Cost Analyses for New Products and Processes Developed in USDA Laboratories [1]

V.E. SOHNS, Northern Regional Research Laboratory,[2] Peoria, Illinois 61604

Abstract

Cost analyses frequently help to implement the research and development program on new products and processes from farm crops. Having cost data available encourages early adoption and application by industry of products and processes that are developed. Furthermore, cost estimates provide information that can serve as a guideline for developing an effective plan of work for research projects. The procedures used to compile cost estimates at the Northern Regional Research Laboratory follow those generally recommended by most cost engineers with appropriate modifications to fit particular situations. Accuracy of an estimate depends upon the quantity and quality of the process data made available to the cost engineer. Both order of magnitude estimates prepared shortly after studies on a process are initiated on a laboratory scale and preliminary cost estimates prepared either from extensive laboratory studies or from process engineering studies in the pilot plant have found application in research investigations. A typical example of such appications is found in our program for evaluating the industrial potential of several nylons which can be produced from *Crambe abyssinica* oil.

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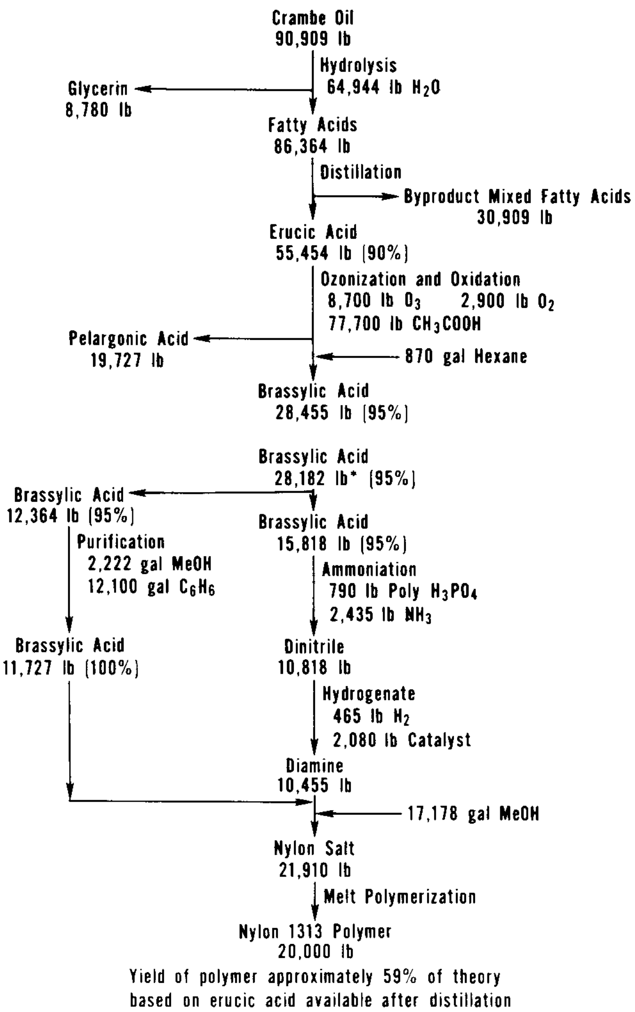
[2] No. Market. Nutr. Res. Div., ARS, USDA.



* Allows for loss of brassylic acid during purification
Figures in ( ) indicate purity

FIG. 1. Flowsheet for daily production of nylon 1313.

Introduction

Research and development programs on new products and processes from farm crops conducted in USDA Regional Research Laboratories generally include some type of cost estimate as an integral part of the investigations. Such estimates, similar to ones prepared by industrial firms, are intended to provide a realistic measure of the economic feasibility of the product or process. When a new product or process is developed in the laboratories, such a development is reported through various communication channels to promote its commercial adoption. Providing cost data along with other technical information encourages early adoption and application by industry of new products and processes from agricultural commodities, which is the goal of the Department of Agriculture's utilization research.

Cost analyses are prepared at various stages of developmental studies. In some instances, an order of magnitude or study estimate is made shortly after research and developmental work is initiated when only meager data are available. Such an estimate may determine the desirability of continuing work on the project. As developmental studies progress, additional appraisals are conducted to obtain more factual information on the economic feasibility of a particular process. Cost studies at this stage serve as a guide in the development of possible improvements and refinements in a process by showing economic advantages of alternative processing methods or by indicating where studies may be concentrated to develop a more practical approach. When pilot plant investigations or extensive laboratory studies have been completed, a preliminary cost estimate is prepared to obtain a more reliable indication of the economic feasibility of a process than is obtained from earlier estimates.

Preparation of an Estimate

The method of preparation of cost estimates as described in this paper has proven satisfactory at the Northern Regional Research Laboratory. Cost studies at this Laboratory are usually limited to order of magnitude or study estimates and preliminary estimates. Sufficient information is obtained from such estimates to fulfill the needs of the laboratory program and more detailed estimates are rarely required. If a company is seriously considering adoption of a process developed at our Laboratory, their overall economic evaluation of the project would probably require a detailed cost estimate. Such an estimate would include equipment specifications, complete drawings and perhaps site surveys.

Basically, the method of preparing a cost estimate in our Laboratory follows procedures generally accepted by cost engineers in industry and research institutions. It is the intent of the cost engineer to have an estimate provide sufficient data for a realistic appraisal of a process. Estimates must show the capital and production costs involved.

Estimating Fixed Capital Investment

Certain essential information must be determined prior

TABLE I
Estimate of Fixed Capital Investment

Items and factors	Expenditure
1. Total delivered equipment cost (tanks, pumps, reactors, etc.)	....
2. Installation of equipment (foundations, platforms)	30–40% of (1)
3. Piping, wiring, instruments	35–45% of (1) + (2)
4. Engineering and contractors' fees	20–25% of (1) + (2) + (3)
5. Contingencies	15–25% of (1) + (2) + (3)
6. Total erected equipment costs	Total (1) through (5)
7. Land and building costs	....
8. Estimated fixed capital investment	(6) + (7)

to the preparation of an estimate. Decisions must be made regarding projected plant capacity and daily production rates. There must be sufficient data from which to prepare a plant flowsheet. Such data should include raw materials required, yields of intermediate products, final products and byproducts. A complete description of operating procedures must be at the disposal of the cost engineer. Figure 1 is an example of a typical process flowsheet. Through the use of the data on the flowsheet and other process information, a cost engineer can proceed with the detailed calculations for the cost estimate.

A decision must also be made as to whether an estimate will be for a "battery limits" plant or for a "grass roots" plant. Bauman (1) defines a battery limits plant as a geographical designation referring to the coverage of a specific project as reflected in a construction contract. It refers to the processing area of a proposed project including all process equipment but excludes site preparation, most storage provisions, utilities, administrative buildup or auxiliary facilities in general, unless so specified. Such an installation may be considered as an extension of an existing plant. A grass roots plant is defined by Bauman as a complete plant erected on a virgin site (1). Investment for such an installation includes all costs of site preparation, battery limits facilities, utilities, administration buildup and auxiliary facilities. A grass roots estimate for some installations may be more than twice that of a battery limits installation. At the Northern Laboratory, almost without exception, battery limits estimates are prepared and only such estimates are discussed in this paper.

After having decided upon the type of cost estimate to be made, a detailed list of equipment needs is compiled from the plant flowsheet. The delivered cost of the individual equipment items is estimated and the total delivered equipment cost is determined. Costs of standard equipment units such as pumps, tanks, dryers and filters are readily available from numerous sources. If the cost of a specific piece of equipment is known, the cost of another unit of the same type but different size or capacity can be estimated by using the "six tenths factor" rule. This rule says that if the cost of a given unit is known, the cost of a similar unit of X times the size of the first is about $(X)^{0.6}$ times the cost of the original unit (2). It is not recommended that this rule be used beyond a 10-fold range of capacity. Some authorities suggest the use of a specific exponent for each type of equipment as a means of improving the accuracy of this rule.

If extremely accurate information is desired, price quotations can be solicited from equipment suppliers. This ordinarily is not necessary for preliminary estimates unless specially designed equipment is required.

The dimensions of a building to house a plant can be calculated by allocating appropriate space requirements for individual equipment and preparing a scaled equipment layout for the entire process. If the dimensions of the structure are known, the cost can be figured on the basis of cost per cubic foot of volume or square foot of floor area. It is possible to obtain a rapid but perhaps less accurate estimate of building cost by assuming that the cost of a building is a certain percentage of either the purchased or installed equipment cost.

Costs associated with installing equipment, such as foundations and platforms, and costs for piping, wiring and instruments, engineering and contractors' fees and contingency allowances are generally calculated by applying a series of factors to the total delivered equipment cost. The sum of these various costs plus the delivered equipment costs represents the erected equipment cost. The latter figure plus land and building costs gives the estimated fixed capital investment for the hypothetical plant. Table I shows the factors and steps used in calculating the fixed capital investment. Percentages used in developing the fixed capital investment may vary somewhat between estimates, depending upon the complexity of the processes and the materials of construction involved. A company-prepared estimate may establish these percentages from actual company experiences.

Published cost estimates should include a reference cost index. Such indices will date a cost study and allow adjustments to be made for the effect of inflation. Three indices that are commonly used are the Marshall and Stevens (M&S) Equipment Cost Index, the Engineering News-Record (ENR) Construction Cost Index and the Chemical Engineering (CE) Plant Cost Index. An estimate prepared in mid-1968 would carry an M&S Index of 275. Since the M&S Index for September 1970 is 307, the ratio of a September 1970 costs to mid-1968 costs is 307:275, or the equivalent of an increase in equipment costs of about 11% during the period.

Estimating Production Costs

When production costs are reported for a plant, it is essential to indicate the expense items which are included. If such information is reported, a fair comparison of total operating costs between estimates from several sources can be made. The selection of items contained in a tabulation of production costs is to some extent a matter of personal preference. Estimates at the Northern Laboratory generally include the following items: raw materials, utilities, labor and supervision, maintenance, fixed charges, miscellaneous factory supplies and expenses, charge on working capital and general plant overhead.

Production costs can be calculated as daily costs with these figures then being converted to a charge per unit of product. Daily requirements for each raw material used in a process are itemized and, from their respective unit prices, daily costs can be calculated. For such raw materials as solvents or catalysts which frequently are recycled to a process, the only charge to the product or process is for the quantities lost. If a raw material is obtained for a process from another division in the company, the unit cost for the material may be either its actual production cost or some value assigned for accounting purposes.

Requirements for utilities such as steam, water, electricity and natural gas must be calculated, for the individual operations in the process. The total requirements for each utility, when multiplied by the proper unit costs, will give the charge to the process for these items. The following unit costs are acceptable average figures but should be adjusted to fit a specific geographic area: steam, 80 cents/1000 lb; water, 15 cents/1000 gal; electricity, 1.5 cents/kw hr; natural gas, 50 cents/1000 ft^3.

After labor and supervisory needs are estimated for operating an installation, prevailing wage and salary rates are then applied to ascertain charges for labor and supervision. Payroll overhead which may represent as much as 25% to 30% of direct wages and salaries should be added. Such items as pensions, insurance, vacation pay and social security make up payroll overhead.

Maintenance costs per year for equipment are usually evaluated as a percentage of erected equipment cost. This percentage is usually 6% to 7%. For land and building, annual maintenance charges usually represent about 2% of their investment.

Fixed charges are those associated with depreciation,

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property taxes and insurance. For estimates of a preliminary nature, the straight line method of figuring depreciation is recommended. This method assumes that depreciation is the same for each year of useful life of the asset. Equipment ordinarily is depreciated over a 10-year period. This period may be changed, for instance, if a process involves highly corrosive conditions. Depreciation of buildings over a 20- or 25-year period is acceptable, but land ordinarily is not depreciated. A combined charge for taxes and insurance of 3% per year on fixed capital investment is a good average figure.

Miscellaneous factory supplies and expenses cover the costs for such materials as charts, lubricants and janitor supplies. Their cost can be estimated at 15–20% of maintenance costs.

Working capital consists of the money invested in raw materials and supplies that are kept in stock, finished goods inventory, accounts receivable and cash on hand to pay salaries, utilities, raw material purchases and similar expenses. Value of raw materials on hand may be as much as the delivered price of one month's supply. Finished goods ordinarily are considered not to exceed one month's production and are valued at their production cost; accounts receivable can be taken as production cost for one month of operation. Cash on hand should be ample to pay one month's salaries, utilities, etc. A charge on working capital of 6% to 8% a year is allowed. For many chemical plants, working capital is 10% to 20% of total capital investment.

General plant overhead costs involve those expenditures required for routine plant services. These expenditures comprise medical services, safety services, cafeteria facilities, plant protection and general engineering among others. Plant overhead costs are about 50% to 60% of the combined expense for maintenance and labor and supervision.

The sum of the individual cost items gives the "cost to make" for a product estimate or the total processing costs for a process estimate. If byproducts are recovered along with the main product, a net cost to make is obtained by adjusting the cost-to-make figure with a credit for the value of the byproducts. When there is an unpredictable market for specific byproducts or their total value from a process is high in relation to the value of the main product, credit given for these materials can introduce an uncertainty about the reliability of a cost estimate. A thorough survey of the byproduct situation is required, therefore, in the overall economic evaluation of a process.

Information on cost estimates which are released or published by the Northern Laboratory rarely will include data beyond the cost-to-make figure. If it is deemed advisable in our evaluation of a new product to have an approximate selling price, the necessary calculations to obtain this figure may be made; however, this information is intended for our own use only. Estimated product selling price can be readily ascertained from the cost-to-make figure by adding research costs and interest on investment, if either of these are applicable plus sales costs, administrative expenses and profits. However, if a cost-to-make figure is available, industry from knowledge gained within its own organization can easily develop a selling price probably more reliable and better suited to meet its own needs than a figure determined in a Department of Agriculture Laboratory.

The recent emphasis on industrial waste disposal and pollution control demands that these factors be considered in the overall evaluation of a new process. Although costs for byproduct recovery are a part of our cost estimates, charges for waste disposal and pollution control have not been included in the estimates. Expenses to cover the cost of these factors, however, may have a decided effect on the economic feasibility of a new process. Problems and costs involved with waste disposal and pollution control may be difficult to evaluate when a new process is being developed; nevertheless, these factors cannot be disregarded entirely.

TABLE II

Estimate of Fixed Capital Investment for a Plant Producing 6 Million Pounds of Nylon 1313 Annually From Crambe Oil (Basis: 300 Operating Days Per Year, 24 Hr Per Day)

Items and factors	Expenditure
Equipment delivered	
Continuous hydrolyzer unit, SS clad	$ 205,000
Glycerin concentrator	37,000
Fatty acid distillation system, SS	108,000
Reactor for ozonization, SS	18,000
Centrifuge, basket, for brassylic acid recovery	20,000
Kettle for pelargonic acid separation	27,000
Kettles, centrifuges and associated equipment for brassylic acid purification	154,000
Kettles for alcohol and benzene recovery	25,000
Ammoniation tower, stripper, pitch tower for nitrile production	111,000
Nitrile distillation unit	36,000
Reactor for hydrogenation in diamine production, SS	92,000
Ammonia compressor	15,000
Filter, plate and frame	5,000
Diamine distillation unit	37,000
Kettles for making nylon salt	9,000
Filter, plate and frame, for salt recovery	8,000
Dryer for nylon salt	30,000
Kettles for polymerization	13,000
Dowtherm units	61,000
Conveyors	23,000
Pumps for processing and transfer	33,000
Process and storage tanks	280,000
Total delivered equipment cost	1,347,000
Installation of equipment	538,000
Piping, wiring, instrumentation	750,000
Engineering and contractors' fees	520,000
Contingencies	405,000
Estimated erected equipment cost	3,560,000
Land and improvements	90,000
Building	350,000
Estimated fixed capital investment	$4,000,000

TABLE III

Production Costs for a Plant Producing 6 Million Pounds of Nylon 1313 Annually From Crambe Oil (Basis: 300 Operating Days Per Year, 24 Hr Per Day)

Item	Daily cost, dollars per day	Cents per pound of product
Raw materials		
Crambe oil, 90,909 lb/day, $0.15/lb	13,636.35	
Ozone, 8,700 lb/day, $0.12/lb	1,044.00	
Oxygen, 2,900 lb/day, $0.07/lb	203.00	
Ammonia, 9,300 lb/day, $0.0475/lb	441.75	
Hydrogen, 100,000 ft^3/day, $3.50/M ft^3	350.00	
Other chemicals (catalyst, alcohol, etc.)	615.20	
Total	16,290.30	81.5
Utilities		
Steam, 320,000 lb/day, $0.80/M lb	256.00	
Electricity, 5,000 kw hr/day, $0.015/kw hr	75.00	
Water, 1 million gal/day, $0.15/M gal	150.00	
Gas, 140,000 ft^3/day, $0.50/M ft^3	70.00	
Total	551.00	2.8
Labor and supervision		
27 Operators, $4.00/hr	864.00	
18 Helpers, $3.40/hr	489.60	
3 Laboratory technicians, $3.50/hr	84.00	
3 Foremen, $34.00/day	102.00	
1 Superintendent, $48.00/day	48.00	
Overhead	396.90	
Total	1,984.50	9.9
Maintenance		
Land and building, 2%/year on $440,000	29.33	
Equipment, 6%/year on $3,560,000	712.00	
Total	741.33	3.7
Fixed charges		
Depreciation		
Building, 5%/year on $350.000	58.33	
Equipment, 10%/year on $3,560,000	1,186.67	
Taxes and insurance, 3%/year on $4 million	400.00	
Total	1,645.00	8.2
Miscellaneous factory supplies and expenses	111.20	0.5
Charge on working capital, 7%/year on $800,000	186.67	0.9
General plant overhead	1,362.92	6.8
Estimated gross cost-to-make	22,872.92	114.3
Byproduct credit		
Crude glycerin, $0.16/lb, 0.44 lb/lb of nylon 1313 (7.0¢)		
Pelargonic acid, $0.20/lb, 0.99 lb/lb of nylon 1313 (19.8¢)		
Mixed fatty acid, $0.16/lb, 1.55 lb/lb of nylon 1313 (24.8¢)		
Total byproduct credit		51.6
Net cost to make, cents/lb of nylon 1313		62.7

Typical Cost Estimates on Nylons from Crambe Oil

As part of a program to evaluate the seed oil of *Crambe abyssinica* as an industrial raw material, the production of a variety of nylons from erucic acid obtained from this oil was investigated. Proposed processes for the production of nylons 13, 1313 and 613 from erucic acid have been developed through rather extensive laboratory scale studies by personnel at the Southern Research Institute, Birmingham, Alabama. These studies, which have been reported in detail previously (3,4), were performed under contract supported by the Northern Laboratory. Cost estimates prepared at this Laboratory for the various processes were then used in an economic evaluation of these nylons.

In these estimates, each hypothetical plant had a capacity for producing 6 million lb of molten polymer annually when operations were conducted 300 days per year, 24 hr per day. The product was prepared as a molten polymer ready for conversion to a fiber or other end use. Crambe oil available at an assumed price of 15 cents a pound to each plant had the following composition: erucic acid, 59%; oleic acid, 18%; linoleic acid, 10%; linolenic acid, 5%; other acids, 8%.

Equipment costs have been adjusted for a M&S Index of 307. Estimated fixed capital investments in all cases are *for battery limits installations only*. Utility costs were calculated with the rates suggested earlier in this paper. Wage rates paid to operators and helpers or semiskilled workers were $4.00 and $3.40 per hour, respectively. Annual maintenance costs for equipment were 6% of the erected equipment cost and for land and building, 2% of their cost. Depreciation allowances for equipment and building were 10% and 5% per year, respectively. Taxes and insurance amounted to 3% per year of the estimated fixed capital investment.

Production of nylon 1313 follows the procedure shown in Figure 1. It is prepared by melt polymerization of the salt of brassylic acid and 1,13-diaminotridecane. Brassylic acid is derived by the oxidative ozonolysis of erucic acid. Ammoniation of brassylic acid yields brassylic acid dinitrile which then is reduced to 1,13-diaminotridecane by catalytic hydrogenation. Predicted yield of product based on laboratory yield data is 22 lb/100 lb of crambe oil.

Estimated fixed capital investment for a plant producing nylon 1313 by the procedure described is about $4 million (Table II). Estimated net cost-to-make per pound of product is about 62 cents (Table III). Included in this figure is a byproduct credit of 51.6 cents.

A possible alternative process for producing nylon 1313 via the methyl ester of brassylic acid had been suggested. Laboratory studies on this system were limited, however, to the production of dimethyl brassylate. An order of magnitude or study estimate prepared for the hypothetical process shows a net cost to make of about 56 cents per pound of nylon 1313. Estimated fixed capital investment for such a plant is $3½ million. Since there were reservations about the technical feasibility of this process and cost data showed no substantial economic advantage for it as compared to the original process, studies on this procedure for producing nylon 1313 were at least temporarily abandoned.

Table IV shows a summary of costs for nylon 1313, 13 and 613 and costs for producing refined brassylic acid.

Production of nylon 13 involves the conversion of erucic acid to eruconitrile by ammoniation. Oxidative ozonolysis of eruconitrile followed by esterification yields methyl 12-cyanododecanoate. The latter is catalytically reduced and upon hydrolysis the monomer for nylon 13, 13-aminotridecanoic acid, is obtained. Melt polymerization gives the nylon 13 polymer. With a yield of 19 lb nylon 13/100 lb crambe oil, the estimated net cost to make is about 68 cents per pound of product.

Brassylic acid and hexamethylenediamine are the monomers for nylon 613. With brassylic acid at 39 cents a pound and hexamethylenediamine at 40 cents a pound, nylon 613 has an estimated cost to make of about 50 cents a pound.

Nylons 13, 1313 and 613 possess qualities that make them attractive for specific applications (5). They can by compression or injection molded and extruded to form

TABLE IV
Summary of Production Costs for Brassylic Acid and Nylons 1313, 13, 613 From Crambe Oil [a]

Item	Cents per pound of product				
	Brassylic acid (99%)	Nylon			
		1313 [b]	1313 [c]	13	613
Crambe oil (15¢/lb)	63.9	68.2	58.4	79.0	
Brassylic acid, 99%, (39¢/lb)					29.6
Hexamethylenediamine (40¢/lb)					14.4
Other raw materials	6.8	13.3	13.4	12,4	1.0
Utilities	1.6	2.8	2.3	2.5	0.2
Labor and supervision	4.3	9.9	9.0	9.4	1.8
Maintenance	2.0	3.7	3.2	3.6	0.4
Fixed charges	4.5	8.2	7.2	8.1	0.9
Miscellaneous factory supplies and expenses	0.3	0.5	0.5	0.5	0.1
Charge on working capital	0.4	0.9	0.9	1.1	....
General plant overhead	3.2	6.8	6.1	6.5	1.1
Gross cost to make, ¢/lb	87.0	114.3	101.0	123.1	49.5
Byproduct credit					
Glycerin (16¢/lb)	6.6	7.0	6.1	8.0	
Pelargonic acid (20¢/lb)	18.4	19.8			
Mixed fatty acids (16¢/lb)	23.0	24.8	21.1	28.6	
Methyl pelargonate (20¢/lb)			18.2	18.6	
Net cost to make, ¢/lb	39.0	62.7	55.6	67.9	49.5
Estimated fixed capital investment, million $	2.35	4.0	3.5	3.9	0.4 [d]
Yield, lb/100 lb crambe oil	23.5	22.0	25.7	19.0	....

[a] Plant capacity for nylons 6 million pounds per year; for brassylic acid, equivalent to 6 million pounds per year nylon 1313.
[b] Polymer from brassylic acid and the diamine.
[c] Polymer from dimethyl brassylate and the diamine.
[d] Includes facilities for making salt and polymer only from brassylic acid and hexamethylenediamine.

films and rods. The injection molding characteristics of nylons 13 and 1313 are similar to those of nylons 11 and 610. The moderate melting point of nylon 1313 helps in the fabrication of the polymer for use as molding and extruding resins and fluidized bed coating operations. The low density of nylon 1313 bears consideration when costs are compared on a volume basis.

Each of the three nylons has good electrical properties although nylon 13 may be superior to the others. They all, and especially 1313, possess low values of water absorption and moisture regain and in this respect are better than either nylon 11 or 610. Since the water absorption and moisture regain values are low for these nylons, their physical properties are not affected by varying humidity conditions.

Examination of the estimated costs for producing nylons 13, 1313 and 613 from crambe oil suggested that these products are in a good position to compete pricewise with nylons 11, 12 and 610. This information and the desirable properties of the new nylons provided assurance that these products possess industrial potential and justified additional engineering studies to refine the processes. Pilot plant studies on nylon 1313 are now in progress. Results from these studies should permit a more critical evaluation of these processes from a technical and economic standpoint than was previously possible. Data provided from studies of these nylons may also be useful in evaluating other processes for nylons from crambe oil, such as nylon 913.

In addition to cost estimates for processes involving vegetable oils, estimates have been prepared for fermentation products and for processes utilizing cereal grains. There is no direct method for judging the accuracy of estimates prepared at the Laboratory, but there have been favorable comments from industry about the cost information made available to them. Several industrial representatives have informed us that their cost estimates in general have been in good agreement with those reported by the Laboratory for the same process.

References for Cost Estimators

In recent years, there has been a substantial increase in published information and data available to cost engineers. Numerous books and journal articles have been published which enable the cost engineer to remain current in his field.

The following references would be excellent additions to a cost engineer's library:

"Cost Engineering In the Process Industries," Edited by Cecil H. Chilton, McGraw-Hill Book Company, Inc., New York, 1960.

"Fundamentals of Chemical Engineering in the Chemical Industry," by H. Carl Bauman, Reinhold Publishing Company, Chapman and Hall, Ltd., London, 1964.

"Modern Cost-Engineering Techniques," Edited by Herbert Popper and the Staff of Chemical Engineering, McGraw-Hill Book Company, New York, 1970.

"Plant Design and Economics for Chemical Engineers," 2nd Ed., by Max S. Peters and K.D. Timmerhaus, McGraw-Hill Book Company, Inc., New York, 1968.

"Cost Engineering," Edited by O.T. Zimmerman and Irvin Lavine, published quarterly by Industrial Research Service, Inc., Dover, N.H.

The references edited by Chilton and Popper contain many of the articles which have appeared as part of the CE Cost File and were published in Chemical Engineering, a McGraw-Hill publication, beginning in 1958.

The American Association of Cost Engineers has prepared "A Cost Engineers' Notebook," an excellent reference which contains information covering the many facets of cost engineering. The association membership provides the information contained in the notebook and supplements to it are issued periodically.

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