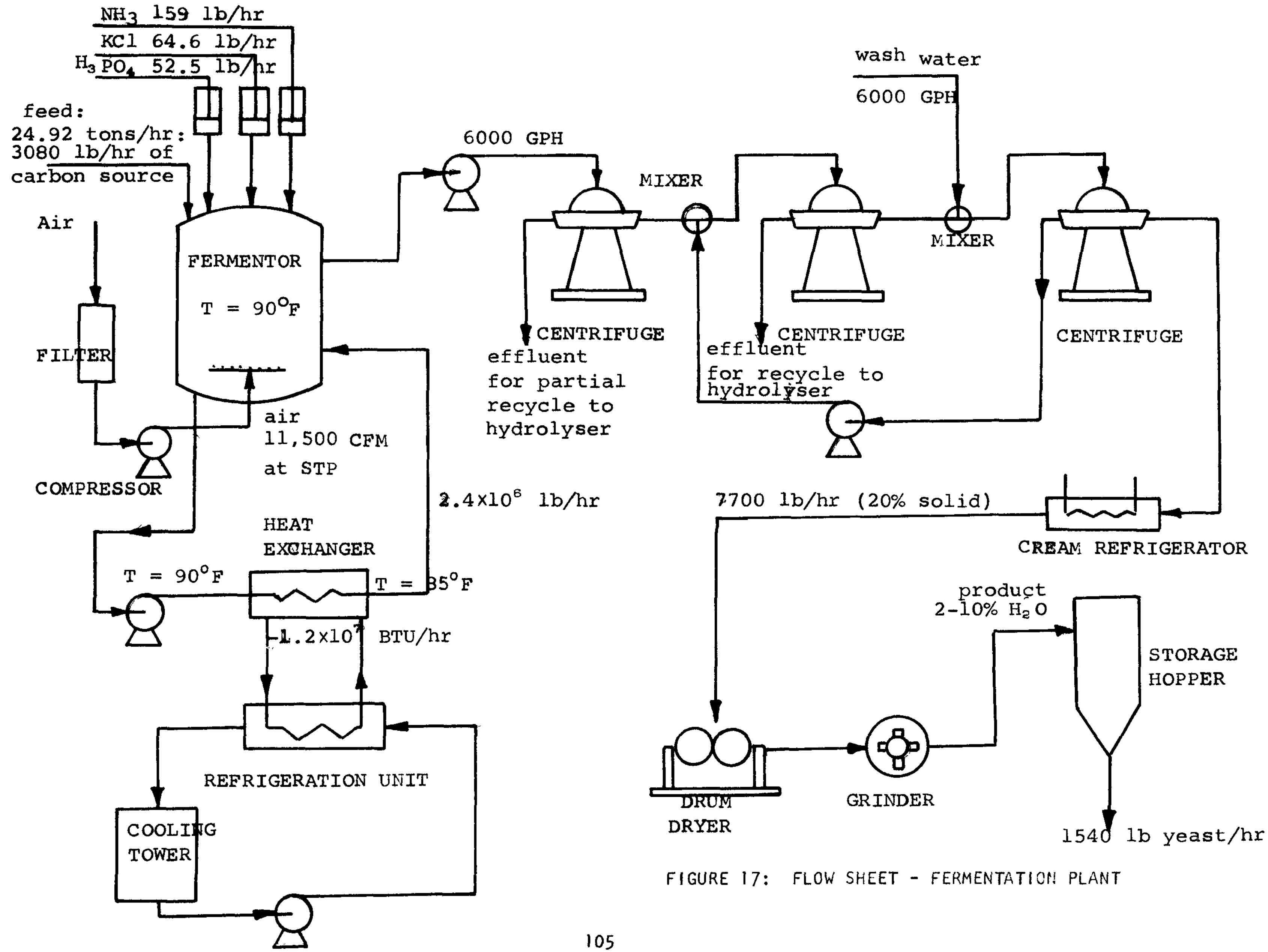

FIGURE 17: FLOW SHEET - FERMENTATION PLANT

Two plant conditions are displayed and developed as: Case 1, the maximum cost plant, and Case 2, the minimum cost plant. The major economics reflected in Case 2 are the substitution of a fermentor of wooden construction for the metal construction indicated in Case 1, and the use of a local surface water source for cooling in place of the refrigeration-cooling tower system proposed in Case 1.

The substitution of wood for metal fermentors is not unusual and had, for many years, been the principal material of construction in many segments of the fermentation industries. Economics attributed to this factor equal $125,000 of the purchased equipment cost. This represents a cost reduction of about 0.5 cents per pound of yeast for the 80 ton per day plant, or expressed in another way it equals a 5 per cent reduction in product costs. This economy should be universally applicable to plants at any location.

The second economy, that of using a large body of surface water for cooling purposes, is more specific in its application. A local large body of cooling water must be present that is available for use to the fermentation plant. Although the opportunity to apply this cost reduction scheme is limited, it is nonetheless very attractive where it can be utilized. Product cost reductions of 2.76 cents per pound or 30 per cent can be realized by employing this method of cooling. Coastal municipalities and perhaps some locations on the Great Lakes appear to have the best opportunity to apply this cost saving factor.

Case 1 data is presented in Tables XXVIII through XXXI. Plant cost figures developed in Tables XXVIII to XXX are based on the 80 ton per day of wastepaper to the hydrolysis operations. Table XXXI expands the plant in increments to the 1000 ton per day size.

Case 2 data is presented in Tables XXXII through XXXV. Tables XXXII to XXXIV refer to the 80 ton per day plant while Table XXXV compares cost factors for the 80 and 500 ton per day plants.

Table XXXVI summarizes yeast product costs in cents per pound for cases 1 and 2 as a function of plant size.

TABLE XXVIII: EQUIPMENT COSTS FOR FERMENTATION SYSTEM[150]

CASE I

Item	Size	Material of Construction	Purchased Cost
Nutrient Makeup			
Metering Pumps	50 GPH	Iron	1,200
Hydrolyzate pump	100 GPM	Cast Iron-Centrifugal	1,000
Ammonia metering equip.		Iron	800
Air Supply			
Air Compressor	11,500 CFM	Iron-Centrifugal	126,000
Fermentor	570,000 Liters	Iron	145,000
Cooling			
Refrigeration System	1000 tons	--	155,000
Broth circulation pump	42 HP	Iron-Centrifugal	2,000
Cooling Tower	17×10^6 Btu/hr		80,000
Recovery and Washing			
Centrifuges, continuous	100-150 GPM		54,000
Pumps	100 GPM	Cast Iron-Centrifugal	3,000
Drying and Packaging			
Dryers-Double Drum	12,400#/hr		86,000
Hammer Mill	1 Ton/hr		10,000
Storage	20 Tons	Aluminum	15,000
Packaging System			5,000
		Total Equipment Cost	$684,000

TABLE XXIX: ESTIMATE OF TOTAL CAPITAL INVESTMENT:FERMENTATION PLANT

CASE I

Item and Basis for Estimation		Cost
1.	Purchased equipment-delivered (P.E.C.)	684,000
2.	Equipment installation (including instrumentation) 43% P.E.C.	294,000
	Installed equipment cost	978,000
3.	Piping (Including insulation) - 27% P.E.C.	184,000
4.	Electrical installations - 15% P.E.C.	105,000
5.	Buildings. (including services)- 35% P.E.C.	239,000
6.	Yard improvements - 10% P.E.C.	68,000
7.	Service facilities - 35% P.E.C.	239,000
8.	Land - 4.8% P.E.C.	33,000
	Total physical plant cost	1,846,000
9.	Engineering and construction - 40% P.E.C.	274,000
	Direct plant cost (D.P.C.)	2,120,000
10.	Contractors fee - 7% D.P.C.	148,000
11.	Contingency - 15% D.P.C.	318,000
	Fixed capital investment (F.C.I.)	2,586,000
12.	Working capital (total operating cost for 30 days)	102,000
	Total capital investment	2,688,000

TABLE XXX: ESTIMATED MANUFACTURING COST:FERMENTATION PROCESS

CASE 1

Item	Units/day	Cost	Daily Cost
A. Direct production cost			
1. Raw Materials (excluding cost of sugar)			
Ammonia, anhydrous	1.91 tons	$92.00/ton	175.80
Phosphoric acid, 53%	1.19 tons	51.00/ton	60.60
Potassium chloride, 95-99%	0.78 tons	30.00/ton	23.40
2. Utilities			
Electricity	42,700 kw-hr	0.007/kw-hr	299.00
Steam	360,000 #	0.52/1000#	187.30
Process water	221,000 gal.	0.25/1000 gal	55.20
3. Operating labor 2 men/shift	48 man-hrs	3.00/man-hr	144.00
4. Supervisor (Use Hydrolysis Plant Supervisor)			--
5. Fringe benefits 15% hourly wage			21.60
6. Operating supplies 10% of labor			14.40
7. Maintenance & Repairs 10% FCI/yr.			719.00
Direct Production Cost			1,700,30
B. Fixed Charges			
1. Depreciation - 12 yr. plant life zero salvage value, = 8-1/3% FCI/yr			600.00
2. Local Taxes - 2% FCI/yr			144.00
3. Insurance - 1% FCI/yr			72.00
Fixed Charges			816.00
C. Plant Overhead - 70% operating labor, supervision and maintenance labor			352.00
D. General Expenses			
1. Administrative 15% of operating labor, supervision and maintenance labor			75.50
2. Distribution and selling cost (not applicable)			-
3. Research and development 5% product cost			170.00
4. Interest 4% TCI/yr			299.00
General expenses			544.50
Total production cost			3,412.80
Production Cost/# Yeast = $0.092/# (excluding cost of sugar)			

TABLE XXXI: DAILY MANUFACTURING COST FOR YEAST AT VARIOUS PLANT CAPACITIES

CASE 1

Item	80 Ton/day	150	300	500	1000
Fixed Capital Investment	2,586,000	4,005,000	6,515,000	9,050.000	14,740,000
A-1 Raw Materials	259.80	487.00	974.00	1,558.00	3,116.00
A-2 Utilities	531.50	995.00	1,990.00	3,180.00	6,360.00
A-3 Operating Labor	144.00	144.00	144.00	144.00	144.00
A-4 Supervisor	-	-	-	-	-
A-5 Fringe Benefits	21.60	21.60	21.60	21.60	21.60
A-6 Operating Supplies	14.40	14.40	14.40	14.40	14.40
A-7 Maintenance & Repairs	719.00	1,114.00	1,810.00	2,520.00	4,100.00
B-1 Depreciation	600.00	930.00	1,510.00	2,100.00	3,420.00
B-2 Local Taxes	144.00	223.00	362.00	504.00	820.00
B-3 Insurance	72.00	111.50	181.50	252.00	420.00
C Overhead	352.00	491.00	734.00	984.00	1,535.00
D-1 Administrative	75.50	105.30	157.20	211.00	329.00
D-2 Dist.&Selling	-	-	-	-	-
D-3 R&D	170.00	293.00	500.00	660.00	1,160.00
D-4 Interest	299.00	465.00	754.00	1,050.00	1,715.00
Daily Prodn.Cost	3,412.80	5,395.00	9,153.00	13,200.00	23,155.00
Prodn./day (#/day)	37,000	69,400	138,500	231,500	463,000
Prodn.cost/# Yeast (Excluding cost of sugar)	9.22¢/#	7.78¢/#	6.60¢/#	5.70¢/#	5.00¢/#

TABLE XXXII: EQUIPMENT COSTS FOR FERMENTATION SYSTEM

CASE 2

Item	Size	Material of Construction	Purchase Price
Nutrient Makeup	(See Table XVIII)		3,000
Air Compressor			126,000
Fermentor	570,000 liters	Redwood or Fir	30,000
Cooling			
Broth circulation pumps	42 HP	Iron-centrifugal	2,000
Heat exchangers	$6000 ft^2$	Admiralty Brass	52,000
Recovery and Washing	(See Table XVIII)		57,000
Drying and Packaging	(See Table XVIII)		116,000
	Total Equipment Cost		$386,000

TABLE XXXIII: ESTIMATE OF TOTAL CAPITAL INVESTMENT: FERMENTATION PLANT

CASE 2

1.	Purchased equipment-delivered (P.E.C.)	386,000
2.	Equipment installation (including instrumentation) 43% P.E.C.	163,000
	Installed Equipment Cost	543,000
3.	Piping (Including insulation) - 27% P.E.C.	103,000
4.	Electrical Installations - 15% P.E.C.	57,000
5.	Buildings (Including Services) - 35% P.E.C.	133,000
6.	Yard Improvements - 10% P.E.C.	38,000
7.	Service Facilities - 35% P.E.C.	133,000
8.	Land - 4.8% P.E.C.	18,000
	Total Physical Plant Cost	1,025,000
9.	Engineering and Construction - 40% P.E.C.	152,000
	Direct Plant Cost	1,177,000
10.	Contractors Fee - 7% D.P.C.	82,000
11.	Contingency - 15% D.P.C.	176,000
	Fixed Capital Investment	1,435,000
12.	Working Capital	66,500
	Total Capital Investment	1,501,500

TABLE XXXIV: ESTIMATED MANUFACTURING COST:FERMENTATION PROCESS
CASE 2

Item	Units/Day	Cost	Daily Cost
A. Direct production cost			
1. Raw materials (excluding cost of sugar)			
Ammonia, anhydrous	1.91 tons	$92.00/ton	175.80
Phosphoric aicd, 53%	1.19 tons	51.00/ton	60.60
Potassium Chloride, 95-99%	0.78 tons	30.00/ton	23.40
2. Utilities			
Electricity	18,300 kw-hr	0.007/kw/hr	128.00
Steam (125% of demand)	360,000#	0.52/1000#	187.30
Process water	144,000 gal	0.25/1000 gal.	36.00
3. Operating labor 2 men/shift	48 man-hrs		144.00
4. Supervisor (Use Hydrolysis Plant Supervisor)			-
5. Fringe benefits 15% hourly wage			21.60
6. Operating supplies 10% of labor			14.40
7. Maintenance & Repairs, 10% FCI/yr			398.00
Direct Production Cost			1,189.10
B. Fixed Charges			
1. Depreciation, 8-1/3% FCI/yr			333.00
2. Local Taxes 2% FCI/yr			80.00
3. Insurance 1% FCI/yr			40.00
Fixed Charges			453.00
C. Plant overhead, 70% of operating labor, supervision, and maintenance labor			240.00
D. General Expenses			
1. Administrative 15% of oper.labor, super, & Maint. Labor			51.40
2. Distrib & Selling			-
3. R & D 5% Product Cost			107.00
4. Interest, 4% TCI/yr			168.00
General Expenses			326.40
Total Production cost			2,208.50

Production Cost/# Yeast = $0.0596/# (excluding cost of sugar)

TABLE XXXV: DAILY MANUFACTURING COST FOR YEAST AT VARIOUS PLANT CAPACITIES

CASE 2

Item		80 Ton/Day	500
	(FCI)	1,435,000	5,020,000
A-1	Raw Materials	259.80	1,622.00
A-2	Utilities	451.30	2,620.00
A-3	Operating Labor	144.00	144.00
A-4	Supervisor	-	-
A-5	Fringe Benefits	21.60	21.60
A-6	Operating Supplies	14.40	14.40
A-7	Maintenance & Repairs	398.00	1,392.00
B-1	Depreciation	333.00	1,165.00
B-2	Local Taxes	80.00	280.00
B-3	Insurance	40.00	140.00
C	Overhead	240.00	588.00
D-1	Administrative	51.40	126.00
D-2	Dist. & Selling	-	-
D-3	R & D	107.00	458.00
D-4	Interest	168.00	588.00
Daily Prodn. Cost		2,208.50	9,159.00
Prodn/Day		37,000	231,500
Prodn cost/#Yeast (Excluding Cost of Sugar)		5.96¢/#	3.96¢/#

TABLE XXXVI: YEAST PRODUCT COSTS VS. PLANT SIZE

Plant Size (Basis: feed to hydrolysis plant)	Product Cost for Yeast - Cents/pound*	
	Case 1	Case 2
80 Ton/Day	9.22	5.96
150	7.78	
300	6.60	
500	5.70	3.96
1000	5.00	

* Note: These figures do not include the cost of the hydrolyzate sugars.

For Case 1 using wood fermentors the product cost for an 80 ton per day plant is 8.72 cents per pound, excluding the cost of hydrolyzate sugar.

D. Comments and Conclusions

Fermentation plant design and location are of great importance in minimizing product costs. Power and cooling water utilization factors are a prime consideration in plant operating costs and certainly make the choice of plant location on or near large bodies of available cooling water desirable if not necessary.

The use of thermophilic bacteria as the active microorganism may be another possible way to circumvent the cooling problem. Here, however, new data must be developed on the usefulness of the product for foods and feeds before markets would be available.

It appears that in any event the fermentation operation will be responsible for a large portion of the total production cost of the product yeast. Process improvements in the aeration, mixing, cooling, separating and dewatering steps can result in useful economic gains.

YEAST IS A COLLECTIVE NAME for those fungi which possess a vegatative body consisting, at least in part, of simple individual single cells. Their use, for the purpose of this study, will be largely as protein and vitamin supplements in human foods and animal feeds. To better understand the applications and the needs of the protein field, brief discussions of the technical aspects and problems of protein acceptance will precede the market analysis.

A. The Protein Problem

In the words of Dr. Ricardo Bressani of the Institute of Nutrition of Central America and Panama (INCAP)[89]: "the idea of a hunger-free world has stirred the imagination of men everywhere."

The scope of the problem has been outlined in many articles, reports[90,91] and bulletins[93,94,95,96] and discussed at conferences.[83,92,97] The observations that today there are over 300 million children who, for lack of sufficient protein and calories, suffer retarded physical and mental growth and that the present population of three billion people is expected to double by the year 2000 have been discussed and documented. It is the problem of feeding this mass of humanity in an acceptable and adequate manner that is the cause of great concern.

One U.N. report states[90]: "It is now recognized that the protein problem is reaching a critical stage. It is essential that the United Nations family urgently take action aimed at closing the present gap between world protein needs and protein supplies and at preventing even more widespread protein deficiency in future generations. ... there is no single or simple solution to the complex problems of providing the required immense quantities of proteins ... in form acceptable to the final consumer."

Wilcke states[98]: "According to history, as the economic level of a given population improves, the consumption of foods from animal sources increases."

Abbott in his presentation on Protein Supplies and Prospects[92] observed that "while animal protein resources are rising in the developed countries, in the developing countries the total per capita protein supply has declined by about 6% since World War II, with increased dependence on protein from grain. On an average, present supplies are generally adequate for nutrition; in practice, variations in individual requirements and economic and social impediments to distribution mean that substantial segments of the population do not receive enough."

Data on the various aspects of population and protein supply are shown in Tables XXXVII through XLII.

The general overall conclusions reached by investigators in this field are:

1. A world protein shortage does exist.
2. Additional protein needs of 2.8 billion pounds per year are predicted for the current rate of population growth.[106]
3. Based on present methods of production, the world population-protein gap will widen.
4. Although animal protein is a preferred diet for most people the productivity and cost make this source less available to segments of the world population which have the greatest need.
5. New and unusual sources of protein indigenous to the population must be developed into nutritious and highly acceptable foods.
6. The protein sources introduced should be utilized to their maximum value as protein and not squandered as calories.
7. The food product developed must compete successfully in the market place.

TABLE XXXVII: PROTEIN SUPPLIES PER CAPITA BY MAJOR FOOD GROUPS AND REGIONS[92,153]

	Vegetable Protein				Animal Protein				
	Grains	Starchy Roots	Pulses Oil-seeds, and Nuts	Vege-tables and Fruit	Meat and Poul-try	Eggs	Fish	Milk and Milk Products	
	Grams per Day								Total
North America	15.7	2.3	4.7	4.6	31.9	6.0	2.5	25.3	93
Australia and New Zealand	24.3	2.4	2.1	3.1	36.8	3.5	2.2	19.5	94
Western Europe	30.5	4.4	5.0	4.1	16.2	3.1	2.4	17.3	83
Eastern Europe and USSR	48.3	8.2	2.0	2.5	12.9	2.2	1.9	16.1	94
Latin America	26.5	2.7	10.7	2.8	13.8	1.2	1.5	7.4	67
Far East	32.2	1.8	12.0	1.7	3.0	0.4	2.2	2.2	56
Near East	48.5	0.7	9.5	3.6	4.6	0.5	1.1	7.4	76
Africa	32.2	7.1	9.0	1.7	5.8	0.4	1.3	3.5	61
Europe, North America, Australia New Zealand Argentina Paraguay Uruguay	33.4	5.2	3.8	3.6	19.8	3.3	2.4	18.5	90
Far East, Near East, Africa, Latin America (except Argentina, Paraguay and Uruguay)	33.2	2.3	11.6	1.8	3.8	0.4	1.9	2.9	58
World	33.4	3.2	9.0	2.4	8.8	1.2	2.3	7.7	68

TABLE XXXVIII: PER CAPITA PROTEIN SUPPLIES IN SELECTED COUNTRIES [92,154]

(Averages 1957-59)

	Total Protein	Animal Protein	Grain	Starchy Roots	Pulses Oilseeds, and Nuts	Vegetables	Fruit	Meat and Poultry	Eggs	Fish	Milk and Products
U.S.A.											
Grams per day	92	65	15	2	5	4	1	32	6	3	24
% of total protein		70	16	2	5	4	1	35	7	3	26
Canada											
Grams per day	95	63	23	3	3	2	1	29	5	4	25
% of total protein		66	24	3	3	2	1	31	5	4	26
Argentina											
Grams per day	98	57	34	3	1	2	1	43	2	1	11
% of total protein		58	35	3	1	2	1	44	2	1	11
Brazil											
Grams per day	61	19	24	2	14	-	2	11	1	2	5
% of total protein		31	39	3	23	-	3	18	2	3	8
Colombia											
Grams per day	48	23	15	2	5	1	2	15	1	-	7
% of total protein		48	31	4	10	2	4	31	2	-	15
Mexico											
Grams per day	68	20	33	-	13	1	1	9	2	1	8
% of total protein		30	49	-	19	1	1	13	3	1	12
Peru											
Grams per day	49	12	22	6	5	3	1	6	-	3	3
% of total protein		24	45	12	10	6	2	12	-	6	6
Ireland											
Grams per day	96	57	29	7	1	2	-	20	5	2	30
% of total protein		59	30	7	1	2	-	21	5	2	31
Finland											
Grams per day	94	53	34	5	1	1	-	12	2	6	33
% of total protein		56	36	5	1	1	-	13	2	6	35
Portugal											
Grams per day	72	26	29	6	4	5	1	6	1	16	3
% of total protein		37	41	8	6	7	1	8	1	23	4
Sweden											
Grams per day	61	52	22	4	1	1	1	17	4	7	24
% of total protein		64	27	5	1	1	1	21	5	9	30
Israel											
Grams per day	84	33	39	2	4	3	2	10	6	3	14
% of total protein		40	47	2	5	4	2	12	7	4	17

TABLE XXXVIII: PER CAPITA PROTEIN SUPPLIES IN SELECTED COUNTRIES[92,154] (CONTINUED)

(Averages 1957-59)

	Total Protein	Animal Protein	Grain	Starchy Roots	Pulses Oilseeds, and Nuts	Vegetables	Fruit	Meat and Poultry	Eggs	Fish	Milk and Products
Libya											
Grams per day	53	10	34	1	4	2	2	4	-	1	5
% of total protein		20	64	2	7	4	4	8	-	2	9
Turkey											
Grams per day	91	15	61	2	7	3	2	5	-	1	9
% of total protein		17	68	2	8	3	2	6	-	1	10
United Arab Republic											
Grams per day	76	13	51	-	7	3	2	5	1	3	4
% of total protein		17	67	-	9	4	3	7	1	4	5
Ceylon											
Grams per day	45	9	27	1	7	2	-	1	-	6	2
% of total protein		20	60	2	16	4	-	2	-	13	4
India											
Grams per day	51	6	30	-	14	1	-	1	-	-	5
% of total protein		12	59	-	27	2	-	2	-	-	10
China (Taiwan)											
Grams per day	57	14	31	3	7	2	-	6	-	7	1
% of total protein		25	54	5	12	4	-	11	-	12	2
Japan											
Grams per day	67	17	31	2	13	4	-	3	1	12	1
% of total protein		26	46	3	19	6	-	5	1	18	1
Pakistan											
Grams per day	46	7	33	-	4	1	-	1	-	1	5
% of total protein		16	72	-	9	2	-	2	-	2	11
Philippines											
Grams per day	47	13	26	2	2	3	1	4	1	7	1
% of total protein		28	55	4	4	6	2	9	2	15	2
Mauritius											
Grams per day	46	11	27	1	6	1	-	2	1	4	4
% of total protein		23	59	2	13	2	-	4	2	9	9
Australia											
Grams per day	92	61	23	3	2	2	1	37	3	3	18
% of total protein		67	25	3	2	2	1	40	3	3	20
New Zealand											
Grams per day	105	72	25	3	2	2	1	36	5	3	28
% of total protein		68	24	3	2	2	1	34	5	3	27

TABLE XXXIX: PROTEIN REQUIREMENTS AND SUPPLIES AVAILABLE[92,153,154]

(Grams per capita daily)

	Requirements	Supplies
U.S.A.	40	92
Canada	42	95
Australia	45	92
New Zealand	44	105
Britain	44	86
France	47	96
Germany, Federal Republic	44	79
Greece	49	95
Ireland	45	96
Italy	46	77
Sweden	48	81
Switzerland	44	90
Yugoslavia	52	96
Argentina	42	98
Brazil	45	61
Chile	46	77
Colombia	48	48
Mexico	44	68
Peru	48	58
Ceylon	47	45
China (Taiwan)	42	57
India	48	51
Japan	43	67
Pakistan	46	46
Philippines	46	47
Israel	44	83
Libya	47	53
Turkey	45	90
U.A.R.	45	76
Mauritius	42	46
South Africa	41	73

TABLE XL: DISTRIBUTION OF WORLD'S POPULATION AND FOOD SUPPLIES, BY REGIONS (1957-1959)[96,104]

Regions	% of Population	% of Food Supplies		
		Total	Animal	Crops
Far East (incl. China, mainland)	52.9	27.8	18.5	44.2
Near East	4.4	4.2	2.8	5.5
Africa	7.1	4.3	2.8	6.3
Latin America	6.9	6.4	6.7	6.5
Europe (incl. USSR)	21.6	34.2	38.4	26.2
North America	6.6	21.8	29.2	10.4
Oceania	0.5	1.3	1.6	0.9
World	100.0	100.0	100.0	100.0

TABLE XLI: AVERAGE YIELDS OF MAJOR CROPS AND CATTLE PRODUCTS BY GROUPS OF REGIONS (1957-60)[96,104]

Commodity	Less Developed Regions	Developed Regions	World
Crops, 100 kg/ha.			
Wheat	9.4	13.3	11.9
Rice, Paddy	19.1	38.4	19.2
Other cereals	9.0	18.0	13.3
Starches	74.5	122.2	97.1
Pulses	6.1	6.5	6.2
Cattle products[a]			
100 kg/head of cattle	2.6	13.9	6.5

[a] Meat and milk in terms of milk equivalent, taking 1 unit of meat as equal to 10 units of milk. Averages for 1958-60

TABLE XLII: CURRENT CONSUMPTION LEVELS FOR INDIA, GROUP I COUNTRIES GROUP II COUNTRIES, AND THE WORLD AS A WHOLE[104,155]

	India	Group I, excl. India	Group I[a]	Group II[b]	World
	Grams per Person per Day at Retail Level				
Cereals	375	393	389	328	370
Starchy roots	30	229	189	316	227
Sugar	45	26	29	88	47
Pulses and nuts	65	50	53	16	42
Fruits and vegetables	80	191	169	362	227
Meat	4	37	30	152	67
Fish	7	28	24	34	27
Eggs	1	5	4	33	12
Milks and milk products (excl. butter)	140	64	79	573	228
Fats and oils	11	12	12	47	22
Calories	1,970	2,190	2,150	3,060	2,420
Animal protein, g.	6	10	9	44	20
Total protein, g.	51	60	58	90	68
Fats,g.	27	36	34	106	56
Calcium, mg.	446	293	324	1,099	557
Iron, mg.	15	13	14	17	15
Vitamin A,IU	1,432	2,945	2,642	5,555	3,516
Thiamin, mg.	1.3	1.6	1.5	2	2
Riboflavin, mg.	0.6	0.7	0.7	2	1
Niacin, mg.	7	14	14	19	15
Ascorbic acid, mg.	26	83	72	116	85

[a]Far East, Near East, Africa, and Latin America, excluding River Plate countries.

[b]Europe, North America, Oceania, and River Plate countries.

Protein requirements and the value of various sources of protein have been investigated and reviewed by many.[89,92,99,100,101,102,103,104,105,106] In October 1963, the Joint Food and Agriculture Organization-World Health Organization (FAO/WHO) recommended the following basis for assessing protein requirements:

Age Group	Protein Requirements (GRAMS/Kg of BODY WEIGHT)
1 - 3	0.9
4 - 9	0.8
10 - 15	0.7
16 and over	0.6

Other factors such as the value of the type of food protein in terms of net protein utilization or protein efficiency ratio, sex, pregnancy, etc. enter into the overall requirements.

The value of a food protein is closely associated with the amino acid balance of the food and the human system's ability to assimilate these useful materials. Tables XLIII through XLVI show amino acid compositions and vitamin contents for various protein sources.

Studies on protein utilization have been conducted. Work in this area is documented in the bibliography of papers by Bressani,[89] and by Morrison and Rao.[107]

Competing sources are being proposed and developed to alleviate the shortage in world protein. Although future competition in process and product development will increase, present predictions are that there will be room for everyone that has the ability to meet the requirements of the market place. The major areas of protein development both usual and unusual are outlined below.

TABLE XLIII: AMINO ACID COMPOSITION OF SOME SELECTED FOOD SOURCES

(Amino Acids as grams per 16 G. N)

Amino Acid	Pork	Lamb	Beef	Poultry Meat	Whole Egg	Wheat	Corn	Rice	Soybean Meal	Cotton-Seed Flour
Alanine	6.30	6.30	6.40	-	-	-	7.50	5.20	-	-
Arginine	6.35	6.86	6.56	6.70	6.49	4.43	4.80	7.20	7.00	11.30
Cystine	1.31	1.34	1.35	1.80	-	-	2.00	1.50	-	-
Methionine	2.50	2.32	2.32	1.70	3.85	0.68	3.10	3.00	1.10	1.61
Phenylalanine	4.14	3.94	4.02	3.60	5.71	3.83	5.00	5.00	4.80	5.20
Tyrosine	3.02	3.21	3.24	2.10	3.63	3.66	6.00	5.70	3.20	-
Leucine	7.53	7.42	8.40	6.30	8.78	6.30	15.00	8.20	7.60	6.23
Isoleucine	4.89	4.78	5.07	4.20	5.67	4.68	6.40	5.20	5.80	3.94
Lysine	7.77	7.65	8.37	7.40	7.24	3.06	2.30	3.20	6.60	4.16
Threonine	5.12	4.88	4.04	3.90	5.29	2.81	3.70	3.80	3.90	3.36
Valine	4.97	5.00	5.71	6.50	8.79	4.00	5.30	6.20	5.20	4.84
Tryptophan	1.35	1.32	1.10	0.70	1.31	1.36	0.60	1.30	1.20	1.55

TABLE XLIV: ESSENTIAL AMINO ACID CONTENT OF YEAST AND OTHER PROTEINS (mg/gN)[89]

Amino Acid	Torula	Brewer's	Casein	Cottonseed	Soybean	Egg
Tryptophan	86	96	84	74	86	103
Threonine	315	318	269	221	246	311
Isoleucine	449	324	412	236	336	415
Leucine	501	436	632	369	482	550
Lysine	493	446	504	268	395	400
Total Sulfur amino acids	153	187	218	188	195	342
Phenylalanine	319	257	339	327	309	361
Valine	392	368	465	308	328	464
Arginine	451	304	256	702	452	410
Histidine	169	169	190	166	149	150

TABLE XLV: ESSENTIAL AMINO ACID CONTENT OF THE SINGLE CELL PROTEINS[42]

Amount (g/100 g protein)

Essential Amino Acid	LSU	ESSO	British Petroleum	Torula Yeast	Ideal Amino Acid Pattern by FAO	Soybean Protein
Arginine	9.84	*	*	*	*	7.0
Histidine	2.38	*	*	2.2	*	2.5
Isoleucine	4.57	3.6	5.3	6.4	4.2	5.8
Leucine	10.82	5.6	8.1	8.0	4.8	7.6
Lysine	6.69	6.5	7.6	8.5	4.2	6.6
Methionine	1.63	2.0	1.7	1.5	2.2	1.1
Phenylalanine	4.10	2.9	5.7	5.1	2.8	4.8
Threonine	5.52	4.0	5.8	5.1	2.8	3.9
Valine	10.60	4.5	5.7	5.6	4.2	5.2
Tyrosine	2.57	*	*	4.3	2.8	3.2
Half Cystine	2.86?	0.6	1.0	1.0	2.0	1.2
Tryptophan	*	*	*	1.37		1.37

* Not reported

TABLE XLVI: VITAMIN CONTENT OF SOME SELECTED MEAT CUTS (RAW)

	Thiamine, Mg./100 G.	Riboflavin, Mg./100 G.	Niacin, Mg./100 G.	B_6, Mg./100 G.	Pantothenic Acid- Mg./100 G.	Biotin, μ G./100 G.	Choline, Mg./100 G.	B_{12}, μ G./100 G.	Folic Acid, Mg./100 G.
Beef									
Chuck	0.08	0.17	4.5	0.38	-	-	-	-	0.013
Round	0.09	0.18	4.8	0.37	1.0	4.6	68	2.0	0.26
Pork									
Ham	0.77	0.19	4.1	0.42	0.72	5.3	120	0.9	0.009
Loin	0.83	0.20	4.4	0.50	2.0	5.5	77	-	0.007
Lamb									
Leg	0.16	0.22	5.1	0.26	0.59	5.9	84	2.5	0.009
Loin	0.14	0.20	4.7	0.22	-	-	-	-	-
Poultry									
Broiler	0.04	0.26	3.76	2.0	6.40	-	-	-	-
Whole egg	0.10	0.29	0.10	-	2.70	22.5	532.0	28.2	0.009
Soybean (solv.ext.)	0.66	0.33	2.68	-	1.45	-	274.3	-	0.07
Cottonseed (solv.ext.)	0.81	0.46	4.55	-	1.78	-	286.2	-	0.09

Grains[89,92,102,105,108]:

Grains provide nearly half of man's total protein supply, and the bulk of his calorie intake. Although grains have been a staple in the human diet for centuries their amino acid balance (See Table XLIII) is below the standards of nutrition set forth by FAO. Their wide supply and general acceptance as foods has spurred research efforts to increase yields of the traditional grain crops. Dr. Edwin Mertz and co-workers at Purdue University have succeeded in producing a maize with improved protein quality. This work is truly revolutionary and should stimulate research of this type on other grain crops.

A tremendous effort has been expended in producing new and acceptable foods with balanced nutritional values from grains and high protein supplements such as Torula yeast. Recent efforts to fortify cereals directly with amino acid values such as lysine and tryptophan show excellent technical and economic promise.

Oilseeds and Pulses[92,101,103,104]:

The rapidly growing world protein need has directed major attention to the food use of oilseed proteins. They play a vital role in relieving protein malnutrition in many areas where animal products are too expensive. Oilseed cakes constitute the main untapped sources of protein for human consumption in India, for example. This protein source is currently employed as an animal feed or fertilizer due to its condition after primary processing for oil removal. Refined oil recovery processes and toxin removal methods have been developed as have appealing and nutritious foods from these protein sources. Their application increases the prospects for expanding production of the wide variety of species available in this group.

B.F. Buchanan[109] noted that "there is potentially as much protein available from today's oilseed production as from all edible animal products." This would be enough, at minimum values, to supply the protein requirement of an additional one billion souls.

Yeasts[89,110,111]:

Yeast consumption by man as a component of unfined alcoholic beverages, cheeses and yoghurt has been going on through all of recorded history, and most probably before. The amount consumed may have supplied a useful portion of early man's protein requirements as well as his needs for the valuable B vitamins. Current uses of yeast other than in fermentation and baking applications include their incorporation in cereal foods as a source of vitamins and amino acids, canned baby foods, canned soups, sausages, sandwich spreads and other products where "meat" flavors are required. It has been stated that food yeasts offer the greatest potential for development of all current sources of protein concentrates. This is due to the high efficiency of yeast in the utilization of carbohydrate to synthesize protein. If available by-product yeast from the top 22 breweries were added to the yeast that would be produced if all molasses, sulfite waste liquors and whey were converted to yeast, an annual production of one million eight hundred and fifty thousand dry tons would be realized in the United States. The utilization of this material is discussed in the marketing section below.

Animal Protein[92,98]:

Livestock protein foods, including milk and eggs, are preferred by most consumers. Consumption rises sharply with income. The conversion of grain protein to animal protein is rather inefficient however, see Figure 18, and in countries where total protein supply is limited, direct consumption of grains by the populace is practiced to a higher degree. The expansion of an animal protein economy within a given country will depend on the nations economic growth factor and improvements in the technology of animal husbandry. The ability for a nation to support livestock is presently affected by the amount of arable land available for growing feed.

Fish[92,100]:

The consumption of fish is limited by marketing problems in many parts of the world. However, fresh,dried and fermented fish find their way into the diets of many peoples. Approximately twenty-five percent of the forty-five million tons of fish caught today is converted to fish meal and incorporated into animal feeds. The prospects for fish protein are of great interest since their production does not require the expenditure of resources that are directly useable as food and the supply is estimated at two and one half times the present consumption. Then too,

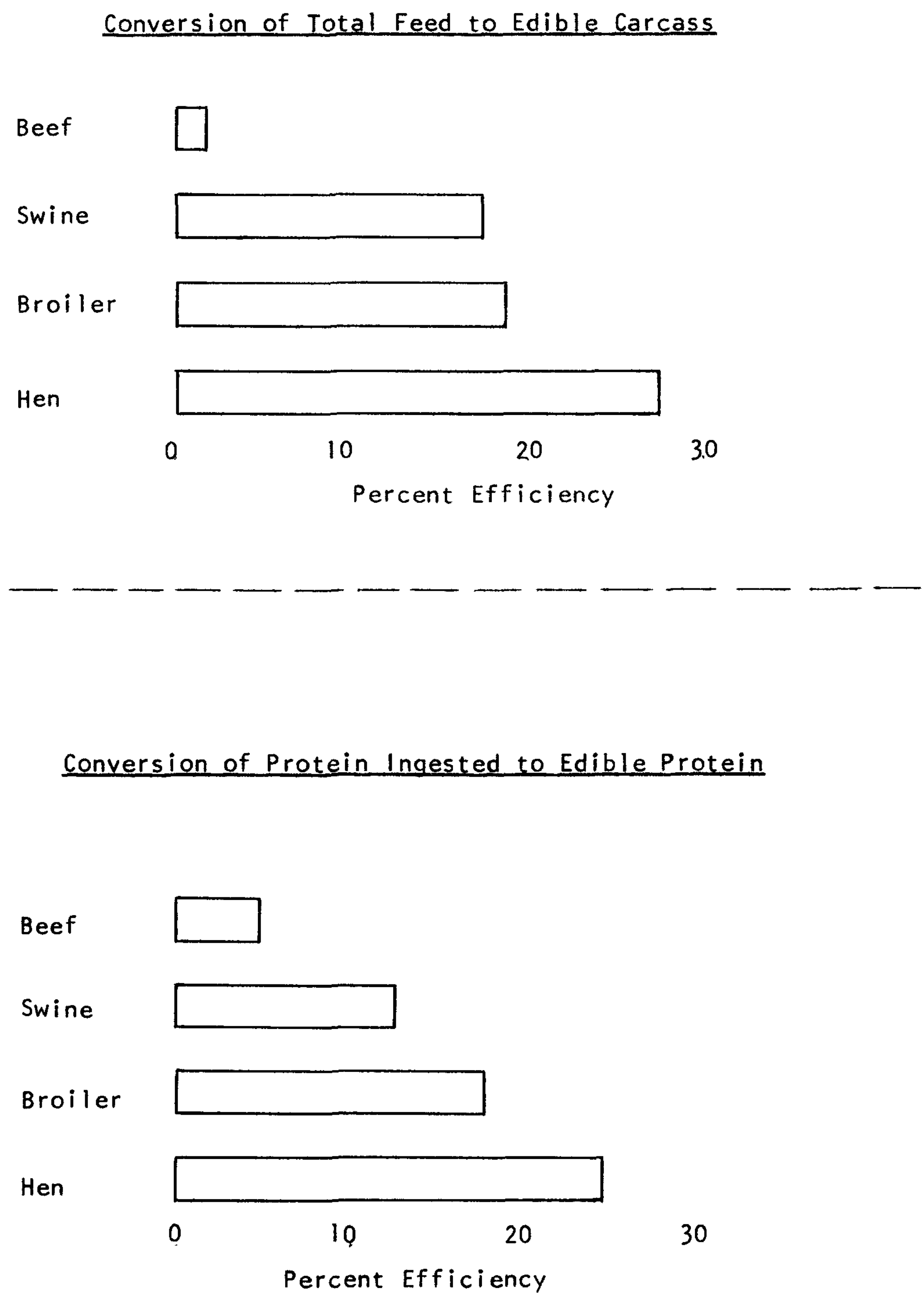

FIGURE 18: CONVERSION OF INGESTED FEED TO FOOD[98]

the new technologies for producing fish protein concentrates (FPC) from "rough fish" extend the supply of fish protein available for human consumption. Technological and economic problems still exist, but the outlook for FPC is very promising.

Algae,[112,113,114,118] Fungi[106,115] and Bacteria[116,117]:

Work has progressed in producing algal, fungal and bacterial protein values in a useful manner. The technologies have progressed to demonstration plant sizes for growing algae on sewage wastes and producing bacterial protein on hydrocarbon substrates. Fungi can convert carbohydrate materials such as potatoes, corn, sugar cane, bagasse, etc. to protein in an effective manner (see Table XLVII). Product separation and growing techniques are reported to be very good for selected species.

Discovery of a blue-green algae, Spirulina, that has been in use as a food in central Africa since ancient times, has increased the interest in this class of protinaceous material. Amino acid compositions of Spirulina compared with the FAO standard are shown in Table XLVIII. Algae production is ideally suited to the sunny hot climates where photosynthesis activity is at the highest levels.

The present anticipated use of these "new" protein foods is as high protein supplements in animal and poultry feeds. Eventual use as components in foods for human consumption is a logical further step. The useful concept employed by these unusual protein sources is their production from waste products or materials of non agricultural origin that are in great supply.

TABLE XLVII: WORLD PROTEIN PRODUCTION POTENTIAL (1962/63) BASED ON CONVERSION OF CARBOHYDRATE OF SEVEN CROP PLANTS TO PROTEIN USING FUNGI AS AGENTS OF BIOSYNTHESIS[106]

Crop	World Production 1962/63, Million Tons	Carbohydrate, %	Total Carbohydrate, Billion Lb.	Protein, %	Total Crop Protein Billion Lb.	Protein Available By Fungus Conversion Billion Lb.	Total Protein, Billion Lb.	Factorial Increase in Protein	No. of People Who Can Be Supplied with 52.2 Lb./Yr., Millions
Manioc	84.600	32	54.144	0.7	1.184	6.768	7.952	6.71X	152
Sugar beet	288.000	16	92.160	0.75	4.320	11.520	15.840	3.66X	305
Sugar Cane	480.000	12	115.200	--	--	14.400	14.400	--	276
Paddy Rice	277.088	70	387.923	7.5	41.563	48.490	90.053	2.19X	1725
Corn	243.600	60	292.320	7.0	34.094	36.540	70.634	2.07X	1350
Yams and sweet potatoes	130.704	28	73.194	1.8	4.705	9.149	13.854	2.94X	265
Potatoes	294.324	19	112.434	2.0	11.772	14.057	25.829	2.19X	494
Totals	1798.316	—	1127.375	—	97.638	140.924	238.562	—	4567

TABLE XLVIII: ESSENTIAL AMINO ACIDS[113]

(g/100g of proteins)

	I.F.P. Spirulina	Standard Combination F.A.O.
Isoleucine	6.03	4.2
Leucine	8.02	4.8
Lysine	4.59	4.2
Phenylalanine	4.97	2.8
Tyrosine	3.95	2.8
Total sulfur amino acids ..	1.80	4.2
Methionine	1.37	2.2
Threonine	4.56	2.8
Tryptophan	1.40	1.4
Valine	6.49	4.2

B. Current Market Situation for Yeast

Yeasts represent one of the richest sources of vitamins, particularly the B complex group, and amino acids available today. Yeast protein is a good source of lysine and has sufficient quantities of other essential amino acids such as tryptophan and threonine. Yeast is however deficient in methionine which can be corrected by supplementation with grains or oilseeds that have an abundance of this material.

Results of various feeding studies, summarized by Bressani,[89] show the yeasts as a group to be generally acceptable as a protein source or high protein supplement for both human and animal consumption. Where the basic diets are deficient in methionine this component must be added for maximum growth to accrue. In poultry feeding studies torula yeast was used satisfactorily as the sole protein supplement and in some cases yeast was the sole protein source.

Yeast, then, has been traditionally used as a vitamin and protein supplement in feeds and represents an accepted component for good nutrition.

Raw Materials Economics[53,111]:

A real appraisal of the economic position of the different available raw materials for fermentation to yeast must consider the fermentation industries as a group. Most of the appraisals attempted in the past are incomplete in this sense and generally out of date.[119,120,121,122] A general comparison of the possible competitive positions of the major raw material groups is considered in the following paragraphs.

The major source of carbohydrate for the fermentation industries is molasses. It is a waste material of the cane and beet sugar industry and as such represents a potential liability if suitable utilization outlets such as the fermentation industries did not exist. Gabriel[123] has indicated that cane sugar manufacturers could better afford to give away their molasses than to go to the expense of disposing of it. Certainly, if this is the case, molasses will always maintain a competitive position in the market and represents a sugar cost that competing processes must approach, other values being equal. An increasing tendency to utilize molasses in countries where it is produced may eventually limit its availability for export.

The utilization of waste liquor from sulfite pulp mills as a fermentation substrate has been pursued in the United States, Canada and to a larger degree in the Scandinavian countries. Yeast and ethanol production facilities have been established using this raw material. The Candida utilis yeasts, commonly called Torula, produced on this substrate have the ability to utilize both the hexose and pentose sugars available. The development of the market for this "new" type yeast has lagged in the U.S. in spite of its favorable sales price position. There has been a general hesitancy on the part of the sulfite paper mills to enter the fermentation business even though this utilization of wastes represents an attractive disposal system. Relatively large capital costs and a new marketing area have limited the participation by the sulfite pulp mills in this field.

Another waste product that has achieved commercial size as a substrate for fermentation operations is whey, or lactose from whey.[125] Smith and Claborn[124] have estimated that 2.7 billion pounds of lactose could be obtained from dairy by products and to a large extent made available for fermentation.

The economic position of wood waste, agricultural residues and other cellulosic materials have been and no doubt will continue to be employed in countries that cannot raise enough food crops to meet the requirements of their populations. A case in point is wartime Germany where saccharification of wood wastes with subsequent fermentation to yeast was developed and practiced to supplement the protein needs of the nation. Current efforts in Russia and Eastern Europe[110] to grossly increase their productive capacity of food and feed yeasts will at least in part consist of cellulose conversion mechanisms. The utilization of cellulosic materials as a raw material for the production of fermentation substrates in the United States will require special circumstances. Favorable conditions of location, waste availability and costly waste disposal situations are some factors that will provide the driving force necessary for the construction of facilities to convert cellulose materials to fermentable sugars. New process developments in the fields of hydrolysis and enzymatic conversion techniques will add to the desirability of this raw material source.

Current Yeast Production:

Peppler states[111]: "In the United States today yeast is produced as a major end product by eight manufacturers operating at sixteen locations. Fourteen of these factories (six companies) will produce in 1967 an estimated 58,500 tons of yeast dry matter in the form of bakers yeast, or about 65% of the total domestic harvest [see Table XLIX]. The remaining third of annual production comprises two small amounts of primary food and feed yeast grown on spent sulfite liquor and whey, and a major portion of secondary yeast recovered as brewers yeast."

TABLE XLIX: U.S. YEAST PRODUCTION[111]

(Estimated 1967)

	Dry Tons	Substrates
Compressed bakers yeast	56,000	Molasses
Active dry yeast	2,500	Molasses
Food grade dried yeast		
Saccharomyces sp.	15,000	Grain, molasses, whey
Candida utilis	1,000	Sulfite liquor
Feed yeast		
Saccharomyces sp.	10,100	Grain, molasses, whey
Candida utilis	1,800	Sulfite liquor
Extracts, autolysates, etc.	3,700	Grain, molasses
Total	90,100	

Surveys of yeast manufacture in 1963 and 1964 for the domestic and world markets is summarized in Tables L and LI. European output of dried yeast represents two thirds of world production. This large quantity is used mainly for animal feed purposes and is reportedly grown on waste materials, wood hydrolysates and beet molasses.

A breakdown of raw material availability for fermentation (alcohol) and yeast end-products by carbohydrate source is shown in Table LII.

U.S. Market Outlook:

American Food and Feed Yeast Enters the Market as[53]:

1. A rich supplementary source of vitamins, growth factors, amino acids, and mineral elements for animal, fish, and poultry feeds, and for substrates in other fermentation processes.
2. A source of vitamins and nutritional factors used in fortifying human food products.
3. A source of vitamins for pharmaceuticals.
4. A source of amino acids, protein fractions, and extracts for food and pharmaceutical use.
5. A source of enzyme materials.
6. A raw material for various other fractionating processes in the pharmaceutical, chemical, and food industries.

TABLE L: UNITED STATES YEAST OUTPUT, 1963[111,126]

(Dry Tons)

Bakers Yeast	43,800
Other Yeast Products:	
For food purpose	8,838
For feed use	16,281
Total	68,999

TABLE LI: WORLD YEAST PRODUCTION[111,127]

(Dry Tons)

	Bakers Yeast	Dried Yeast
Europe	67,600	125,500
North America	61,000	37,500
The Orient	12,900	21,300
South America	6,300	1,200
Africa	2,350	2,200
World Total	150,150	187,700

TABLE LII: CARBOHYDRATE MATERIALS USED FOR YEAST FERMENTATIONS[111,128,129]

(United States 1965)

			Utilization	
	Unit	Supply	Fermentation	Yeast
Molasses	million gal.	613	67(11%)	50(8.2%)
Sulfite Liquor	million gal.	12,000	298(2.5%)	75(0.6%)
Whey	million gal.	3,530	10(0.3%)	5(0.4%)
Fruit Products	1000 tons	4,624	2,454(53%)	Nil
Grains	1000 tons	154,700	3,569(2.3%)	--

Food Yeasts:

The largest segment of the domestic yeast industry, molasses grown yeast, is expected to maintain its present annual growth rate of 2 per cent[111] which is consistent with population growth. Some increases might accrue from heavier usage of leavening yeast in modern continuous dough making systems in the baking industry.

New large scale uses of yeast for human consumption in the United States are not apparent at this time. American yeast production might find increased outlets in the export field where new high protein foods such as Incaparina, containing 3 per cent torula yeast, are being used in increasing volume (see Table LIII). Local production of yeast for this purpose and direct supplementation of the foods by the required amino acid components will be strong competitors for this market.

TABLE LIII: PRODUCTION OF INCAPARINA IN LATIN AMERICA[103]

(Pounds)

Year	Trimester First	Second	Third	Fourth	Total
1961	--	44,250	100,755	100,731	245,736
1962	68,772	9,568	128,515	--[a]	206,805
1963	63,134	154,464	106,977	163,995	488,570
1964	475,055	237,411	722,844	728,034	2163,344
1965	720,458	832,648			

[a]Not produced because of low availability of cottonseed flour.

Animal Feeds:

The value of high protein feed is illustrated by W.E. Huge in his article in Soybean Horizons Unlimited.[130] Comparing output/feed conditions over a thirty year span, Mr. Huge recorded the following data:

	1930	1959
pounds feed/pound poultry	5	2.5
pounds feed/pound turkey	6.5	3.6
pounds feed/dozen eggs	7.3	4.0
eggs/hen/year	123	195

Recent data lowers the feed-poultry figure to less than two pounds of feed per pound of poultry.[98]

The increase in livestock feed concentrate use is projected to rise faster than livestock production which will be favored to grow faster than population due to increased per capita consumption. High protein feedstuffs is estimated to increase faster than that of other concentrates.[131] Figure 19 shows average feed grain and feed concentrates fed during 1948-1950 and 1958-1960 with predicted consumption for 1980. The 1958-1960 figures when compared with 1980 figures show an annual consumption increase in feed concentrates of 86 million tons with an annual growth rate in consumption of about 2.3 perccent . Since high protein feedstuffs utilization is predicted to increase at a greater rate than concentrates in general the 2.3 per cent per year increase should represent a conservative figure for high protein feed needs. Figure 20 summarizes this requirement based on current high protein feed availability of 18 million tons.[132] The separate curve showing soybean meal and animal meal components are based on current values and the 2.3 per cent progression. Yeast substitution levels as shown are based on 100 per cent substitution for soybean meal, values adjusted for protein content, and 50 per cent substitution for animal protein values. Soybean meal was calculated at 44 per cent protein, animal meal at 50 per cent and yeast at 50 per cent. The choice of 100 per cent substitution for soybean meal and 50 per cent replacement of aminal meal by yeast is based on animal feeding studies reported in the literature.[89,122]

Price fluctuations, converted to price per pound of protein, for soybean meal, animal and fish meal are shown in Figure 21. Data on feed price and consumption is available from the U.S. Department of Agriculture's Economic Research Service.[132,133,134,135]

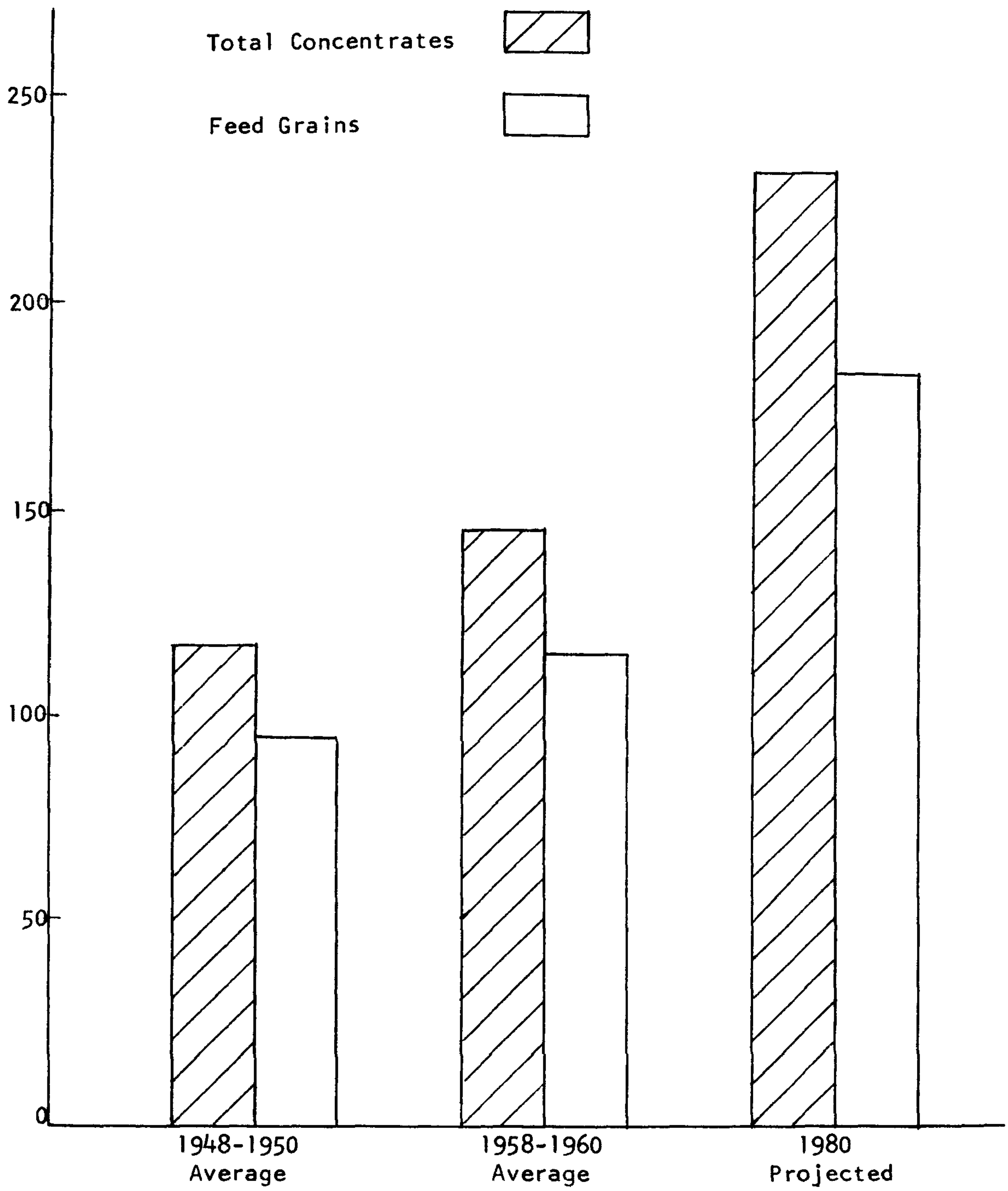

FIGURE 19: TOTAL CONCENTRATES AND FEED GRAINS FED[131]

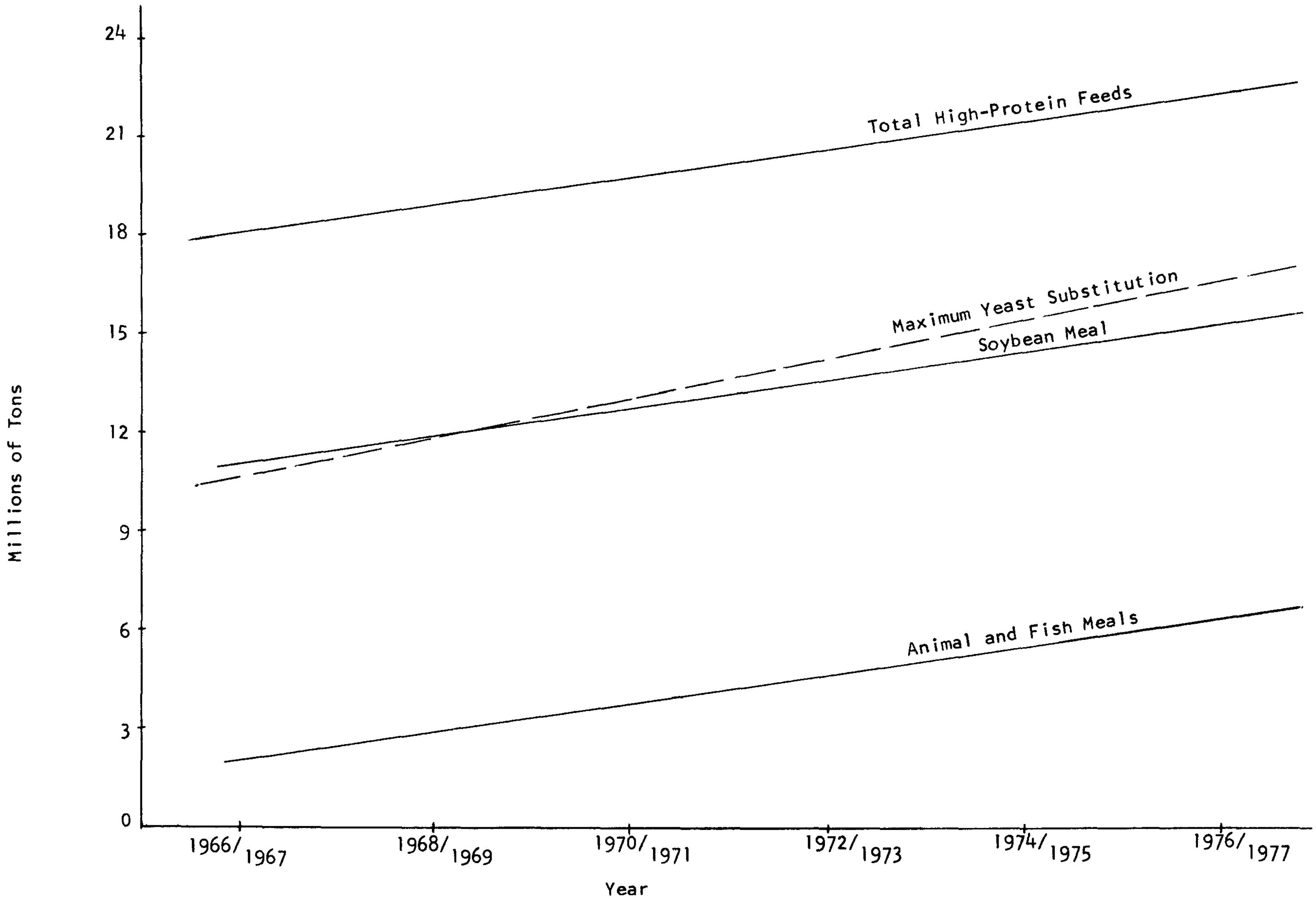

FIGURE 20: PROJECTED CONSUMPTION OF HIGH PROTEIN ANIMAL FEEDS[132]

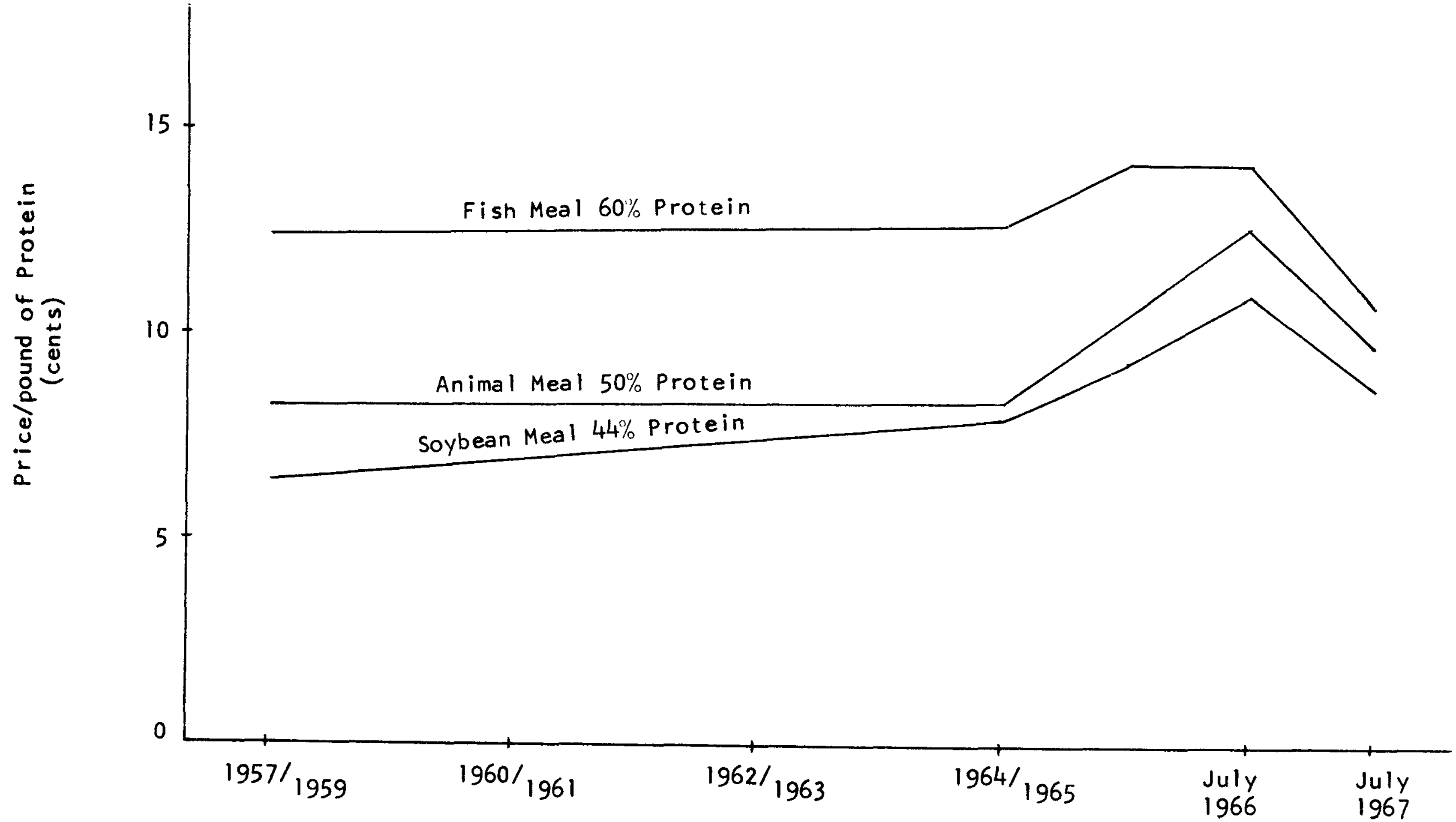

FIGURE 21: TEN YEAR PRICE TREND AND RECENT VARIATION[134]

Any new feed components will have to compete favorably with the present market to be considered as a feed protein source. A case in point is the evolution and growth of urea feeding to ruminants. The utilization of non protein nitrogen by ruminants allows the formulation of corn-urea, sorghum grain-area mixtures that represent a significant price advantage for these feeds. Recent prices show $25 to $30 per ton price reductions for the urea based feeds over soybean or cottonseed meal feeds.[132] Competition for the poultry, turkey and hog feeding market which cannot utilize urea feeds will probably result in increased downward pressure on the price of the traditional high protein sources. Oilseed protein is a by product of the vegetable fat and oil market and is thereby largely controlled by the demands for these commodities.

Requirements for vitamin supplements to feeds represents a smaller but significant market. B vitamins and D vitamin supplements can be obtained from dried yeast and irradiated yeast respectively. The total market for this application is perhaps ten per cent of the high protein feed market. [122] Competition from other yeast sources such as brewer's yeast is to be expected. The magnitude of the market is price oriented with the ten percent figure cited above as being the maximum value predictated on maximum beneficial additions of vitamin supplements to livestock rations. The relatively high current cost of yeast makes it desirable to attempt to satisfy the animal's vitamin requirements through careful selection of feedstuffs which make up the ration and to use yeast only when the nutrient requirements cannot be satisfied by other feeds.[136]

The livestock feed market is perhaps the best potential domestic application for the large volumes of yeast that can be produced on the cellulose wastes available. Entries in this field to date have been limited to special situations such as the use of torula yeast additives with dried citrus wastes for feeds in Florida.[137] The principal current U.S. outlet for torula yeast is as a poultry feed supplement.[86]

Price Considerations:

Current prices and ranges based on quantity discounts and location are recorded in Table LIV for various protein sources. Current sales prices for Torula yeasts produced on sulfite waste liquor at 27-29 cents per pound of protein equivalent is considerably above that of competing protein sources such as soybean meal at 8-14.8 cents, animal meal at 8-12 cents and fish meal at 11 to 14 cents per pound of protein for the livestock feed market.

For yeast to compete significantly in the feed market an operating cost in the range of 10 to 12 cents per pound of protein product appears desirable.

TABLE LIV: ALTERNATE PROTEIN SUPPLY SOURCES

Material	Price/Pound (cents)	Price/Pound Protein (cents)
Soy Meal and Flour[111,134]	3.5-6.5	8-14.8
Soy Protein Conc.[138]	21.5	26.5-35
Soy Protein Isolate[138]	-	36.3-39.3
Fish Meal (feed grade)[134]	6.3-8.5	10.5-14.2
Fish Protein Conc.[138]	10-16	13-20
Cottonseed Flour[138]	11	20
Wheat (Kansas City)[138]	220/bu.	30
Wheat Flour[111]	6.6	60
Dry Skim Milk[138]	14.4-21.0	40-60
Animal Meal (feed grade)[134]	4.1-6.3	8.2-12.6
Chicken (dressed)[138]	30	150
Beef (retail)[138]	80	444
Yeast - Torula (Sulfite waste)[111,139,140,141]	15-16	27-29
S. Fragilis (Whey waste)	19-25	35-46
Brewers Yeast	12-15	26.6-33.3
Brewers Yeast Debittered	23-38	46-76
Bakers Yeast	21-42	42-84

Product Volume Considerations:

At a refuse production rate of 4.5 pounds per capita per day consisting of 46.6 percent cellulosic base organic matter a city of 200,000 population would have an input to a hydrolysis plant on a 100 percent recovery basis of $(4.5 \times 0.466 \times 200{,}000)/2000 = 210$ tons/day

Fermentable sugars from this plant would be 82 tons per day based on a three stage hydrolysis plant resulting in a yeast production of 41 tons per day and an equivalent protein production of 20.5 tons per day. Yearly production rates based on a 300 operating day year would be 6,150 tons of yeast protein for a city of 200,000 population. Considering the current U.S. population at 200 million people a maximum, albeit unrealistic, production of 6,150,000 tons of yeast protein per year can be realized from municipal refuse sources in the United States alone. To convert back, this represents 12.3 million tons of yeast.

Since the type yeast produced on waste will be the torula strain due to the need for converting pentose as well as hexose sugars, it will not be applicable to the major food uses in the U.S. where the Saccharomyces cerevisiae is normally employed. The export food market for such final products as Incaparina may utilize some of the volume available. Present needs for the Incap program are a requirement of approximately forty-five tons of Torula yeast per year based on a 3 percent addition to the last four quarters production noted in Table LIII. This yearly yeast requirement could be met by converting the refuse from one city of 200,000 people in little more than one day.

It is apparent that the livestock feed market is the only current volume outlet for the large tonnages of product available from this process. Annual maximum consumption of yeast protein supplements in animal feeds is estimated in excess of 12 million tons at present livestock production rates, Figure 20.

C. Economics of Yeast from Wastes

Data has been developed in earlier sections of this report on the various costs of raw materials, plant and operating costs for hydrolysis, and the plant and operating costs for fermentation of the sugars produced.

The data as summarized here is based on multiple choices of the raw material source and a 500 ton per day feed rate to the hydrolysis plant. The size community needed to support this facility on the basis of raw material requirements is about one half million people for urban organic refuse, a city the size of Philadelphia for 20 percent additional recovery of paper wastes, or the combined output of two high efficiency cane mills for a bagasse feed. Current molasses costs[134] are included as a comparison factor for hydrolyzate sugars.

TABLE LV: COST SUMMARY ON SUGAR FROM ORGANIC WASTE HYDROLYSIS
(Basis: Cost of raw sugar)

Sugar Source	Cost/pound (cents)	Cost/pound of sugar** (cents)
Molasses (1966-1967 range)[134]	1.2-1.6	2.4-3.2
Bagasse	0.25-0.75	3.03-4.32
Wastepaper, No.1 mixed	0.20-0.60	2.91-3.93
Mixed Urban Refuse	0.125-0.225*	2.08-2.34
Organic Urban Refuse	0.125-0.225*	1.81-2.07

*Credits based on municipal dumping fees.

**Costs other than molasses based on a 500 ton per day 3 stage, continuous hydrolysis plant. Table XXVII.

The production costs for sugar from organic waste materials appears reasonably competitive with the main market source of fermentable sugar, molasses. The most recent molasses prices are the high end of the range noted above. However, molasses is expected to compete favorably with any of the prices developed for alternate market sources for sugar due to the fact that it is a liability waste commodity for the sugar industry. Alternate uses and disposal costs are the key elements in the molasses market.

The low bagasse sugar costs should be considered as significant when evaluating this material, as the additional costs represented by the higher range are for loading and shipping purposes. It would appear that the hydrolysis operation at a sugar central is the only desirable route to take when considering bagasse as the raw material. The supply of bagasse is such that no upward price fluctuations are envisioned.

Wastepaper as a raw waste source appears, from the numbers presented, to be more competitive than is actually the case. It would be unrealistic to assume that any steady supply of wastepaper would be available at the low end of the range indicated. Although the prices cited represent a ten year price range for this commodity, the entry of a big consumer into the market, such as a wastepaper hydrolysis plant, would tend to keep the prices at the high end of this range, and perhaps, depending on demand, exceed these figures entirely. Since the raw material represents approximately 41 percent of the product cost for a 500 ton per day plant the effect of the market cannot be minimized. As noted in Table VII, of this report prices for No. 1 mixed paper ranged to 35 dollars per ton in 1951 this would result in a hydrolyzate sugar cost of 6.88 cents per pound. It would appear that the market risks for wastepaper as a sole raw material source are too great for serious consideration.

The utilization of urban refuse is in general the most attractive waste commodity evaluated in this study. The cost factors or credits, however, are subject to much local influence. The choice of hydrolysis-fermentation as contrasted to sanitary landfill or incineration as a refuse disposal means must be evaluated on a local basis. The existence of local markets for secondary materials such as metals and paper, or for garbage for hog feeding will influence decisions. But again, these are specific decisions for individual municipalities. On a general basis, the cost range of 1.81 to 2.34 cents per pound of hydrolyzate sugar appears to be competitive with its market alternate for yeast production, molasses. These costs have been developed on the best information available today and include factors of municipal dumping fees, segregated refuse and sorting operations for non-segregated refuse.

The conversion of the hydrolyzate sugar to yeast and its economic position as a potential animal feed source is summarized below. Costs of significant livestock feed protein is included for ease of comparison as is the sales price of Torula yeast from sulfite waste liquor.

TABLE LVI: SUMMARY-YEAST COSTS VS ALTERNATE ANIMAL FEEDS

Protein Source	Percent Protein	Cost/pound (cents)	Cost/pound protein
Soy bean meal[134]	44	3.5-6.5	8.0-14.8
Animal meal[134,138]	50	4.1-6.3	8.2-12.6
Fish meal[134]	60	6.3-8.5	10.5-14.2
Torula yeast (Candida utilis)	55		
Sulfite Waste Liquor[111]		15-16	27-29
Bagasse		10-14.3	18.2-26
Wastepaper		9.8-13.6	17.8-24.7
Mixed Urban Refuse		8.1-10.4	14.7-18.9
Organic Urban Refuse		7.6-9.8	13.8-17.8

The protein cost figures from the various sources of hydrolyzate sugars are based on the sugar price ranges summarized in Table LV, a 50 percent utilization factor in the conversion to yeast and the maximum and minimum fermentation costs developed in the two cases in the Fermentation Process section of this report. The cost ranges then represent the total spread of values for the conditions considered.

It can be seen from Table LVI that the low range of the hydrolysis-fermentation system protein cost is comparable to the high range of the traditional animal feed protein price used in the U.S. today. Since conservative estimates were used in developing the hydrolysis-fermentation costs, it may be presumed that these numbers may be improved upon in actual practice.

It must be recognized that this cost situation results from a set of unique circumstances. They are: 1) The availability of segregated urban wastes, 2) the willingness of the municipality to pay a "dumping fee" to the hydrolysis plant for waste disposal and 3) the availability of a large body of cooling water for the fermentation plant. Alternates such as mixed urban refuse with a satisfactory secondary material market may be substituted as can other local situations which influence the cost picture.

The availability of a local feed market will enter into the total evaluation as it did in Florida[137] where Torula yeast was locally produced and mixed with citrus wastes as a feedstuff.

At the above calculated prices it is expected that yeast can capture a more significant segment of the animal feed market than it currently enjoys. However, significant improvements in cost must be achieved before yeast can become a major factor in the animal feed field.

Cost levels developed above should result in a better market penetration in the human food and vitamin supplement field of animal feeds. Although this market is significantly smaller, and more complex, it presents an alternative initial marketing route for these lower cost yeast products.

It must be remembered that the above comparisons have been made on a double standard. That is, manufacturing costs for the hydrolysis-fermentation yeasts compared with market price for the other protein sources. The application of proper levels of return on investment and sales costs must be included in the final analysis. They are not included here because of the wide variety of circumstances that can be applied to alter the acceptable returns to industries or municipalities. Then too, the total economic picture cannot be presented without a definition of the valuable by-products that can be obtained from the proposed processes. This detailed economic evaluation must, of necessity, be based on laboratory studies of the processes involved.

D. A Brief Look into the Future

The concept that current situations will remain constant at elevated levels of production activity due to population growth presupposes unlimited land resources for producing the foods using todays technology. European nations are currently producing more than three times North America's output of dried yeast (Table L1) most of which is going to produce animal feeds. Russia is planning to increase its yeast production to 900,000 tons per year by 1970[74] and significant developments in Czechoslovakia[74] and France[80] growing protein on petroleum substrates for the purpose of increasing livestock feeds and to a lesser degree as food for direct human consumption are reported. This appears to be a direct consequence of the inability of these nations at their current level of population density to produce enough traditional crops for animal feeding in a more economic manner.

If we assume that man will continue to value animal protein as a prestigious diet and further concede that the current experience in Europe must eventually become universal, we are obligated to devise systems that will produce animal protein and animal feeds that do not rely on traditional farming concepts. If we add to these concessions the premise that efficient utilization and disposal of wastes must be devised and put into effect, total system designs such as the "City Farm Concept" discussed in the Appendix must evolve.

Alternate concepts of "food factories" based on the development and acceptance of non-agricultural manufactured foods and food concentrates are already being seriously proposed in Eastern Europe.[108]

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APPENDIX

The City Farm Concept

THE "CITY FARM CONCEPT" proposes the establishment of urban growing centers for animal protein, utilizing to the fullest extent possible animal feeds generated from urban refuse sources at their central collection point and recycling solid wastes and liquid streams from the growing area for their unused and available food and chemical values within the various operations of the integrated plant. Animal protein products, meat, milk and eggs, will be returned locally to the community and residual wastes from the total complex will be treated by a central waste treatment plant resulting in a gross reduction and controlled release of pollutants to the surrounding environment.

Basis for the Concept:

Walter Mercer stated[24]: "Farms of the future will tend toward large, well-managed, and mechanized business paralleling the trends already evident in other industries. Surrounding the land, designated by law for agricultural use, will be highly urbanized areas beginning abruptly where the farm land ends."

Dr. P.H. McGauhey observed[143]: "The rapid spread-out of cities, popularly known as "urban sprawl", which followed World War II is widely recognized as having revolutionized our concepts of urban life. ...

It has become evident in recent years that solid wastes management has taken on a community-wide dimension involving all sectors -- urban, suburban, and rural -- of the modern community."

John Wiley adds[144]: "Our urban and suburban population growth has not only resulted in greater use and increased values of land but has greatly increased the quantities of solid wastes to be disposed of. While more people require greater food and industrial production, they also crowd out the farmer and agricultural industry either by demanding lands for their own needs or by less direct means, such as annexing, zoning, or claiming nuisance or health hazards."

Dr. E. Paul Taiganides concludes[23]: "The trend in livestock production is to automation. This is particularly exemplified by the recent history of confinement rearing of poultry and swine. During the last few years, many of the problems associated with livestock and poultry production within a confined area have been satisfactorily solved. Consequently, many farmers are changing from pasture to pen confinement. In this manner, the full advantages of central feeding, push-button operation and small land area use per animal can be better utilized.

The trend to confinement production is firmly established. In the poultry industry, units housing over one hundred thousand birds have been in operation for quite some time now. Those who are close to the swine industry indicate that, in the near future, by far the majority of hogs will be raised in confinement units, each capable of marketing from 3,000 to 10,000 hogs per year. For example, in Red Oak, Iowa, pilot units designed to market 10,000 hogs per year are now marketing 15,000 and a 10-year expansion to 100,000 hogs per year is anticipated. The number of dairy and beef cattle per farm is increasing with correspondingly less area per animal."

Utilization and Disposal:

One method of utilizing urban organic refuse is the subject of this report and will be used as the example process here.

Disposal of waterborne wastes and the amelioration of the carrier waters is a steadily advancing science. Municipal systems discharging high quality effluents suitable for reuse are a technological reality. The application of these treatment systems to animal manures and in plant reuse is feasible.

The nature of wastes resulting from livestock production has been summarized by Taiganides.[23] Waste loads from chicken, swine and cattle manure alone are equivalent to 10 times that of the human population in the United States. Dead animals and birds, (mortality rate in hen production is 1 percent per month) plus viscera, feathers, blood etc. from meat processing operations add to the overall wastes load to be considered. The designer of systems handling these wastes must consider the odor nuisance, fly breeding problems and the multitude of health hazards associated with the wastes being treated.

The physical and chemical properties of animal wastes are affected by the particular characteristics of the animal, the feed ration and the environment. The quality of the feed influences the quantity of manure produced, conversion efficiency of feed to animal protein and the chemical composition of the manure. Taiganides states [23, 145]: "that most of the feed ingredients of the animals will be excreted in the feces and urine. The amount of each feed constituent found in manure depends on the size and kind of animal, its condition (laying hen vs broilers, or milking cow vs a steer), the environmental temperature and the feed conversion and water consumption of the animal. On the basis of these parameters, the quantity and composition of manure can be estimated theoretically." It is interesting to note that chemical components, although utilized metabolically, are almost all recovered in the animal excreta. Unused protein in the feces and protein in wasted feed due to spillage are also present to a significant degree in the waste load.

Studies using litter[146] and manure [147, 148] as components in animal feeds or nutrients for fish ponds show interesting possibilities. These studies on animal waste utilization were presented at the 1966 National Symposium on Animal Waste Management at Michigan State University.

Present disposal techniques for animal manures are becoming undesireable. Farmers no longer use this material as a fertilizer as a matter of course since the advent of the cheap chemical fertilizers. The fly and odor problems associated with collecting this material along with the ever increasing encroachment of suburban areas and the resulting complaints leaves manure management as the number one headache for livestock producers.

The system proposed here can be designed to deal effectively with two major problems of our society: (1) organic solid wastes generated by urban populations and (2) manure wastes generated in livestock operations.

System Components and Considerations:

Figure A-1 is a "black box" representation of a typical "city farm" system. No attempt has been made here to quantify any of the inputs to or effluents from the various components of the system. This represents a totally new technical and economic study and is beyond the scope of this report.

Comments on each component and operation are offered for clarity and are not meant to be limiting on the system. Persons skilled in the individual technologies involved would, no doubt, have more specific and worthwhile comments to add.

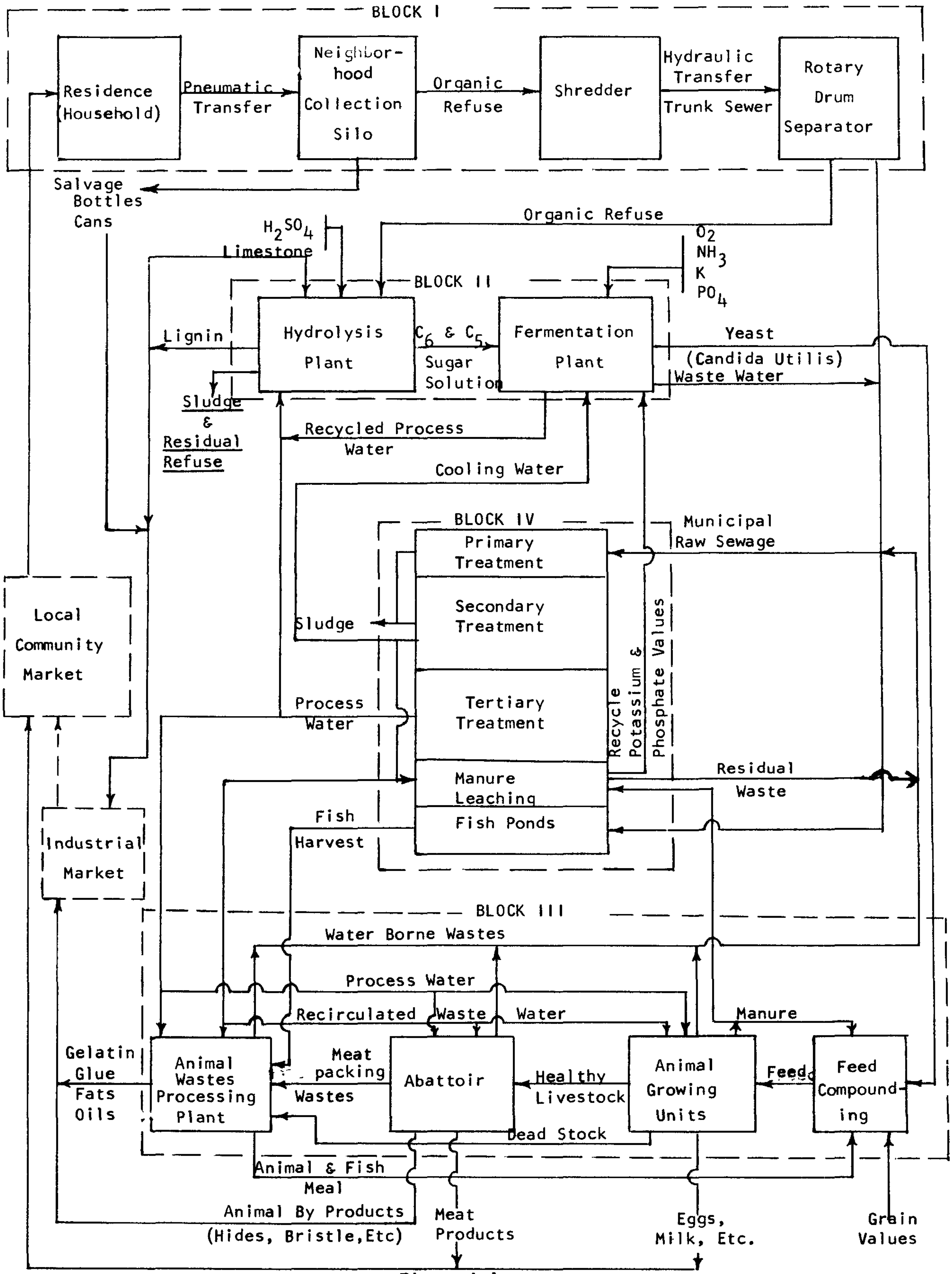
BLOCK I
Residence (Household)
Pneumatic Transfer
Neighbor-hood Collection Silo
Organic Refuse
Shredder
Hydraulic Transfer
Trunk Sewer
Rotary Drum Separator
Salvage
Bottles
Cans
Organic Refuse
H_2SO_4
Limestone
O_2
NH_3
K
PO_4
BLOCK II
Lignin
Hydrolysis Plant
C_6 & C_5
Sugar Solution
Fermentation Plant
Yeast
(Candida Utilis)
Waste Water
Sludge & Residual Refuse
Recycled Process Water
Cooling Water
BLOCK IV
Municipal Raw Sewage
Primary Treatment
Secondary Treatment
Sludge
Tertiary Treatment
Recycle Potassium & Phosphate Values
Process Water
Manure Leaching
Residual Waste
Fish Ponds
Fish Harvest
Local Community Market
Industrial Market
BLOCK III
Water Borne Wastes
Process Water
Recirculated Waste Water
Manure
Gelatin
Glue
Fats
Oils
Animal Wastes Processing Plant
Meat packing Wastes
Abattoir
Healthy Livestock
Animal Growing Units
Feed
Feed Compound-ing
Dead Stock
Animal & Fish Meal
Animal By Products (Hides, Bristle, Etc)
Meat Products
Eggs, Milk, Etc.
Grain Values

Figure A-1

Block 1

Operations in block 1 are essentially related with refuse collection and transfer to the utilization plant site.

Inputs include all types of solid domestic and light commercial (restaurants, offices, etc.) nonmanufacturing wastes. Typical wastes include bottles, cans, garbage, paper and plastics refuse. Leaf and garden wastes are discretionary commodities and may or may not be included in design consideration. Bulky wastes such as automobiles, tree branches, etc would not be included in this group.

Outputs include segregated organic rubbish including plastic wrapping materials and aluminum foil, salvage materials such as cans and bottles and an increased load of dissolved and suspended solids resulting in considerably higher BOD loadings in the liquid feed to the sewage treatment facility.

Operations:

1. Placement of rubbish in residential collection chute
2. Pneumatic transfer to neighborhood collection site
3. Sorting of waste into salvage and organic refuse components
4. Disposal of salvageable components to secondary materials users. By surface transport
5. Shredding of organic refuse to trunk sewer transfer
6. Hydraulic transfer to sewage treatment plant - rubbish utilization plant location
7. Removal of organic refuse from transfer stream by rotating drum separator
8. Conveyor transfer of refuse to Block 11 operations

Comments:

Costs for waste water treatment and refuse disposal were summarized by McKee.[11] The magnitude of the annual per capita costs in each case is similar. However, the cost distribution is markedly different. In the case of wastewater treatment approximately seventy one percent of the cost is amortization of plant and equipment. Refuse disposal shows eighty five percent of the costs as operating expenses, largely collection costs. With this cost distribution, and wastewater treatment facilities a must, economies in refuse collection should be possible in a combined system. Although municipal financing problems would increase, the convenience of a pneumatic local collection system with a reduction in fly and odor breeding problems may show substantial support and approval on the part of the populace served.

The pneumatic rubbish transfer system has been tested successfully in Sweden.[14] Sorting of waste for salvage values may, with favorable markets, be self sustaining. Transfer of organic refuse shredded to the sewer has been successfully demonstrated in California.[13] Particle sizes for this test were in the three to four inch dimensional range. Successful continuous rotary drum separators have been developed and can be applied here.[149]

No untried technologies are proposed. The application considerations to this point are largely economic.

Block 11

Operations in block 11 are concerned with the conversion of organic rubbish in a two stage process to edible protein in the form of yeast. The basic technologies of the two processes, hydrolysis and fermentation, are discussed in the body of this report.

Inputs to the system include:

For hydrolysis; cellulosic raw material in the form of organic refuse, heat and electrical energy, sulfuric acid, limestone, and process water.

For fermentation; fermentable sugars from hydrolysis process, nutrient sources including ammonia, potassium, and phosphorous compounds, oxygen source, electrical energy, cooling media, and process water.

Outputs of the system include:

For hydrolysis; hexose and pentose sugars in solution, lignin, calcium sulfate, waste steam, organic by products such as furfural, methyl furfural, etc., and residual sludges.

For fermentation; Candida utilis yeast, residual sugars and nutrients in waste water stream for use in the hydrolysis plant.

Operations:

1. Reduction of organic refuse to fiber state in hydrapulpers[116]
2. Continuous hydrolysis in screw press reactors[116]
3. Neutralization of sugar solution
4. Removal of calcium sulfate sludge from sugar solution
5. Fermentation of sugars
6. Concentration of yeast cells
7. Drying and packaging of yeast
8. Shipment to feed compounding

Comments:

The economic feasibility study of this waste utilization approach indicates a possible value even under conditions of todays market when utilizing mixed organic wastes on a dumping fee or assessment basis. Research on process and equipment development is required and will probably show areas for reducing costs as presently estimated.

Block III

Operations in block III are entirely associated with animal production and by-product industries. Innovations and conveniences in feeding, hygiene and handling are points of major consideration.

Inputs

Feed compounding; yeast protein and vitamins from fermentation plant, animal and fish meal protein from animal waste processing plant, recycled manure from growing area, grain components, lignin from hydrolysis plant, grain additives for other growth factor considerations.[89,98,122,133,147,148]

Animal growing units; compounded feeds, water, litter, and environmental controls.

Abattoir; livestock, poultry, water, chilling or freezing media and packaging materials.

Animal wastes Processing Plant; bones, eviscera, blood and feathers from abattoir, dead animals from growing units, process water, and fish from waste treatment plant.

Outputs:

Feed compounding; controlled special purpose feeds for various animal growing and manure waste control functions.[23]

Animal growing units; eggs, milk, healthy stock to abattoir, dead stock to animal waste processing plant, manure, and waste water.

Abattoir; meat and poultry, hides, bristle, etc., processing wastes to animal waste processing plant, waste water.

Animal wastes processing plant; animal and fish meal to feed compounding, gelatin, glue, animal fats and oils, etc., waste water.

Operations:

1. Dry milling and blending of feeds
2. Various breeding, hatching and growing stages providing optimum environmental and hygienic conditions
3. Preparation and marketing of eggs, milk, etc.[150]
4. Slaughter house [151]
5. Meatpacking and marketing[152]
6. By product preparation and marketing
7. Animal and fish meal production

8. Glue and gelatin manufacture and marketing
9. Animal fat and oil manufacture and marketing

Comments:

The operations inputs, and outputs noted above are over simplified examples of possibilities in block III activities. Raw materials for feed that include items such as manure require considerable genetic research. The selection of animals for the growing units will probably tend more to poultry and swine rather than ruminants due to space and feed considerations. The animal waste processing operations are discretionary, controlled by local economics and markets. In some cases end products may be produced, whereas, in other instances chemical intermediates may be the more desireable products.

The design and operation of an environmentally controlled, nutritionally controlled flock or litter with predicted yields and waste effluents represents a significant challenge to the animal protein industry and one that would hopefully yield satisfying technical and economic results.

Block IV

Operations in block IV are the final and perhaps most important overall steps in the system. This is true at least from the consideration of maintaining and improving the terrestrial, atmospheric and aquatic environments in which we live. Treatment of the residual solid wastes produced in the "City Farm" complex plus the amelioration of the various liquid streams emanating from the processing plants and the community require advanced design and planning if the waters are to be made available for in plant reuse and acceptable for dumping into recreational waters.

Inputs:

Community sewage, hydrolysis plant water, fermentation plant effluent, animal and poultry manure, abattoir wastes, animal waste processing plant wastes, electrical energy, oxygen.

Outputs:

Dried sludge, methane, carbon dioxide, ammonia, phosphate and potassium values, partially purified water suitable for cooling operations or recycling as waste carriers, purified water for process waters or animal drinking water, scavenger fish.

Operations:

1. Settling
2. Sludge digestion
3. Activated sludge plant
4. Trickling filters
5. Clarifiers
6. Tertiary treatment of effluents for process reuse
7. Chlorination
8. Wet Oxidation (Zimmerman process for sludge oxidation)
9. Sludge drying
10. Sludge disposal
11. Fish growing units for sewage consumption

Comments:

The operations noted above are discretionary and utilization of one process in favor of another is a technical-economic optimization problem.

The utilization of sewage for fish production requires the maintenance of a fixed minimum level of dissolved oxygen in the growing pond.[114] Perhaps fish growth can be accomplished in activated sludge units. Oxygen levels may be maintained by current methods of pumping air through spargers or perhaps by other techniques such as direct feeding with liquid oxygen, electrolysis, or membrane transfer techniques. In any event this final utilization of the wastes available to produce a useful commodity is the type of approach that must be present in planning waste utilization systems of the future.

General Comments:

Considering the most efficient animal protein producer, the hen (See Figure 18), as a basis for discussion the following general observations can be made:

1. The amount of feed protein required to produce the U.S. per capita animal protein availability of 65 grams per day (Table XXXVIII) is 273 grams.
2. The equivalent amount of feed yeast (50 percent protein) required to provide this protein requirement is 546 grams.
3. The per capita yeast production available from waste loads of 4.5

pounds per capita per day consisting of 46.6 percent cellulosic base organic matter is 186 grams via acid hydrolysis-fermentation processing.

4. The maximum feed protein fraction available from yeast is therefore 34 percent.
5. Poultry feeding studies summarized by Bressani[89] indicated that 100 percent of the protein requirement can be supplied from yeast without harmful effects.
6. The total quantity of yeast protein produced in a "City Farm" operation is technically consumable by the animal population.

When considering other poultry or animal species the 34 percent feed protein fraction supplied by yeast shrinks to the following values:

Broilers	-	25.8%
Hogs	-	17.9%
Beef Cattle	-	7.15%

It is important to note that additional high grade protein meal is available within the "City Farm" complex from animal wastes and possibly fish.

Advantages of the "City Farm" System

1. A current liability, organic refuse, is used to produce a useful and desireable end product, animal protein.
   a) Eliminates associated land and air pollution problems, fly and vermin breeding sites and the attendant reductions in property values presently experienced with "dump" disposal systems.
   b) By employing advanced collection techniques rapid disposal of putrescible materials should enhance health, reduce fly breeding sites, provide increased convenience to the populace and reduce costs associated with solid waste collection.

2. Contiguous operations for feed blending, animal growing, meat preparation and waste utilization reduce shipping problems, maximize material and technical personnel utilization and provides local total process control.

a) The market for consumer products produced is the surrounding city. Refrigerated shipments and attendant spoilage should be largely eliminated.

3. Association of the animal growing units, meat processing and chemical plant operations with the municipal sewage treatment plant provides technical competence in waste disposal and maximizes reuse of the treated water.
   a) Environmental pollution is minimized and controlled.
   b) Water of "engineered purity" can be delivered for various uses reducing overall treatment costs.

The Challenge

The "City Farm" concept is one approach to the tremendous problem facing this nation and eventually the world to make use of the ever increasing waste of resources. The eventual solutions to the problem of municipal waste utilization may attempt to solve other problems existing such as those of food production and animal waste handling approached here.

The challenge to science and engineering today is the economic utilization of our myriad wastes.

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