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Whey Powder and Whey Protein Concentrate Production Technology, Costs and Profitability

by

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Part 4 of a Research Effort on Cheddar Cheese Manufacturing

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PREFACE

Susan Hurst, Richard D. Aplin, and David M. Barbano are research associate, Department of Agricultural Economics; Professor of Agricultural Economics, College of Agriculture and Life Sciences; and Associate Professor of Food Science, Cornell University, respectively.

This publication is the fourth in a series of publications on Cheddar Cheese manufacturing costs. The series of publications will report the results of a major research effort aimed at helping to answer questions such as the following:

1. How do aged Cheddar cheese plants in the Northeast differ from plants in Wisconsin, Minnesota and other important cheese-producing states with respect to efficiency and other key factors affecting their economic performance?

2. How large a cost advantage do large Cheddar cheese plants have over smaller-scale plants?

3. How much do operational factors, such as number of operating days per week, number of shifts per day, yield potential of milk supplies and recovery of solids at the plant affect the costs of production?

4. What are the differences in costs among plants using the most modern commercial technologies (e.g., continuous systems) and those using more traditional batch systems for manufacturing Cheddar cheese?

5. What is the feasibility and what would be the impact on plant costs of using some of the production capacity in Cheddar cheese plants to produce other cheeses including, perhaps, some specialty, European-style cheeses? In other words, what are the growth opportunities in the other cheeses for the Cheddar cheese industry as it faces increasing competitive pressures?

6. What are the costs and relative profitability of producing whey powder and whey protein concentrate? What are key factors affecting the costs of producing these whey products?

7. What would be the impact on manufacturing costs of using milk concentration processes (i.e., ultrafiltration, reverse osmosis and evaporation) in Cheddar cheese plants?

This publication focuses on question #6 above. It reports the results of using the economic-engineering approach to estimate and analyze the costs of handling sweet whey and producing whey powder and whey protein concentrate. In addition the relative profitability of producing whey powder and whey protein concentrate under various conditions is analyzed.

Questions 1 through 5 above are addressed in earlier publications which involved the study of 11 plants operating in the Northeast and North Central regions. The study of the 11 plants is reported in a 1987 publication entitled "Economic Performance of 11 Cheddar Cheese Manufacturing Plants in Northeast and North Central Regions." Data from these plants were used as part of the base for an economic-engineering study with the results reported in "Cheddar Cheese Manufacturing Costs -- Economies of Size and Effects of Difference Current Technologies," also issued in 1987.

The feasibility and potential profitability of producing specialty cheeses, such as Jarlsberg and Havarti, in modified Cheddar cheese plants as well as in plants designed to produce only specialty cheese was reported in a July 1989 publication entitled "Diversification of the Cheddar Cheese Industry Through Specialty Cheese Production."

The results of the research on whey products production will be merged with the cost estimates of producing Cheddar cheese in the six different size model plants from our earlier work to examine the costs and profitability of integrated cheese and whey operations under various operating and revenue conditions. The publication reporting the combined Cheddar and whey operations should be available later in 1990.

The remaining phase of the project is aimed at providing a basis for determining the cost impact of adopting milk concentration or fractionation technologies, especially reverse osmosis and ultrafiltration, in Cheddar cheese manufacturing. Work is essentially done to superimpose new milk concentration technologies (i.e., ultrafiltration, reverse osmosis and energy efficient MVR evaporators) on a number of the model plants developed in the first phase of the study. This phase of the research should be published in the fall of 1990.

Financial assistance for the overall cheese manufacturing cost project has been provided from four sources. One was a research agreement with the Agricultural Cooperative Service of the United States Department of Agriculture. Another source was the New York State Department of Agriculture and Markets. The research also is supported in part by funds provided by the dairy farmers of New York State under the authority of the New York State Milk Promotion Order. Still a fourth source is a research agreement with the Wisconsin Milk Marketing Board. In addition, the funds to publish this phase of the research partially came through the Cornell Program on Dairy Markets and Policy with a grant from the New York State Department of Agriculture and Markets.

Many have contributed importantly to the development and success of this project. Cornell University contracted with Mead & Hunt, Inc., an engineering consulting firm based in Madison, Wisconsin, with broad experience in various industries including cheese, to provide much of the information needed to budget costs. Daniel Surfus was the key staff person at Mead & Hunt, Inc. on this project. Tedd Sleggs of Empire Cheese, Inc., Cliff Cole of Universial Foods, Tom Everson of Wisconsin Dairies, Artur Zimmer of GEA Food and Process Systems Corporation, and Greg Haugen and Mark Haak of the Damrow Company provided valuable guidance and input at various stages. Several other dairy equipment companies provided cost and engineering data on general dairy equipment.

Scott McPherson helped write the computer programs needed for data analysis. Mary Jo DuBrava did an excellent job in typing and processing the manuscript. We thank them both.

Constructive criticisms of the manuscript were made by Andrew Novakovic and James Pratt of Cornell's Department of Agricultural Economics, and by a number of people in industry.

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DIGEST AND HIGHLIGHTS

Objectives and Methodology

The principle objectives of this study were to estimate the costs of manufacturing human food grade whey powder and whey protein concentrate (WPC) containing 34.5% protein and to assess the impacts of different plant sizes, various production schedules, and various other operating conditions on the costs of producing these two whey products. A secondary objective was to compare the relative profitability of manufacturing whey powder and whey protein concentrate under various powder and WPC prices and various permeate handling conditions (i.e. loss, breakeven or gain).

A three-step economic-engineering or synthetic costing approach was used to estimate production costs for six plant sizes and nine different production schedules in each plant both for manufacturing whey powder and WPC.

The costs calculated in this manner indicate what could be expected with a new plant, engineered according to the specifications of the design and operated according to the assumed, achievable standards. For any given plant design or operating schedule, costs that would be achieved in an actual plant would vary with the quality of management and labor, actual prices paid for fixed or variable inputs, milk composition and quality factors (which affect yields) and actual losses of whey solids during processing. The effect on costs of any of these real-life factors could be very significant. Nevertheless, this study demonstrates the importance of scale economies and operating schedules when the vicissitudes of management, milk quality, and so on are neutralized.

Results-Production Costs

Both whey powder and WPC manufacturing costs varied widely among plants of different sizes and with different production schedules. The costs of manufacturing whey powder ranged from 7.9 cents per pound of powder in a plant serving a Cheddar cheese plant with a capacity of 2.4 million pounds of milk per day and operating around the clock to 25.9 cents per pound of powder in a plant associated with a Cheddar plant that had a capacity of 480,000 pounds of milk per day which was operating at about 50% of capacity. The costs of manufacturing WPC ranged from 18.7 per pound of WPC for the largest plant operating at capacity to 78.6 cents per pound of WPC in the smallest plant operating at 50% of capacity.

Economies of Size

Large economies of size were observed in both whey powder and WPC production. Plant size was by far the most important factor affecting unit costs of production in the model plants. For example, the unit costs of manufacturing either whey powder or WPC in a plant that would serve a Cheddar plant receiving 2.4 million pounds of milk per day were more than 30 percent lower than a whey product plant associated with a Cheddar plant with a 960,000 pounds of milk daily capacity. In turn, the unit costs of manufacturing either whey powder or WPC were 35 percent or more lower in a whey plant serving the 960,000 pounds of milk per day capacity Cheddar plant than a whey plant serving a Cheddar cheese plant that had a daily capacity of 480,000 pounds of milk.

Two of the major cost components in whey powder and WPC manufacture, labor and capital costs, have significant economies of scale. On the other hand, the cost of utilities and materials on a cost per pound of whey product basis are not affected much by the size of the plant. There are no significant economies of scale in either of these expense categories.

Production Schedules

Next to the size of plant, the daily and weekly production schedules had the largest impact on the cost per pound of manufacturing whey powder and WPC. As the number of operating hours per day and/or the number of operating days per week increases for any plant size, the unit cost of production decreases because of the higher utilization of plant capacity. Increasing the number of hours per day whey is processed results in larger reductions in the unit costs of production than increasing the number of days per week the plant operates. Any change in production schedules, either in the number of operating hours per day or number of operating days per week, affects the absolute unit costs in smaller plants more than it does in larger plants.

Sensitivity of Cost Estimates

Whey powder and WPC manufacturing costs are rather sensitive to differences in wage rates, differences in initial capital investment levels and to differences in utility rates because labor expense, the costs associated with the level of capital investment (i.e. depreciation, interest, property taxes, and insurance) and utility expenses are such important cost components. Changes in wage rates and differences in the level of capital investment had a larger impact on smaller plants than on larger ones because of lower labor productivity and higher capital investments per pound of product in the smaller plants. Because there are relatively small economies of scale in utilities, the impact of changes in utility rates is about the same regardless of the size of the plant.

Assessment of Profitability of Whey Powder and WPC

The final objective of this research was to estimate the profitability of manufacturing whey powder and WPC under various product price conditions, in different size plants and, in the case of WPC, with different yields and different permeate handling scenarios.

The profitability of manufacturing either whey powder or WPC is very sensitive not only to the market prices of the products but also, because of the significant economies of scale, to the size of the whey product plant.

The prices for whey powder and WPC averaged approximately $.18 and $.72 per pound, respectively, during the two years ending December 1989. At these product prices, and assuming no charge to the whey plant for the raw whey and a breakeven situation on permeate in the WPC operation, it would have been profitable to produce either whey powder or WPC in all of the model operations studied (when operating 6 days, 21 hours), except the smallest whey powder plant which would have lost $.18 per cwt of milk on handling whey. In fact, for a whey product plant serving a Cheddar plant receiving 960,000 pounds of milk per day or more, the manufacture of either whey powder or WPC would contribute an operating profit of $.25 or more per cwt of milk received for cheese manufacture.

The profitability of producing whey powder at prices as low as $.13 a pound and WPC at prices as low as $.52 per pound were studied. Still assuming no charge for the raw whey, the manufacture of whey powder was profitable at $.13 per pound only in whey plants serving Cheddar cheese plants with capacities of more than one million pounds of milk per day. Assuming a breakeven situation on permeate, the manufacture of WPC when the WPC price is only $.52 per pound was profitable in all but the smallest plant studied.

Results suggest that at the average prices prevailing from January 1988 to December 1989, namely $.18 for whey powder and $.72 per pound for WPC, the manufacture of WPC would be more profitable than whey powder unless the plant lost more than 6 cents per pound of solids in handling permeate. The profitability of manufacturing WPC relative to whey powder is very sensitive to whether the plant makes a gain, breaks even, or loses on handling permeate as well as to the relative product prices.

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WHEY POWDER AND WHEY PROTEIN CONCENTRATE PRODUCTION TECHNOLOGY, COSTS AND PROFITABILITY

INTRODUCTION AND BACKGROUND

Whey is a by-product of cheese production. On average, for example, a Cheddar cheese plant starts with 100 pounds of milk and ends with 10 pounds of Cheddar cheese and 90 pounds of liquid whey. Historically, whey was viewed as a waste product from the manufacture of cheese and was dumped into streams or fed to animals on nearby farms. The local impact of this method of whey disposal was small when there were thousands of small cheese plants dispersed throughout the countryside. During the period from 1950 to today, however, the number of cheese plants has declined and the production capacity of individual cheese plants has increased dramatically. This change in the structure of the cheese manufacturing industry, plus the growth in total cheese production due to increased per capita consumption of cheese, caused volumes of whey for most cheese plant locations to increase substantially. At the same time, the environmental protection regulations on discharge of wastes became more strict, making the disposal of whey in sewage treatment plants much more costly.

The high cost of whey disposal stimulated an extensive amount of both university and industry research to find new uses for the milk solids that remain in whey after cheese manufacture. Today, there is a wide spectrum of possible utilizations of sweet whey, (e.g. whey from Cheddar and Mozzarella cheese) but the ones that are most financially attractive are those that use whey solids as an ingredient in formulated foods. The major milk solids present in separated (fat already removed by centrifugation) Cheddar cheese whey are lactose, protein, and minerals. Lactose is approximately 80% of the solids content of Cheddar cheese whey. Early methods for recovery and by-product use of whey solids involved crude drying processes that produced a material suitable for use as an energy source in cattle feeds. Next, the sanitary powders suitable for use as an ingredient in human food products were developed. Whole whey powders were used as partial or total replacements for nonfat dry milk powder in some formulated foods. In many cases, the use of whey powder did not alter the characteristics of the formulated food, and since the price of whole whey powder was much lower than nonfat dry milk powder, human food grade whey powder sales increased.

The proteins are the most valuable milk solids component in Cheddar cheese whey. However, they are only a fraction of the solids content of whey and are not easily removed from whey without damaging their functional characteristics. A new filtration technology called ultrafiltration offered the dairy industry an opportunity to produce a new class of whey products called whey protein concentrates (WPC). The proteins in whey can be selectively concentrated and removed from whey by ultrafiltration without drastically damaging their functional characteristics. The products of this process are whey protein concentrates. The two main milk proteins in WPC are beta-lactoglobulin and alpha-lactalbumin.

In theory, a wide range of products can be manufactured to suit many different specific applications as food ingredients. However, in practice a WPC with 34 to 35% protein on a total nitrogen basis has become the standard WPC product produced by the cheese industry. The advantage of WPC powder over whole whey powder is the fact that the proteins have better functionality (i.e. foam stability, whipping characteristics, etc.) and there is less lactose and minerals which may produce undesirable color or flavor characteristics in a food product. As the market and utilization of whey proteins as functional ingredients in human food systems becomes more developed, there will be more WPC product diversification and development of a market for whey protein isolates. Whey proteins isolates are more pure forms of beta-lactoglobulin and alpha-lactalbumin. Today, whey protein isolates are available for use as food ingredients. However, at the present time the adoption of whey protein isolates by the food manufacturing industry as functional ingredients has been slow compared to the growth in use of whey powder and WPC.

The previous study of factors influencing Cheddar cheese manufacturing cost found that there were large economies of plant size for cheese plants. Today, a large cheese manufacturing plant must have, for profitable operation, some method of recovering milk solids from whey and selling these solids as a by-product. Therefore, almost every cheese plant will have some form of whey processing plant associated with it. The purpose of this study was to characterize the factors influencing the costs of manufacturing human food grade whole whey powder and WPC. In addition, an evaluation of the relative profitability of these two whey product options was conducted.

STUDY OBJECTIVES

The primary objectives of this phase of our research were to:

(1) Estimate the costs of producing whey powder and whey protein concentrate in efficient plants in order to measure the cost effects of plant size and different operating conditions.

(2) Measure the effects of different wage rates, utility rates and capital investment levels on the cost of producing whey powder and whey protein concentrate.

(3) Measure the effects of different yields on whey protein concentrate production costs.

(4) Compare the relative profitability of manufacturing whey powder and whey protein concentrate under various whey powder and whey protein concentrate prices and various permeate handling conditions.

METHODOLOGY

Methodological Considerations

Estimation of plant cost relationships has been done for many different products using different approaches. In general, cost estimation approaches fall into one of three broad categories: 1) descriptive analysis of accounting data, which mainly involves combining point estimates of average costs into various classes for comparative purposes, 2) statistical analysis of accounting data, which attempts to estimate functional relationships by econometric methods, and 3) the economic-engineering approach, which "synthesizes" cost relationships from technical engineering data on factor usages, factor prices and other estimates of the components of the cost functions.

Each method has its advantages and disadvantages. The computational procedures involved in the accounting data approach are straightforward and simple. The popularity of the descriptive analysis relies mainly on its use of actual data and the interest among plant operators in comparing their own cost experience to the experience of others. However, there are significant limitations to the accounting data approach. Differences among plants in record keeping and accounting classifications, as well as differences in managerial efficiency, scale, production methods, input prices, degree of plant utilization and other operational and environmental conditions, make cross classifications and comparisons of limited value in determining the importance of individual cost-influencing factors.

The statistical analysis uses much of the same data as the descriptive analysis with the difference that the former tries to develop quantitative estimates of cost functions. Some of the weaknesses of the statistical method are: 1) data limitations and defects which usually lead to biased estimates, 2) its inability to clearly isolate the effects of various cost-influencing factors (e.g. changes in scale and utilization of the plant), and 3) its extreme sensitivity to the functional form chosen for estimation.

The alternative to the descriptive and the statistical analyses of plant accounting data is to synthesize cost functions from engineering input-output specifications. This approach is known as the synthetic or economic-engineering analysis. It focuses exclusively on technical economies because input prices, managerial effectiveness and other factors can be held constant across all plants modeled. The technique allows for comparisons among systems where different physical and operational characteristics are standardized or varied systematically. For this reason, it is appropriate to the estimation of economies of size and the minimum efficient size plant. Moreover, the economic-engineering approach can be used for the analysis of efficient plants or systems that may not actually exist but which are achievable. This is very valuable for evaluating costs of new manufacturing techniques or variations of current operations. Some find objectionable the artificial aspect introduced with the synthetic approach. The probability that operational efficiencies may be influenced by unidentified factors which are not evenly distributed among plants is another shortcoming of this method. The technique is also more sensitive to omitting some costs simply because they are never identified. This should lead to caution in the use of final results. However, the main strength of the estimates still lies in their comparability.

Given the objectives of this study, especially in determining the effects on costs of different plant sizes with various operational procedures, the economic-engineering approach was chosen to estimate production costs.

Overview of Research Methodology Used

To ascertain the costs and potential profitability of manufacturing whey powder and whey protein concentrate (WPC), model plants were specified, a costing procedure defined, and production costs and profitability estimated.

The model whey plants were designed to simulate the production of either whey powder or WPC. Production costs were determined for each whey product using six plant sizes and nine different operating schedules. The sensitivity of the cost estimates to various wage rates, utility rates and product yields was analyzed. Finally, costs and possible revenues were compared to assess the relative profitability of manufacturing whey powder and WPC under various possible product prices, different possible yields of WPC and various handling conditions for the permeate produced in a WPC operation.

A three-step economic-engineering or synthetic costing approach was used to estimate production costs for the twelve plant designs. The first step was to define the production process. After careful investigation of production practices for whey powder and WPC manufacture, process flow diagrams were constructed. The production process was divided into operating stages, or centers, which were delineated on the basis of: identifiable operations, flow of the product and materials, and importance of the operations.

The second step identified the particular method and equipment used in the operation of each center. Then the processing costs of activities in each center were estimated over different output rates.

In the third step the production costs of each center were summed along with cost components associated with the overall whey plant which were not tied to any single operating stage or center. This cost represented the total cost of production for each plant. In all plants, production costs were reduced to an average cost per unit of whey product.

The data and insights needed to successfully use the economic-engineering method to estimate realistic manufacturing costs came from several sources: 1) the survey of 11 actual Cheddar plants[1]; 2) an engineering consulting firm (Mead & Hunt, Inc., Madison, Wisconsin), and 3) equipment manufacturers.

MODEL PLANT SPECIFICATION

Processing Conditions

Whey Powder Plant

All equipment is designed and operated for production of human food grade product (U.S. Public Health). The whey is received from the cheese plant after it has been through a fines saver and cream separator. The 100^{0} F whey is heated to pasteurization temperature (172^{0} F), held for 15 seconds, and then pumped directly to a single effect evaporator with turbofan/thermal recompression and a finishing concentrator stage. Whey enters the evaporator at 168^{0} F, leaves the evaporator at 52% to 53% solids, and enters a flash cooler. When the condensed whey exits the flash cooler it is 88^{0} F and 54% to 55% solids (water is removed in flash cooling). It is pumped to crystallization tanks where it is slowly cooled to 44^{0} F and held for crystallization. Once the proper crystallization has occurred, the whey is spray dried in a filter mat dryer to a final moisture content of 3%. Whey powder contains approximately 13% protein on a total nitrogen basis. The whey powder

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[1]Mesa-Dishington, J.K., R.D. Aplin and D.M. Barbano. "Economic Performance of 11 Cheddar Cheese Manufacturing Plants in Northeast and North Central Region", A.E. Res. No. 87-2, Department of Agricultural Economics, Cornell University, Ithaca, NY. 1987.

is milled, sifted, filled into 50 lb bags, palletized and over-wrapped before shipping. Dry storage is available at the plant for ten days production.

Whey Protein Concentrate Plant

All equipment is designed and operated for production of human food grade product (U.S. Public Health). The whey is received from the cheese plant after it has been through a fines saver and cream separator. The 100° F whey is heated to pasteurization temperature (172° F), held for 15 seconds, and then cooled to 130° F before entering the surge tank for the ultrafiltration (UF) system. The UF system is a multistage, spiral-wound membrane system with polysulfone membranes. The whey enters the system at .72% true protein and 6.5% solids. The retentate leaves the UF at 3.16% true protein (3.38% protein on a total nitrogen basis) and 9.75% solids at 128° F. At this point the retentate enters a two-effect vapor recompression evaporator. It leaves the evaporator at 118° F with 45% solids (34% to 34.5% protein on a total nitrogen basis). The condensed whey protein concentrate is cooled to 40° F and run through a cone-style spray dryer. The final product contains 3% moisture and is palletized and over-wrapped in 50 lb bags. The plant has dry storage space available for ten days production.

Plant Sizes and Production Schedules

The whey plants are modeled to accompany six sizes of Cheddar cheese plants: 480,000, 720,000, 960,000, 1,440,000, 1,800,000, and 2,400,000 lbs. These sizes are the maximum volumes of raw milk each cheese plant can handle in a 24 hour day with 18.5 hours of vat fill time. These plant sizes were chosen on the basis of their use in previous research[2]. Maximum whey volumes for each plant are 428,585, 642,878, 857,170, 1,285,755, 1,607,194, and 2,142,925 lbs respectively, once the 10% cheese yield and whey cream and fines have been removed.

Operating schedules were also assumed to coincide with those of the cheese plants and were selected due to their use in previous research[3]. The nine production schedules used were 24, 21, and 18 hour days and 5, 6, and 7 day weeks.

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[2] Mesa-Dishington, J.K., R.D. Aplin, and D.M. Barbano. Cheddar Cheese Manufacturing Costs, Economies of Size, and Effects of Different Current Technologies. A-E Res. 87-3, Department of Agricultural Economics, Cornell University, Ithaca, NY. 1987.

[3] Ibid.

COST ESTIMATION

Introduction

The economic-engineering or synthetic cost estimating technique requires detailed information on technical input-output relationships of production and on the cost of resources used in the manufacturing processes.

This section presents the methods used to determine production costs for the whey powder and whey protein concentrate (WPC) plants. Assumptions concerning raw materials and composition of outputs are discussed, along with data sources. Finally, production cost items and methods of calculating costs are described.

Assumptions

Certain assumptions were made so that valid comparisons of manufacturing costs could be drawn among plants handling different volumes of whey and producing the two whey products. The assumptions concern inputs, outputs, and production techniques of all the model plants.

It is assumed that operation of each of the model whey plants reflects good management practices. Plants are assumed to operate at a high, but achievable, level of efficiency with respect to input usage and product yields.

Whey powder is assumed to have a yield of 5.80 lbs per cwt raw milk, while WPC is assumed to yield 1.64 lbs per cwt raw milk. The basic assumptions regarding whey and whey product composition follow, as well as sample yield calculations for whey powder and WPC, using as examples whey plants which would accompany Cheddar plants with a capacity of 960,000 pounds of raw milk per day.

Whey and Whey Product Composition Assumptions for Model Whey Powder Plants.

Raw Milk Composition = 3.72% fat, 3.2% total protein

Cheese yield = 10 lbs per cwt. of raw milk

91.5% fat recovery in the cheese

90% fat recovery of whey fat, whey cream = 40% fat

Unseparated Whey = .72% true protein, 6.5% solids, .25% fat

Separated Whey = 6.30% solids

Whey Powder = 97% solids

ILLUSTRATIVE CALCULATIONS

Raw milk received by cheese plant = 960,000 lbs per day

Cheese produced = 96,000 lbs per day; (960,000 / 10 lb yield)

Unseparated Whey = 864,000 lbs per day; (960,000 - 96,000 lbs cheese)

Whey Cream = 6,830 lbs per day; (960,000 X 3.72% (milk fat) X 8.5% (fat not retained in cheese) X 90% (fat retained in whey cream) / 40% (amount of fat in whey cream))

Separated Whey = 857,170 lbs per day; (6.3% solids, .72% true protein) (864,000 lbs unseparated whey - 6,830 lbs whey cream)

Whey Powder = 55,672 lbs per day (857,170 X 6.3% (solids in separated whey) / 97% (percent solids in whey powder)

Whey and Whey Product Composition Assumptions for Model WPC Plants.

Raw Milk Composition = 3.72% fat, 3.2% total protein

Cheese yield = 10 lbs per cwt. of raw milk

91.5% fat recovery in the cheese

90% fat recovery of whey fat, whey cream = 40% fat

Separated Whey = .72% true protein, 6.3% solids

UF Retentate = 3.16% true protein, 9.75% solids

WPC = 34.5% protein, 97% solids

Actual WPC yield is 80% of theoretical yield, due to processing losses. This estimate of processing losses was based on discussions with various producers of WPC.

ILLUSTRATIVE CALCULATIONS

Raw milk received by cheese plant = 960,000 lbs per day

Cheese produced = 96,000 lbs per day; (960,000 / 10 lb yield)

Unseparated Whey = 864,000 lbs per day; (960,000 - 96,000 lbs cheese)

Whey Cream = 6,830 lbs per day; (960,000 X 3.72% (milk fat) X 8.5% (fat not retained in cheese) X 90% (fat retained in whey cream) / 40% (amount of fat in whey cream))

Separated Whey = 857,170 lbs per day; (6.3% solids, .72% true protein) (864,000 lbs unseparated whey - 6,830 lbs whey cream); 54,002 lbs solids per day.

$$\text{Concentration factor} = \frac{\text{true protein in UF retentate}}{\text{true protein in separated whey}} = \frac{3.16\%}{.72\%} = 4.389$$

100 lbs of whey / 4.389 = 22.78 lbs retentate & 77.22 lbs permeate
Retentate = 195,305 lbs per day; (3.16% true protein and 9.75% solids); (857,170 lbs separated whey / 4.389 concentration factor); 19,042 lbs solids per day

Permeate = 661,865 lbs per day; (857,170 lbs separated whey - 195,305 lbs retentate); 34,959.8 lbs solid per day

Retentate = 9.75% solids and WPC = 97% solids

WPC = 19,631 lbs per day; (195,305 lbs retentate X 9.75% solids) / 97% solids; (2.04 lbs WPC per cwt. milk = theoretical yield)

Actual WPC Yield = 15,705 lbs per day; (80% of theoretical WPC yield) (1.64 lbs WPC per cwt milk)

Data Sources

Data used to estimate whey powder and WPC production costs and prices of the outputs were obtained from several sources. Mead & Hunt, Inc., of Madison, Wisconsin, an engineering consulting firm with extensive experience in the cheese industry, provided the technical coefficients used in this study. Prices and specifications on major equipment were obtained by the consulting engineers from equipment manufacturers. Information provided by the consulting engineers included cost information on land, building structures, production equipment, labor requirements, utility demands and other expenses. Mead & Hunt, Inc. compiled the technical data on the Cheddar cheese plants modeled in the earlier study[4].

Land, Building and Equipment Costs

Engineering consultants determined the amount of land necessary for construction of each size whey plant, including space for employee parking,

[4]Ibid.

truck parking and turn-arounds. The plants were designed to accompany cheese plants although the cheese plant operations are not included in this report. Land purchase costs were assumed to be $31,000 per acre or approximately $0.72 per square foot. Rough and finish grading, paving, landscaping, underground utility installation, and engineering fees were estimated at an additional $33,000 per acre.

Building costs were determined by the engineering consultants based on the equipment size and specifications for each center in the plant. Building costs include engineering fees, electrical, plumbing, pneumatic, refrigeration, structural, and ventilation aspects for each operating center in the plant. Equipment requirements and costs were determined by the engineering consultants and by equipment manufacturers for each plant center. All plants were modeled using modern, present-day automation. Equipment costs include engineering fees, and delivery and installation costs.

Details of the building areas and land requirements for each size whey powder and WPC plant are given in Appendix Tables A1 and A2. Details of selected items of equipment are given in Appendix Table A3.

The plants are constructed to be economically functional for the long run, yet not plush. No office space is included in the whey plants as this is assumed to be part of the accompanying cheese plant. A metering/monitoring manhole is provided for BOD tests, suspended solids tests and flow measurement to verify discharge volumes. Sewage costs are budgeted at a fixed rate per 1000 gallons.

Capital Investment Costs

The initial capital investments for the model whey powder and WPC plants designed to process whey from 6 different size Cheddar cheese plants are shown in Table 1. The investment costs are the totals for land, building and equipment, as well as charges for the capital tied up in construction of each plant prior to the start of production. A breakdown of these total capital investments into land, building and equipment are given in Appendix Tables A4 and A5.

Capital investment costs reported here are for the whey plant only and do not include any investment in the cheese plant. The initial capital investments are categorized into land, building, and equipment, and charged annually for capital costs and depreciation. Assumptions made concerning capital costs tied up in the construction of the whey plants were that the land would be purchased two years before the plant became operational, with 30% of the sitework and structural costs occurring 18 months before plant completion. The remaining 70% of these costs would be incurred one year before the plant opened, with equipment purchased six months before the opening. A 6% real interest rate was assumed, with no appreciation or depreciation of the land.

It is assumed that the lifespan of the whey plant is 25 years when operated at 100% capacity or up to 35 years at less than 100% capacity (35 years is assumed to be the maximum lifespan due to obsolescence, regardless of the capacity the plant has actually operated at). Three equipment lifespans were assumed; 5, 10, and 15 years, based on 100% utilization. At lower levels of utilization, equipment lifespans are also lengthened. Equipment costs are based on prices in Fall 1988. Salvage values of the building and equipment are assumed to be zero.

TABLE 1. Whey Powder & Whey Protein Concentrate Plant Capacities and Total Capital Investments for Six Model Plant Sizes, Fall 1988
Note: Capital investment includes land, building and equipment costs for whey product production only. Whey protein concentrate plant does not include any investment for permeate handling.

Cheese Plant Capacity (1000 pounds of milk per day)					
480	720	960	1,440	1,800	2,400
Whey Powder Plant Capacity (million pounds of powder per year)[a]					
10.1	15.2	20.3	30.4	38.0	50.6
WPC Plant Capacity (million pounds of WPC per year)[b]					
2.9	4.3	5.7	8.6	10.8	14.4
Whey Powder Plants' Capital Investment					
$5,218,866	$5,984,890	$6,611,985	$7,577,377	$8,522,529	$10,008,873
Whey Protein Concentrate Plants' Capital Investment					
$4,344,247	$4,516,238	$4,763,899	$5,132,930	$5,310,857	$5,497,350

[a]Assumes plant operates 24 hours, 7 days; whey powder yield is 5.80 lbs per cwt of raw milk.
[b]Assumes plant operates 24 hours, 7 days; WPC yield is 1.64 lbs per cwt raw milk.

Repair and Maintenance

Repair and maintenance was estimated by the engineering consultants using recommendations from the equipment manufacturers for purchased parts and labor. In-house labor used for repair and maintenance was included in the general "labor" category, rather than in this "repair and maintenance" item. Structural maintenance was divided into fixed and variable categories while equipment maintenance was considered entirely variable. Variable maintenance is tied to the whey volume processed in the plant, while fixed maintenance is a set amount regardless of the plant's utilization. Both structural and equipment maintenance were applied by operating center and then totaled for each whey plant.

Insurance

Insurance was assumed to be fire and extended protection, with the total value of the building and equipment insured at 85% of the initial capital investment. The insurance costs per year were estimated using an average rate of $5.46 per $1000 of building and equipment value.

Property Taxes

Property taxes were based on the market value of the land, building, and equipment. Market value of land and building was assumed to be 100% of the original investment cost, while market value of equipment was assumed to be 50% of the original cost. An average rate of $39.00 per $1000 of market value was used to determine the annual property taxes of each whey plant.

Salaries, Wages, and Labor Costs

Labor requirements for the model plants were determined based on production schedules and times, technology used, and activities performed in each center. These estimated labor requirements were established by the consulting engineers and equipment suppliers, and evaluated by the authors.

Labor costs were divided between supervisory and direct labor. Supervisory labor includes only the plant manager, with one shift of supervisory labor assumed per day, regardless of the production schedules. Supervisory labor is designated as a wholly fixed cost per year. All other employees are considered direct labor which is divided into variable and fixed components. Variable labor is used where the amount of work varies with the amount of whey being processed, while fixed labor is for positions which require a constant effort, such as cleaning or setting up the plant at the start of each operating day. Both direct and variable labor requirements for each plant center were determined by the engineering consultants and equipment manufacturers. The basic labor requirements for each of the twelve model whey plants are given in Appendix Tables A6 and A7.

A flat wage rate of $9.75 per hour was assumed for all direct labor, with 32% fringe benefits. Supervisory labor was estimated to cost 30% more per hour than direct labor, with an additional wage adjustment based on plant size. Fringe benefits include welfare fund, retirement fund, social security, life insurance, medical and dental insurance, unemployment insurance, sick leave, and paid vacations.

Utility Costs

The major utilities in the whey plant are electricity, gas, water, and sewage. The engineering consultants and the equipment manufacturers determined the utility needs of each piece of equipment. Where steam was used, the natural gas required to produce the steam was estimated. Water consumption was calculated using known flow rates for equipment and estimated usage. Both electricity and natural gas were estimated based on fixed and variable usage in each operating center, with the fixed component charged at a flat rate per kilowatt hour or therm. The variable amount was based on usage per million lbs of milk in the cheese plant. Electricity was assumed to cost $.06 per kilowatt hour, natural gas $.38 per therm.

The whey plants are assumed to have their own water wells, so there are no direct charges for water. The costs of building and maintaining the water well are included in the capital costs section. A flat rate of $1.65 per 1,000 gallons of sewage treated was assumed. The basic utility requirements for each of the model whey powder plants are shown in Appendix Table A6 and for the WPC plants in Appendix Table A7.

Supplies

Production and laboratory supplies are fairly minimal for whey plants, although the requirements are slightly higher in the whey fractionation plants. Novalox is needed to bleach whey created from colored Cheddar with the assumption that half of the whey entering the plant is colored. Lab supplies include materials necessary to perform all tests needed under good management of the whey plant; these include fat and moisture level tests on powdered whey, and fat, moisture, and protein tests for WPC.

Packaging supplies include bags, pallets, and overwrap for the pallets. Each 50 lb bag is assumed to cost $0.52. Cleaning supplies were determined by the engineering consultants and by the equipment manufacturers. The WPC plant requires additional cleaning supplies for the membranes. For centers with CIP equipment, cleaning supplies were estimated by calculating the flow rate and the length of time the CIP system operated each day.

Other Expenses

Other expenses include communications, travel, laundry, telephone, and other services. The costs for these expenses were based on earlier studies of cheese plants and modified by the engineering consultants to be applicable to whey plants [5, 6]. These expenses were calculated on a monthly or yearly basis with some variation due to plant size.

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[5] Mesa-Dishington, J.K., R.D. Aplin, D.M. Barbano. Economic Performance of Eleven Cheddar Cheese Plants Manufacturing in Northeast and North Central Regions. A.E. Res. 87-2, Department of Agricultural Economics, Cornell University, Ithaca, NY. 1987.

[6] Mesa-Dishington, J.K., R.D. Aplin, and D.M. Barbano. Cheddar Cheese Manufacturing Costs, Economies of Size, and Effects of Different Current Technologies. A-E Res. 87-3, Department of Agricultural Economics, Cornell University, Ithaca, NY. 1987.

RESULTS

PRODUCTION COSTS AND PROFITABILITY

Introduction

This phase of the research on cheese manufacturing focused on estimating the costs of producing whey powder and whey protein concentrate (WPC) in different size plants and under various manufacturing scenarios, using the economic-engineering method. Also assessed was the profitability of producing whey and WPC under various manufacturing and price situations.

Production cost estimates include costs associated with producing whey powder and WPC starting with whey which has been run through a fines saver and cream separator in the companion cheese plant. Costs associated with the fines saver, whey cream separator, and whey cream pasteurization are charged to the cheese plant and, thus, not reflected in the costs reported herein. Whey powder and WPC costs also do not include any costs of raw milk, milk assembly, raw whey, whey marketing, permeate handling, or administration and management, other than the direct whey plant management.

In estimating WPC production costs and profitability, it is assumed that the ultrafiltration (UF) permeate is a breakeven situation. Thus, no costs (labor, capital, etc.) are included for permeate and no revenues or losses are reflected. The impact of net profit or loss scenarios for permeate processing on the total WPC plant profitability is considered separately using sensitivity analysis.

Equipment, packaging, production materials, and structural costs all reflect late 1988 prices. The model whey plants are assumed to be new plants, operating under good management, in conjunction with an attached Cheddar cheese plant. The whey plants are assumed to handle only the whey from these cheese plants; no additional whey is purchased.

The budgeted costs reflect production costs in new whey operations using the technologies studied and facing the factor costs described earlier. The cost estimates do not necessarily reflect the production costs of current whey operations that have been in operation for a period of time. Many older plants, among other things, still use assets that are largely, or perhaps fully, depreciated.

Whey Powder Production Cost Estimates

Summary Findings

Conclusions regarding the cost of manufacturing whey powder are;

1) Estimated whey powder manufacturing costs varied widely among the six model plants, from 25.9 to 7.9 cents per pound of whey powder.

2) The size of plant was the most important factor affecting the cost of whey powder production. The two major cost components in whey powder manufacture, labor and capital costs, have significant economies of scale.

3) Next to the size of plant, the daily and weekly production schedules had the largest impact on the cost per pound of manufacturing whey powder.

4) Whey powder manufacturing costs are rather sensitive to differences in wage rates and levels of initial capital investment, but less sensitive to increases in utility rates.

Variability In Costs

Estimated whey powder manufacturing costs varied widely among plants of different sizes and with different production schedules. Both plant size and production schedule had distinct impacts on the absolute level and the relative importance of different cost items.

To illustrate the range of cost estimates obtained and the composition of costs for whey powder production, Table 2 reports the costs per pound of powder for a plant serving a cheese plant with a capacity of 960,000 pounds of milk per day and operating 21 hours per day, 6 days per week. Additionally, the range in costs of whey powder production for plants of different sizes and with different production schedules is provided to indicate the magnitude of the cost variability. The composition of costs for each of the six model whey powder plants operating on a 21 hour day, 6-day week production schedule is found in Appendix Table A8.

A whey powder plant associated with a Cheddar cheese plant with 960,000 pounds of daily milk capacity and operating 21 hours per day, 6 days per week had production costs of 13.6 cents per pound of whey powder. Such a plant would produce approximately 14.5 million pounds of whey powder per year, while the cheese plant was producing 25 million pounds of Cheddar.

Production costs varied between 7.9 and 25.9 cents per pound of whey powder across plant sizes and production schedules (Table 2). The low end of the range, 7.9 cents per pound of powder, represents a whey plant serving a Cheddar plant with a capacity of 2.4 million pounds of milk per day, operating 24 hours per day, 7 days per week. In this situation, the annual production of whey powder would be nearly 50.6 million pounds. On the other hand, the cost of producing whey powder would be approximately 25.9 cents per pound in a whey powder plant operating 18 hours per day, 5 days per week in conjunction with a cheese plant with a daily milk capacity of only 480,000 pounds. This small whey powder plant would produce 4.8 million pounds of powder per year, operating 18 hours per day, 5 days per week.

TABLE 2. Whey Powder Manufacturing Costs, Model Plants, Fall 1988

Cost Item	Cost Per Pound of Powder[a]	Percentage of Total Costs	Cost Range for Different Size Plants & Operating Schedules[b]
	(cents)	(%)	(cents/pound)
Labor			
Supervisory	0.3	2.2	(0.1 - 0.8)
Direct Fixed	0.2	1.5	(0.1 - 0.6)
Direct Variable	3.0	22.1	(1.4 - 5.9)
Total Labor	3.5	25.8	(1.6 - 7.3)
Capital Costs			
Depreciation and Interest	4.2	30.9	(1.8 - 9.7)
Utilities			
Electricity	1.1	8.1	(1.0 - 1.3)
Fuel	1.2	8.8	(1.1 - 1.3)
Sewage	0.3	2.2	(0.3 - 0.4)
Total Utilities	2.6	19.1	(2.4 - 3.0)
Materials			
Production	0.1	0.7	(0.1 - 0.1)
Packaging	1.0	7.4	(1.0 - 1.0)
Cleaning	0.3	2.2	(0.2 - 0.5)
Total Materials	1.4	10.3	(1.3 - 1.6)
Repair & Maintenance	0.4	2.9	(0.2 - 0.7)
Property Tax & Insurance	1.4	10.3	(0.6 - 3.4)
Other Expenses	0.1	0.7	(0.0 - 0.2)
TOTAL	13.6	100.0	(7.9 - 25.9)
Lbs of Whey Powder per Year	14.5 Million		(50.6 - 4.8)

[a] Cost per pound in a plant serving a cheese plant with a capacity of 960,000 pounds of milk, operating 21 hours per day and 6 days per week.

[b] The lower end of the range is the cost in a plant serving a cheese plant with a capacity of 2,400,000 pounds of milk per day operating 24 hours a day, 7 days per week. The higher cost figures are for a plant serving a cheese plant with a capacity of 480,000 pounds of milk per day operating 18 hours per day, 5 days per week.

In all but the smallest whey powder plant studied, the capital costs (i.e. depreciation and interest) was the most important cost category, accounting for approximately 30% of the total costs of manufacturing powder (Figure 1). Capital costs varied from 1.8 cents per pound of powder in the largest plant studied when it was operating around the clock to 9.7 cents per pound of whey powder for the smallest plant, operating only 18 hours per day, 5 days per week (Table 2).

Labor cost varied from 1.6 to 7.3 cents per pound of powder (Table 2). In the smallest plant studied, the labor cost was slightly more than the cost of depreciation and interest, unless the plant was operating way below capacity. Labor cost was second in importance to capital cost in the powder plants associated with cheese plants that could receive 720,000 or 960,000 pounds of milk (Figure 1). In the three largest plants, utilities were the second most important component of whey powder manufacturing costs. In fact, utility costs, which did not vary much from plant to plant on a cost per pound of powder basis, were essentially as important as capital costs in the largest plant studied.

Economies of Scale in Whey Powder Production

The size of plant was, by far, the most important factor affecting the manufacturing cost per pound of whey powder in the model plants (Figure 2). For example, a plant with a processing capacity of slightly more than 50 million pounds of whey powder per year had manufacturing costs of 7.9 cents per pound, while a plant with capacity of only 10 million pounds of powder production per year had costs of approximately 18.5 cents per pound (Table 3). Thus, with plants operating at capacity, the whey powder manufacturing cost per pound of powder in the smallest plant studied were nearly two and a half times the powder manufacturing cost in the largest plant studied. Operating 7 days, 24 hours, the cost per pound of powder was 4.2 cents lower (35 percent) in the largest powder plant studied (the one that would be associated with a 2.4 million pounds of milk per day cheese plant) than in a powder plant associated with a Cheddar cheese plant with a 960,000 lbs. daily milk capacity. Manufacturing costs for all modeled whey plant sizes under nine different operating schedules are found in Table 3.

FIGURE 1. COMPONENTS OF WHEY POWDER MANUFACTURING COST

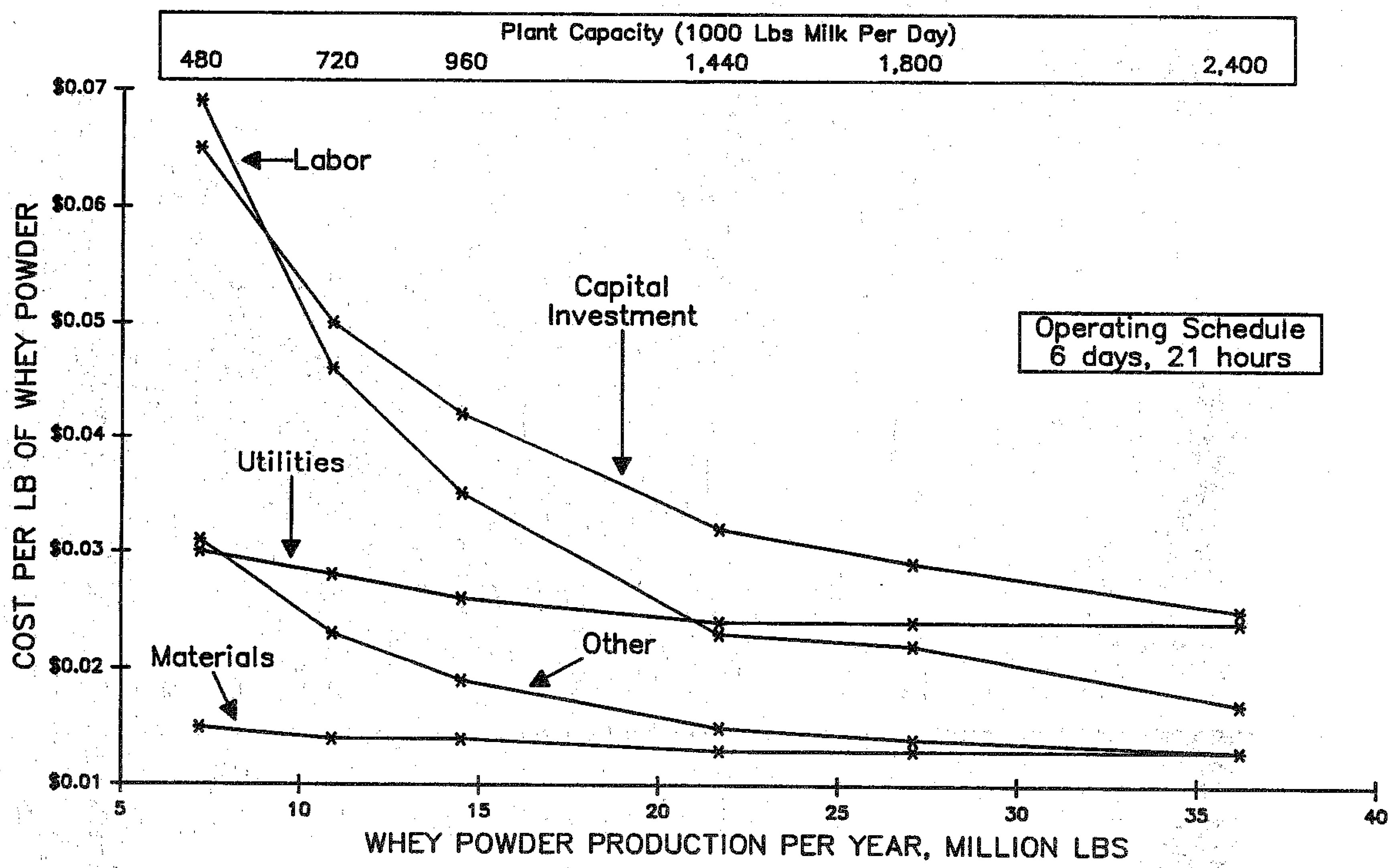


FIGURE 2. ECONOMIES OF SCALE,
WHEY POWDER MANUFACTURING COSTS

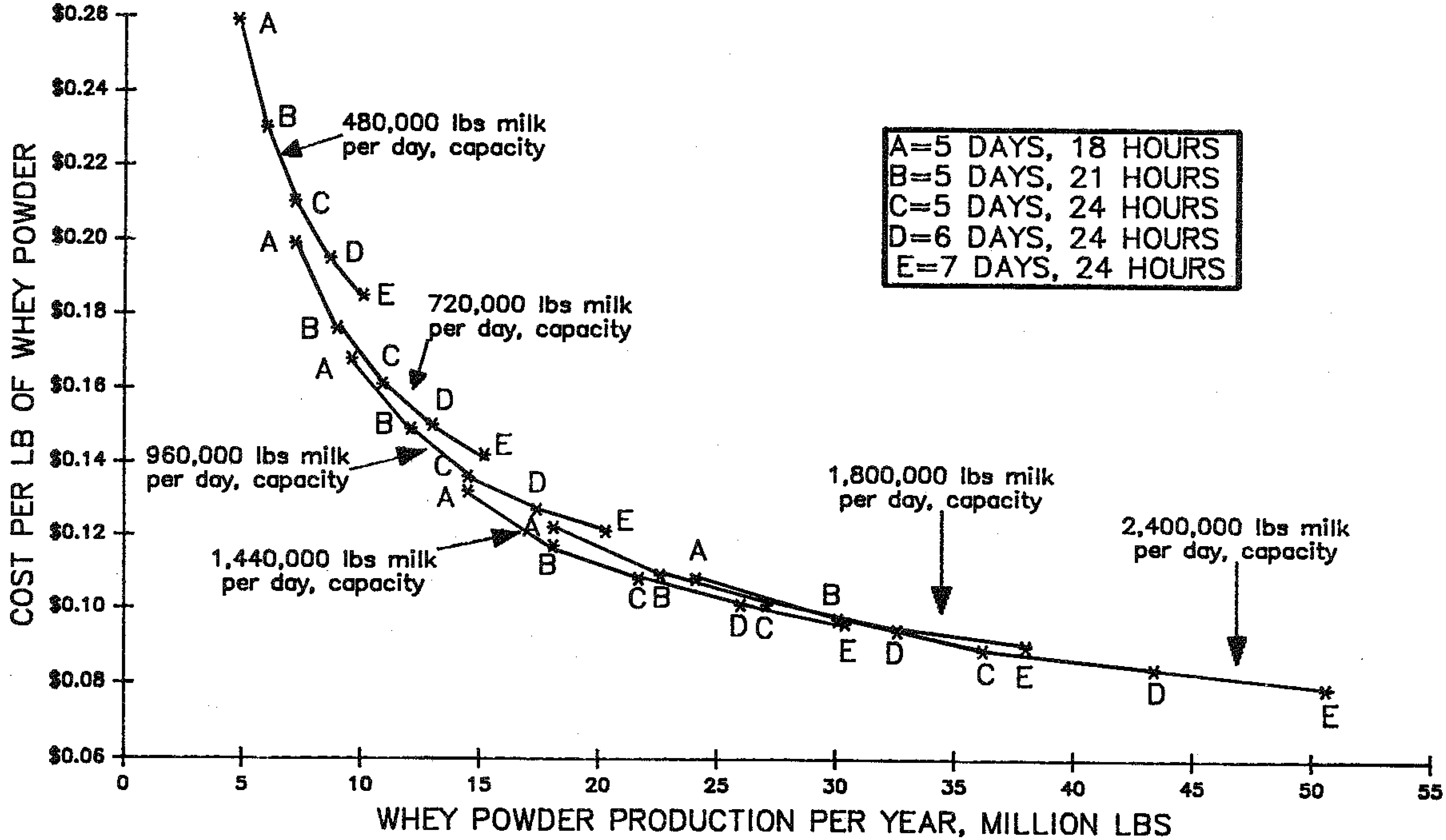


TABLE 3. Whey Powder Manufacturing Costs, Six Model Plants, Operating with Nine Production Schedules, Fall 1988[a]

Operating Schedule		Cheese Plant Capacity (1000 Pounds of Milk Per Day)					
Days	Hours	480	720	960	1,440	1,800	2,400
		cents per pound of whey powder					
5	18	25.9	19.9	16.8	13.2	12.2	10.8
	21	23.0	17.6	14.9	11.7	10.9	9.7
	24	21.0	16.1	13.6	10.8	10.1	8.9
6	18	23.8	18.2	15.4	12.1	11.3	9.9
	21	21.0	16.1	13.6	10.7	10.2	9.2
	24	19.5	15.0	12.7	10.1	9.4	8.4
7	18	22.2	17.0	14.4	11.3	10.6	9.3
	21	20.0	15.3	13.0	10.3	9.6	8.5
	24	18.5	14.2	12.1	9.6	9.0	7.9

[a]The whey powder plants accompanying these six model cheese plants would respectively produce 10.1, 15.2, 20.3, 30.4, 38.0, and 50.6 million lbs of whey powder annually operating 24 hours, 7 days per week, assuming a 5.80 lb whey powder yield per cwt raw milk.

As portrayed in Figure 2, much of the significant economies of scale in whey powder production comes from labor and capital investment. The labor and capital investment (depreciation and interest) costs per pound decrease dramatically as the size of the plant increases. The costs of utilities and materials on a per pound of powder basis are not affected much by the size of the plant. The "other" expenses, (i.e. property taxes, repair and maintenance and miscellaneous expenses), show significant economies of scale. This would be expected because property taxes and maintenance repair expenses represent the vast majority of "other expenses" in Figure 2, and both of these expenses are closely related to the capital investment, for which there are significant economies of scale.

Production Schedules

Three daily production schedules, 24, 21, and 18-hours per day, were considered together with three weekly production schedules, 7, 6, and 5-days per week. The combination of a weekly and a daily schedule determines the amount of milk and whey processed and at the same time determines the percent of plant capacity utilization. A 24 hour processing day is 18 hours of processing and 6 hours of clean-up, while a 21 hour operating day is 15 hours of processing. The resulting levels of plant utilization from each of these nine production schedules are indicated in Table 4.

TABLE 4. Percent Plant Capacity Utilization for Model Whey Plants with Different Production Schedules.

Daily Schedule	Weekly Schedule		
	7-day	6-day	5-day
	(Percent)		
24-hours	100	86	71
21-hours	83	71	60
18-hours	67	57	48

Next to the size of plant, the daily and weekly production schedules had the largest impact on manufacturing costs per pound of whey powder. The importance of production schedules on unit costs can be seen in both Figure 1 and Table 3. As the number of operating hours per day and/or the number of operating days per week increases for any size plant, the unit production costs decrease. In other words, the higher the plant capacity utilization, the lower the cost per pound of whey powder in a given size plant. By and large, the reductions in manufacturing costs associated with longer production schedules resulted from increasing the use of the fixed assets and from spreading certain fixed labor, utility, and cleaning requirements over more production.

Increasing the number of hours per day whey is processed results in a larger reduction in the unit costs of production than increasing the number of days per week the plant operates. Any change in production schedules, either in the number of operating hours per day or number of operating days per week affects the absolute unit costs in smaller plants more than it does in larger plants.

Sensitivity of Whey Powder Production Cost Estimates

The whey powder production cost estimates reported thus far have been calculated for stated conditions. The various assumptions used in modeling the whey powder plants were fixed and no changes considered up to this point. Sensitivity analysis was done to measure the impacts of different wage rates, utility rates and levels of capital investment on whey powder production rates.

Effect of Various Wage Rates. Because labor represents approximately 25% of the total costs of manufacturing whey powder in most size plants, a change in the wage rate had a rather significant effect on the manufacturing cost per pound (Table 5). Changes in wage rates had a larger effect on smaller plants than on larger ones because of lower labor productivity in the smaller operations.

Effect of Various Utility Rates. The effect of dramatic increases in utility rates (i.e. 25 and 50%) on whey powder manufacturing costs are also shown in Table 5. Because utility costs represent a relatively significant proportion of the costs of producing powder, a change in utility rates had a significant impact on powder manufacturing costs. Moreover, because there are only slight economies of scale in utilities, the impact on unit costs of production are almost as great in the large plants as in the small.

Effect of Differences in Investment Costs. Although the initial capital investments in the model plants were carefully estimated for late fall 1988, managers, for various reasons, might be interested in the effects on production costs of somewhat lower or higher initial capital investments than those assumed in the basic model plants. Thus, the effects of having two different levels of investments, (20 % lower and 20% higher than assumed), on the cost per pound were determined (Table 5).

As discussed earlier, the costs associated with the level of capital investment, namely depreciation, interest, property taxes and insurance, are very important parts of the total cost per pound of manufacturing whey powder. Thus, if for some reason the initial capital investment in buildings or equipment were different than assumed in our basic models, the cost per pound of manufacturing powder would be significantly affected. Moreover, because of significant economies of scale in the costs associated with capital investments, the effects of either higher or lower capital investments on absolute manufacturing costs are much greater in small plants than larger plants.

TABLE 5. Effects of Different Wage Rates, Utility Rates & Capital Investments on Whey Powder Manufacturing Costs, Six Model Plants Operating 21 Hours Per day, 6 Days Per Week, Fall 1988[a]

	Cheese Plant Capacity (1000 Pounds of Milk Per Day)					
Level of Cost Factor	480	720	960	1,440	1,800	2,400
	cents per pound of whey powder					
Wage Rate Per Hour						
$ 7.75	19.6	15.2	13.0	10.2	9.7	8.9
9.75	21.0	16.1	13.6	10.7	10.2	9.2
11.75	22.5	17.0	14.5	11.2	10.6	9.5
Utility Rate						
Fall 1988	21.0	16.1	13.6	10.7	10.2	9.2
+ 25%	21.7	16.7	14.3	11.2	10.7	9.7
+ 50%	22.4	17.3	14.9	11.8	11.2	10.2
Initial Capital Investment						
- 20%	19.2	14.7	12.6	9.8	9.4	8.5
Study Base	21.0	16.1	13.6	10.7	10.2	9.2
+ 20%	22.8	17.4	14.9	11.5	10.9	9.9

[a]The whey powder plants accompanying these six model cheese plants would respectively produce 7.2, 10.9, 14.5, 21.7, 27.1, and 36.2 million lbs of whey powder annually operating 21 hours, 6 days per week, assuming a 5.80 lb whey powder yield per cwt raw milk.

Whey Protein Concentrate Production Cost Estimates

Summary Findings

All conclusions on whey protein concentrate (WPC) production costs assume breakeven returns on permeate[7]. Conclusions regarding the cost of manufacturing WPC are similar to those for manufacturing whey powder, namely:

1) Estimated WPC manufacturing costs varied widely among the six model plants, from 18.7 to 78.6 cents per pound of WPC.

[7]The affects of relaxing this assumption are explored in a later section.

2) The size of plant was the most important factor affecting the cost of WPC production. The two major cost components in WPC manufacture, labor and capital costs, have significant economies of scale.

3) Next to the size of plant, the daily and weekly production schedules had the largest impact on the cost per pound of manufacturing WPC.

4) The cost per pound of manufacturing WPC is very sensitive to the yield of WPC. The basic analysis assumes a yield of 1.64 pounds of WPC per cwt of milk. This assumed yield, which is considerably below the yield that should be achievable, was used to conform with experience of several plant operators with whom we conferred.

5) WPC manufacturing costs are also rather sensitive to differences in wage rates and levels of initial capital investment, but somewhat less sensitive to increases in utility rates.

Variability in Costs

As with the manufacture of whey powder, the estimated WPC manufacturing costs varied widely among plants of different sizes and with different production schedules.

The range in WPC production estimates obtained, as well as the relative importance of the various cost components, are illustrated in Table 6. The composition of costs for each of the six whey protein concentrate plants operating on a 21 hour day, 6-day week production schedule is found in Appendix Table A9.

The estimated cost of producing WPC is 37.3 cents per pound in a plant associated with a Cheddar cheese plant with a daily milk capacity of 960,000 pounds, operating 21 hours per day, 6 days per week (Table 6). Such a plant would produce approximately 4.1 million pounds of WPC annually, while the cheese plant produced 25 million pounds of Cheddar.

The costs of producing WPC ranged from 18.7 cents per pound to 78.6 cents per pound across plant sizes and production schedules (Table 6). The low end of the range represents a WPC plant serving a Cheddar plant with a capacity of 2.4 million pounds of milk per day, operating around the clock, 7 days per week. In this situation, where the costs of producing WPC are 18.7 cents per pound, the annual production of WPC would be 14.4 million pounds, assuming a 1.64 pounds yield of WPC. On the other hand, the cost of producing WPC would be approximately 78.6 cents per pound in a WPC plant linked to a Cheddar plant with a capacity of only 480,000 pounds of milk per day, operating 18 hours per day, 5 days per week. Such a small plant would produce only 1.4 million pounds of WPC annually, operating 18 hours per day, 5 days per week.

TABLE 6. Whey Protein Concentrate Manufacturing Costs, Model Plants, Fall 1988
Note: Assumes breakeven on permeate. No costs associated with handling permeate included.

Cost Item	Cost Per Pound of WPC[a]	Percentage of Total Costs	Cost Range for Different Size Plants & Operating Schedules[b]
	cents	percent	cents/pound
Labor			
Supervisory	1.2	3.1	(0.5 - 2.7)
Direct Fixed	0.9	2.5	(0.3 - 2.3)
Direct Variable	10.0	26.6	(4.0 - 20.1)
Total Labor	12.1	32.2	(4.8 - 25.1)
Capital Costs			
Depreciation and Interest	10.9	29.0	(3.7 - 29.6)
Utilities			
Electricity	0.3	.9	(0.2 - 0.6)
Fuel	5.7	15.2	(5.3 - 6.1)
Sewage	0.4	1.2	(0.3 - 0.6)
Total Utilities	6.4	17.2	(5.8 - 7.3)
Materials			
Production	0.3	.9	(0.3 - 0.3)
Packaging	1.0	2.8	(1.0 - 1.0)
Cleaning	1.0	2.8	(0.6 - 2.1)
Total Materials	2.3	6.4	(1.9 - 3.4)
Repair & Maintenance	1.9	5.1	(1.3 - 3.0)
Property Tax & Insurance	3.4	9.1	(1.1 - 9.5)
Other Expenses	0.3	0.9	(0.1 - 0.7)
TOTAL	37.3	100.0	(18.7 - 78.6)
Lbs of WPC per Year	4.1 Million		(14.4 - 1.4)

[a]Cost per pound in a plant serving a cheese plant with a capacity of 960,000 pounds of milk per day, operating 21 hours per day and 6 days per week.
[b]The lower end of the range is the cost in a plant serving a cheese plant with capacity of 2,400,000 pounds of milk per day, operating 24 hours per day, 7 days per week. The higher cost figures are for a plant serving a cheese plant with a capacity of 480,000 pounds of milk per day, operating 18 hours per day, 5 days per week.

Economies of Scale In WPC Production

As in the production of whey powder, the most important factor affecting the manufacturing cost per pound of WPC was the size of plant (Figure 3). For example, the cost per pound of producing WPC in a plant producing 14.4 million pounds per year was 18.7 cents per pound, or only one-third that of the costs of producing WPC in a plant that produced only 2.9 million pounds of WPC per year, where the costs would be approximately 55.6 cents per pound (Table 7). The cost per pound of WPC was 14.3 cents lower, (i.e. 43 percent lower) in the largest WPC plant studied (the cost that would be associated with a 2.4 million pounds of milk per day Cheddar plant) than in a WPC plant that would be linked to a Cheddar plant with a 960,000 lbs daily milk capacity.

Essentially all of the economies of scale in WPC production stem from economies of scale in labor, capital investment (depreciation and interest), and the so-called "other expenses" (Figure 4). The "other expense" category in this figure is largely composed of repair and maintenance expense, property taxes, and insurance, with the latter two closely tied to the level of capital investment. These three expense categories decrease dramatically on a per pound of WPC basis as the size of plant increases. On the other hand, utilities and materials expenses exhibit essentially no economies of scale.

Labor and capital (depreciation and interest) costs were the most important cost categories in all but the largest plant, which was designed to serve a Cheddar plant with a capacity of 2.4 million pounds of raw milk per day (Figure 4). In that largest plant, the cost of utilities was slightly higher per pound of WPC than either labor or capital costs. In the three smallest model WPC plants, labor represented a slightly higher proportion of the total cost per pound of producing WPC than did depreciation and interest. In the next two largest WPC plants, the labor cost per pound of WPC and the depreciation and interest cost per pound were essentially the same.

Utilities were the third most important component of WPC production costs in all but the largest plant, where they exceeded labor and capital costs (Figure 4). Utility costs did not vary widely from plant to plant on a cost per pound of WPC basis.

FIGURE 3. ECONOMIES OF SCALE,
WHEY PROTEIN CONCENTRATE MANUFACTURING COSTS

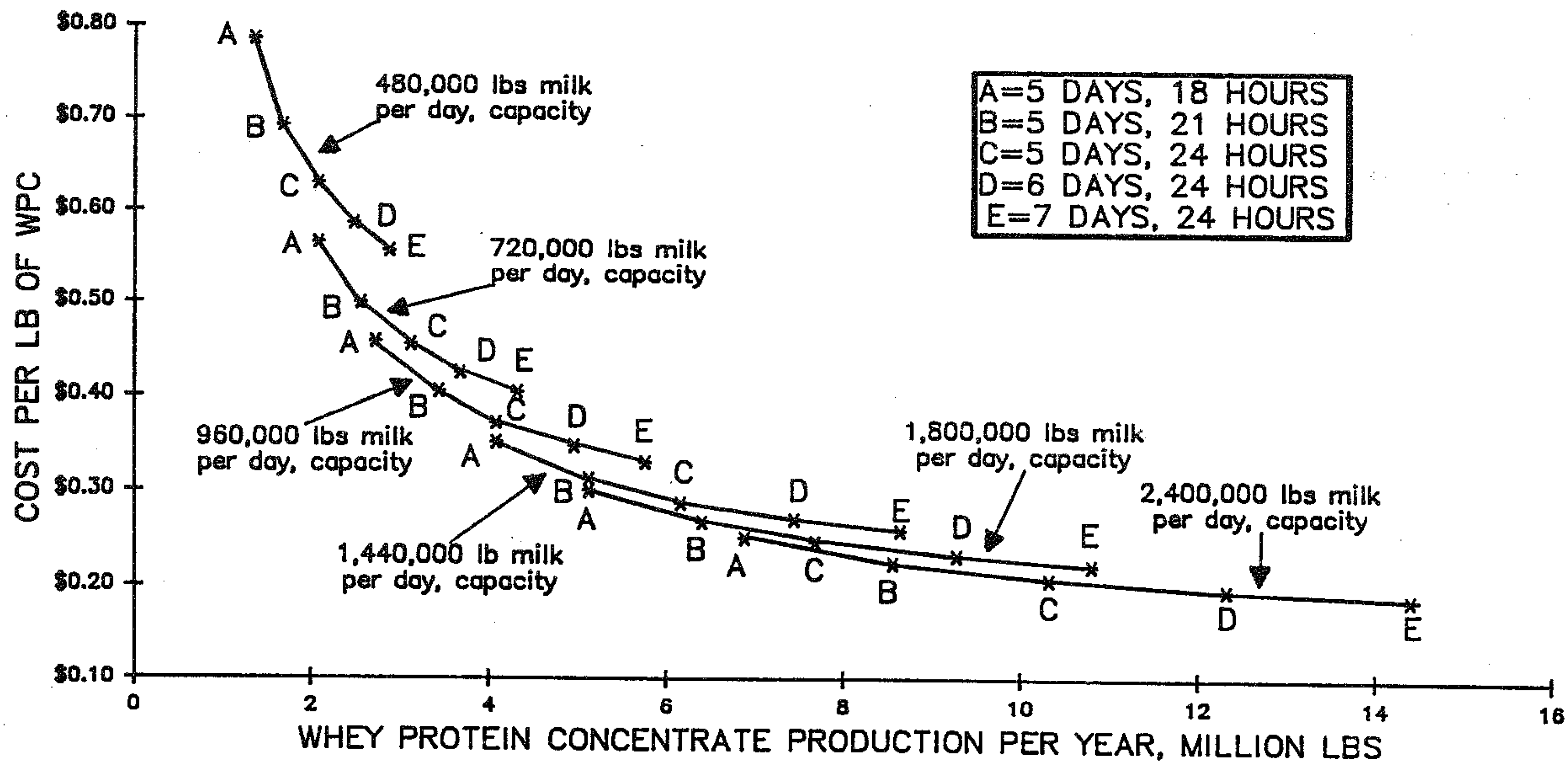
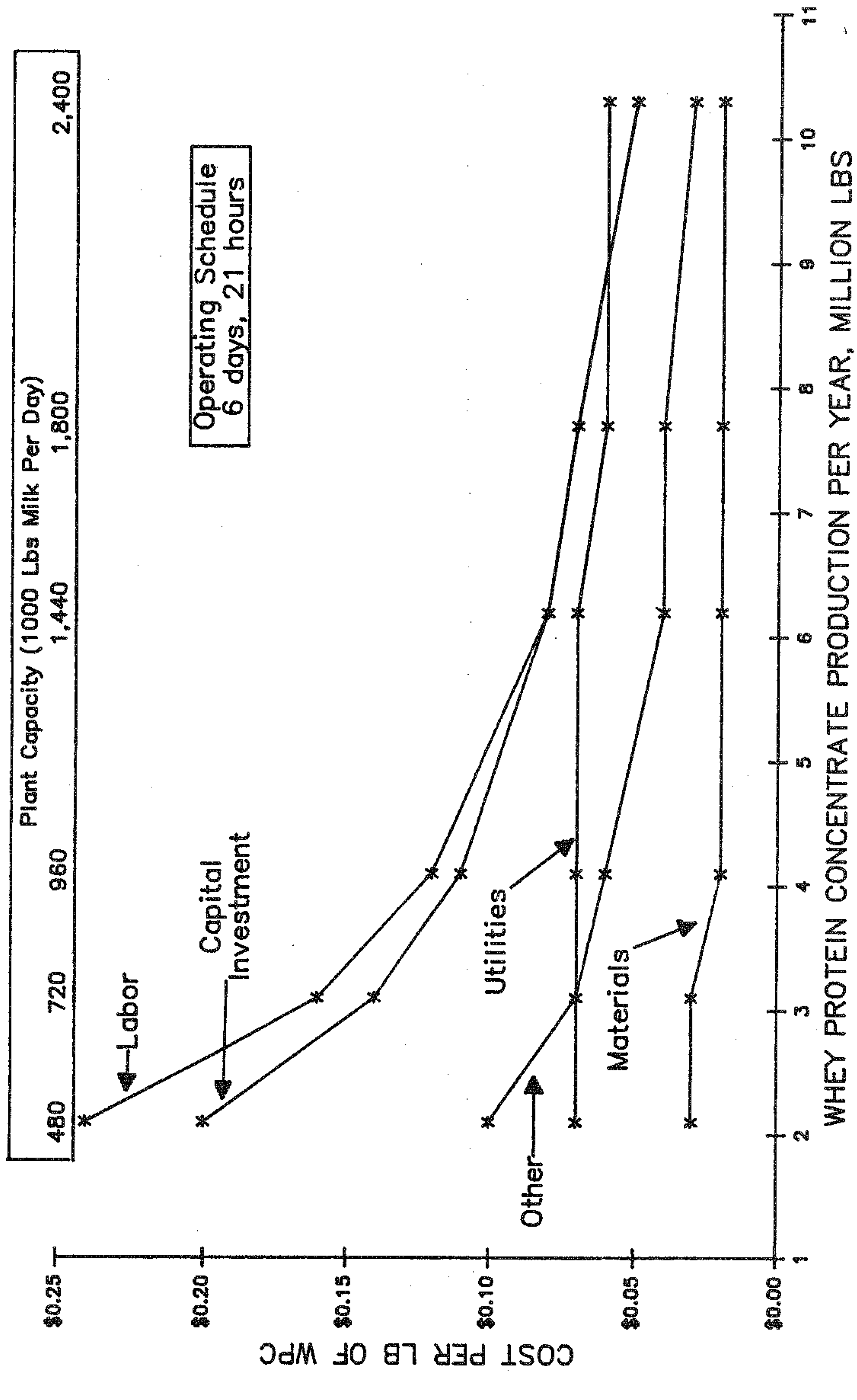


FIGURE 4. COMPONENTS OF WPC MANUFACTURING COST



Production Schedules

Again, as with whey powder production, the daily and weekly production schedules had a significant impact on the cost of manufacturing WPC, second only to plant size in their cost impact (Table 7). As the number of operating hours per day and/or the number of operating days per week increased for any given size plant, the cost per pound of WPC decreased.

Increasing the number of hours per day that a WPC plant operates results in a larger reduction in the unit costs of production than increasing the number of days per week the plant operates. Any change in production schedule, either a change in number of operating hours per day or number of operating days per week reduces the absolute cost per pound of WPC production more in a small plant than in a large plant.

TABLE 7. Whey Protein Concentrate Manufacturing Costs, Six Model Plants, Operating With Nine Different Production Schedules, Fall 1988[a]
Note: Assumes breakeven on permeate.

Operating Schedule		Cheese Plant Capacity (1000 Pounds of Milk Per Day)					
Days	Hours	480	720	960	1,440	1,800	2,400
		cents per pound of WPC					
5	18	78.6	56.5	45.8	35.1	30.0	25.0
	21	69.2	49.9	40.5	31.2	26.7	22.4
	24	62.9	45.5	37.1	28.7	24.6	20.7
6	18	72.1	51.9	42.1	32.4	27.8	23.2
	21	64.0	46.2	37.3	29.1	24.8	21.1
	24	58.6	42.5	34.7	27.0	23.2	19.6
7	18	67.4	48.6	39.6	30.6	26.2	22.0
	21	60.3	43.7	35.6	27.7	23.8	20.1
	24	55.6	40.4	33.0	25.8	22.2	18.7

[a]The whey protein concentrate plants accompanying these six model cheese plants would respectively produce 2.9, 4.3, 5.7, 8.6, 10.8, and 14.4 million lbs of WPC annually operating 24 hours, 7 days per week, assuming a 1.64 lb WPC yield per cwt raw milk.

Sensitivity of WPC Production Cost Estimates

The sensitivity of our WPC production cost estimates to differences in wage rates, utility rates, level of initial capital investment and yield differences was analyzed.

Effects of Wage Rates and Levels of Capital Investment. As in the case of whey powder production costs, both labor expenses and the costs associated with the level of capital investment (i.e. depreciation, interest, property taxes and insurance) represent such a large proportion of the total cost of producing WPC that differences in wage rates and differences in initial capital investment levels have significant impacts on the cost per pound of WPC (Table 8). Changes in wage rates and differences in the level of capital investment had larger impacts on smaller plants than on larger ones because of lower labor productivity and higher capital investments per pound of WPC production in the smaller plants.

TABLE 8. Effects of Different Wage Rates, Utility Rates & Capital Investments on <u>Whey Protein Concentrate</u> Manufacturing Costs, Six Model Plants Operating 21 Hours Per day, 6 Days Per Week, Fall 1988
Note: Assumes breakeven on permeate.

Level of Cost Factor	Cheese Plant Capacity (1000 pounds of Milk Per Day) 480	720	960	1,440	1,800	2,400
			cents per pound of WPC			
Wage Rate Per Hour						
$ 7.75	59.0	43.0	34.9	27.5	23.6	20.1
9.75	64.0	46.2	37.3	29.1	24.8	21.1
11.75	68.9	49.5	39.8	30.8	26.1	22.1
Utility Rate						
Fall 1988	64.0	46.2	37.3	29.1	24.8	21.1
+ 25%	65.6	47.8	38.8	30.7	26.2	22.4
+ 50%	67.3	49.4	40.4	32.2	27.5	23.8
Initial Capital Investment						
- 20%	58.8	42.7	34.6	27.1	23.1	19.7
Study Base	64.0	46.2	37.3	29.1	24.8	21.1
+ 20%	69.3	50.0	40.2	31.2	26.5	22.4

[a]The whey protein concentrate plants accompanying these six model cheese plants would respectively produce 2.1, 3.1, 4.1, 6.2, 7.7, and 10.3 million lbs of WPC annually operating 21 hours, 6 days per week, assuming a 1.64 lb WPC yield per cwt raw milk.

Effect of Utility Rates. The effects of dramatic increases in utility costs (i.e. 25 and 50%) are shown in Table 8. An increase of 25 percent in utility rates increases the cost of WPC production from 1.3 cents to 1.6 cents per pound of WPC in the model plants, depending on the size of plant. However, since there are only small economies of scale in utilities, the impact on unit costs is only slightly greater in small plants than large.

Effect of WPC Yields. Because widely varying WPC yields were reported by plant operators, all of which were significantly lower than the seemingly achievable theoretical yield, sensitivity of WPC production costs to changes in yield in the model plants was analyzed (Table 9). Keep in mind only the effects on costs of production are reflected in Table 9. The much more important effect of lost revenue from lower yields is analyzed later when the profitability of WPC production is considered.

A yield of 1.64 lbs of WPC per cwt of milk received at the cheese plant was assumed in the basic model plants. To appraise the effects of variation in WPC yields on production costs, yields of 1.5 lbs per cwt of milk and 1.78 lbs per cwt of milk were also analyzed. As seen in Table 9, differences in WPC yield significantly affected costs. The direct impact on costs is due to the fact that with lower yields, less WPC is produced with the same amount of labor, utilities and equipment. The lower the yield, the higher the production cost per pound of WPC.

The absolute changes in production costs due to changes in WPC yield are larger for the smaller, higher-cost plants than for the larger lower-cost plants. However, the percentage impact of a change in WPC yield on production costs is similar for all size plants. A change in WPC yield of one percent results in a change of about one percent, in the opposite direction, in the production costs per pound of WPC. This relationship reflects the fact that, except for packaging supplies which vary directly with the total weight of WPC produced, the total production costs in a WPC operation are not affected by changes in the WPC yield. On the other hand, the volume of WPC over which these essentially stable production costs are spread varies the same relative amount as the WPC yield.

TABLE 9. Effects of Different WPC Yields on Whey Protein Concentrate Manufacturing Costs, Six Model Plants Operating 21 Hours Per Day, Six Days Per Week, Fall 1988.
Note: Assumes breakeven on permeate.

	Cheese Plant Capacity (1000 Pounds Milk Per Day)					
WPC Yields	480	720	960	1,440	1,800	2,400
	Manufacturing Costs, cents per lbs of WPC					
WPC = 1.50 lbs/cwt milk	69.7	50.4	41.0	31.8	27.1	23.0
WPC = 1.64 lbs/cwt milk	64.0	46.2	37.3	29.1	24.8	21.1
WPC = 1.78 lbs/cwt milk	58.8	42.5	34.6	26.8	23.1	19.4
	Annual WPC Production, Million Lbs					
WPC = 1.50 lbs/cwt milk	1.9	2.8	3.7	5.6	7.0	9.4
WPC = 1.64 lbs/cwt milk	2.0	3.1	4.1	6.2	7.7	10.3
WPC = 1.78 lbs/cwt milk	2.2	3.3	4.4	6.7	8.3	11.1

Profitability of Whey Powder and Whey Protein Concentrate Manufacturing

Overview and Assumptions

The final objective of this research was to estimate the profitability of manufacturing whey powder and WPC under various product price conditions, in different size plants and, in the case of WPC, with different yields and different permeate handling cost scenarios.

The profitabilities of whey powder and WPC production were estimated using the approach illustrated in Table 10. The estimated profitabilities of whey powder and WPC manufacture are quoted in terms of dollars per cwt of raw milk received for Cheddar cheese because that provides a common denominator needed given the different yields of the two types of whey products.

Several things should be kept in mind regarding the profitability analyses that follow:

1. No charge for raw whey is made by the cheese plant to the whey plant operation.

2. The whey powder and WPC manufacturing cost estimates are based on the earlier reported model plants operating 6 days per week, 21 hours per day (i.e. at 71 percent of capacity). For any given size plant, operating the whey plant closer to capacity would make the whey handling operation more profitable. Conversely, operating the plant fewer hours per day or fewer days per week would lead to higher powder or WPC manufacturing costs and lower profits.

3. For the basic profitability analyses, the whey powder yield is assumed to be 5.80 pounds per cwt of milk received for Cheddar cheese. The yield of WPC is assumed to be 1.64 pounds per cwt of milk. Sensitivity analysis is done to measure the effects of WPC yields ranging from 1.5 lbs to 1.78 lbs per cwt of milk received for Cheddar cheese manufacture.

4. The whey powder price of $.18 per pound and WPC price of $.72 per pound used in the basic analyses represent the average prices for human food grade whey powder and WPC for the two years January 1988 through December 1989.[8] However, the sensitivity of the profitability of the whey handling operations is estimated with prices of whey powder ranging from $.13 to $.28 per pound and WPC prices from $.52 to $.82 per pound. All powder and WPC prices are

[8]USDA, Dairy Market News, Agricultural Marketing Service, Dairy Division, selected issues, 1988-90.

the whey plant loading docks and do not cover any costs associated with product marketing.

5. In the basic analysis of WPC profitability, it is assumed that after the UF permeate exits the UF hardware all further costs and revenues breakeven. However, sensitivity analysis is used to evaluate the impacts of net losses or net gains on permeate. As will be seen, the profitability of manufacturing WPC relative to whey powder is very sensitive to whether the plant makes a gain, breakeven, or loses on handling permeate.

TABLE 10. Sample Worksheet to Calculate the Operating Profit Per Cwt of Milk From Whey Handling In a Cheddar Plant That Can Receive 960,000 Pounds of Milk Per Day[a]
Note: No charge made to whey operation for raw whey.

WHEY POWDER		$ Per Cwt of Milk
REVENUES		
Whey Powder Yield (lbs/cwt raw milk)	5.80	
Whey Powder Price ($/lb powder)	.18	
Total Revenue		$1.04
COSTS		
Whey Powder Yield (lbs/cwt raw milk)	5.80	
Whey Powder Manufacturing Costs ($/lb powder)	.14	
Total Costs		.81
OPERATING PROFIT FROM WHEY POWDER		.23
WHEY PROTEIN CONCENTRATE -- ASSUMING BREAKEVEN ON PERMEATE		
REVENUES		
Whey Protein Concentrate Yield (lbs/cwt raw milk)	1.64	
Whey Protein Concentrate Price ($/lbs WPC)	.72	
Total Revenue		1.18
COSTS		
WPC Yield (lbs/cwt raw milk)	1.64	
WPC Manufacturing Costs ($/lb of WPC)	.37	
Total Costs		.61
OPERATING PROFIT FROM WHEY PROTEIN CONCENTRATE		$ .57

[a]Assumes plant operating 6 days, 21 hours per day.

Profitability Under Various Conditions

During the two-year period ending December 1989, the prices of human food grade whey powder and WPC ranged widely. The following figures and analyses demonstrate the effects of these varying product prices on total profitability. Remember, these profitability estimates assume there is no charge to the whey plants for the raw whey and that the WPC plants breakeven on permeate handling.

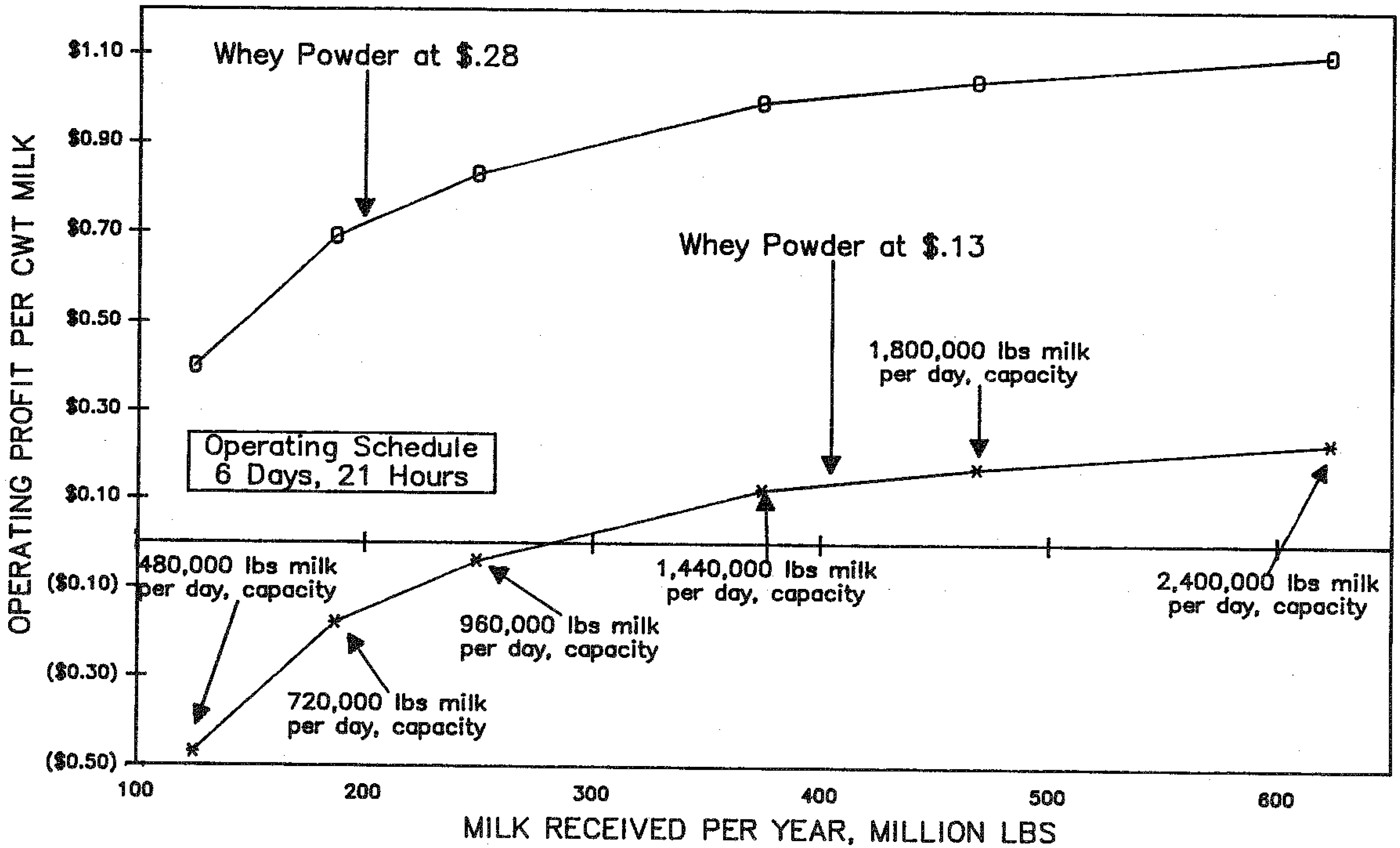
As shown in Figure 5 and Table 11, with whey powder at $.28 per pound, it would be profitable to manufacture powder in all size plants studied. In fact, in the four largest plants studied (i.e. 960,000 lbs milk per day capacity or more), the estimated operating profit from the whey operation would range from $.83 to $1.10 per cwt of raw milk received for Cheddar cheese, depending on plant size. On the other hand, with powder at $.13 per pound, the three smallest plants studied would lose money on whey powder and the maximum profit would be $.23 per cwt in the largest plant size, (Table 11).

TABLE 11. Whey Plant Operating Profits With Different Whey Powder and WPC Prices, Six Model Plants Operating 21 Hours Per Day, Six Days Per Week, Fall 1988.
Note: Assumes no charge to whey operation for raw whey and breakeven on permeate.

Cheddar Plant Capacity Lbs Raw Milk Received Per Day	Whey Powder[a] Price of Whey Powder Per Lb				WPC[b] Price of WPC Per Lb			
	$.13	$.18	$.23	$.28	$.52	$.62	$.72	$.82
	dollars per cwt of milk							
480,000	-.47	-.18	.11	.40	-.20	-.03	.13	.29
720,000	-.18	.11	.40	.69	.09	.26	.42	.58
960,000	-.04	.25	.54	.83	.23	.40	.56	.72
1,440,000	.12	.41	.70	.99	.37	.54	.70	.86
1,800,000	.17	.46	.75	1.04	.44	.61	.77	.93
2,400,000	.23	.52	.81	1.10	.50	.67	.83	.99

[a]Assumes whey powder yield = 5.80 lbs per cwt raw milk
[b]Assumes WPC yield = 1.64 lbs per cwt raw milk

FIGURE 5. WHEY POWDER PROFITABILITY
WHEY POWDER = $.13 & $.28 PER LB



Turning to WPC, Figure 6 shows the profitability of manufacturing WPC under prices of $.52 and $.82 per pound. Assuming the plant breaks even on handling the permeate and has a WPC yield of 1.64 pounds per cwt of milk received for cheese, the manufacture of WPC is profitable in all except the smallest plant size studied, even at $.52 per pound (Figure 6 and Table 11). To be profitable in the smallest plant studied, however, the WPC price would have to be approximately $.65 per pound, indicating again the dramatic economies of scale. At a WPC price of $.82 per pound, profits range from $.29 to $.99 per cwt of milk, depending on plant size (Table 11).

During the two years ending December 1989, the actual whey powder and WPC prices averaged $.18 and $.72 per pound, respectively.[9] Figure 7 and Table 11 show that at these product prices it would have been profitable to produce either whey powder or WPC in all of the model operations studied except the smallest powder plant, which would have lost $.18 per cwt of raw milk received for Cheddar. For all other sizes of whey powder plants studied and for every size of WPC plant studied, these actual average product prices would have resulted in an operating profit.

Figure 7 and Table 11 also indicate that at these average prices, namely $.18 for whey powder and $.72 per pound for WPC, the manufacture of WPC would be decidedly more profitable than whey powder (by approximately $.30 per cwt of raw milk for most plants) <u>if permeate handling were a breakeven operation</u>. However, as indicated in the next section, the relative profitability of WPC and whey powder is quite sensitive to whether the WPC plants gain, break even or lose money due to permeate handling.

<u>Still assuming breakeven on permeate handling</u>, the prices at which manufacturing whey powder and WPC would be approximately equally profitable are presented in Table 12 and are valid for all plant sizes studied. Thus, manufacturing <u>either</u> whey powder or WPC would be approximately equally profitable for the following whey powder, WPC price combinations for all plant sizes: powder at $.13 per pound, WPC at $.36 per pound; powder at $.18, WPC at $.53; powder at $.23, WPC at $.71; and powder at $.28 with WPC at $.89 (Table 12). Realize also, that these are only four examples, and that any whey powder price could be used to calculate an equally profitable WPC price or vice versa.

[9] ibid.

FIGURE 6. WHEY PROTEIN CONCENTRATE PROFITABILITY
WPC = $.52 & $.82 PER LB

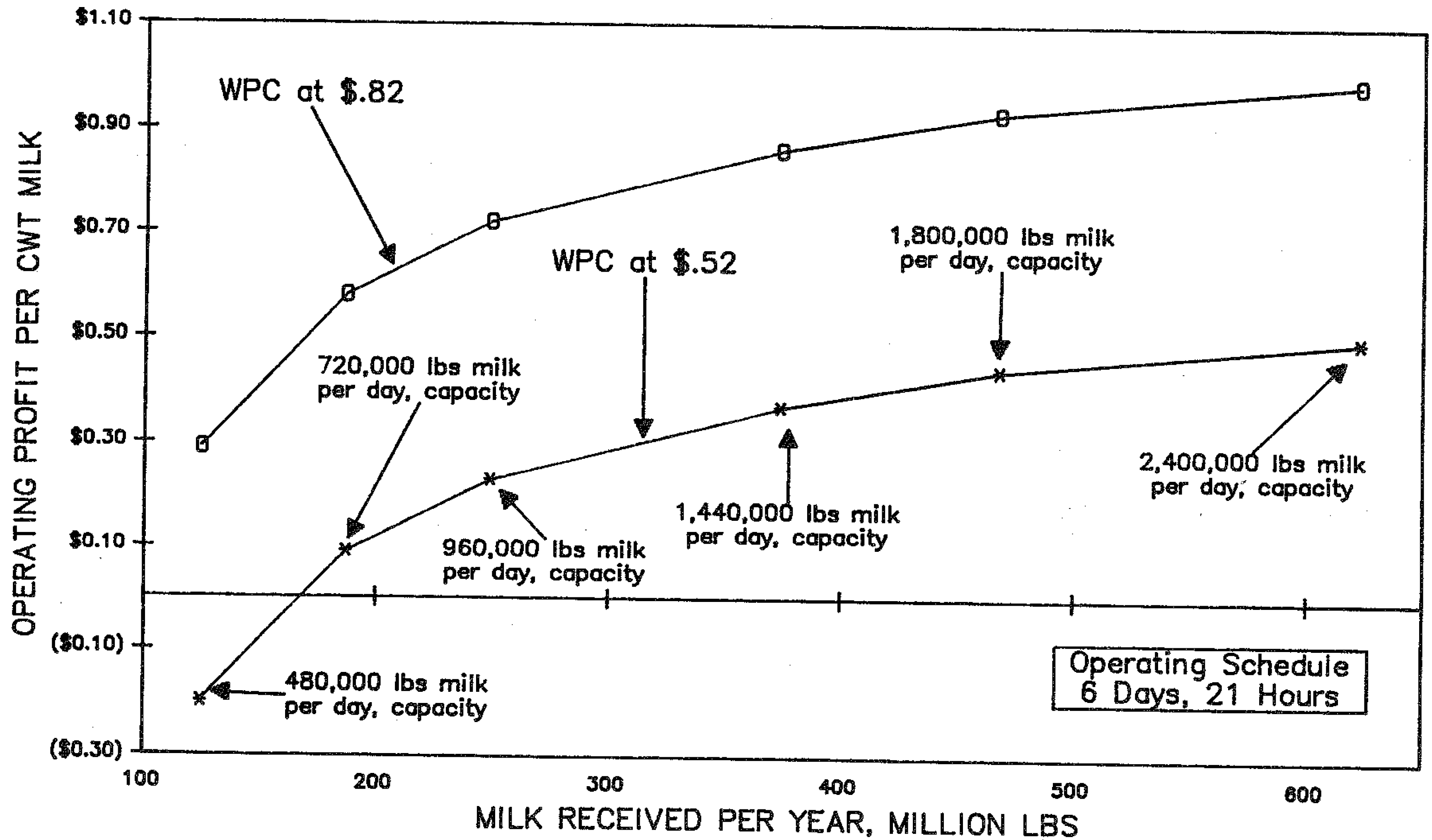


FIGURE 7. PROFITABILITY OF WHEY POWDER COMPARED TO WPC
WHEY POWDER = $.18 WPC = $.72, 1988–89 AVERAGES

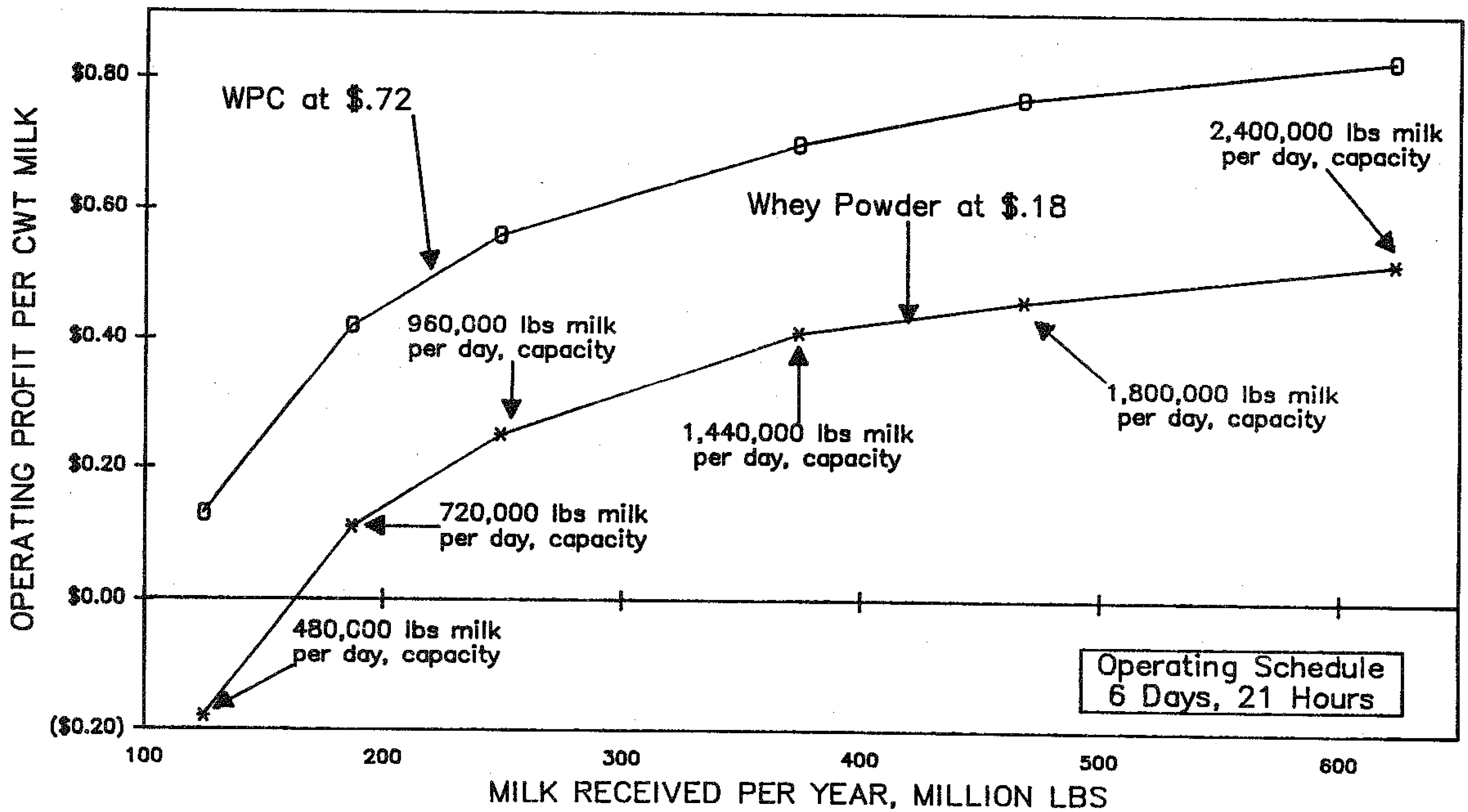


TABLE 12. Whey Powder and WPC Prices that Yield the Same Profitability Regardless of Plant Size, Assuming Breakeven on Permeate, with All Plants Operating 21 Hours Per Day, 6 Days Per Week, Fall 1988. Note: Assumes no charge to whey operation for raw whey.

Whey Powder Price[a]	Price of WPC Yielding Same Profit per Cwt of Milk Received[b]
Dollars Per Lb	
.13	.36
.18	.53
.23	.71
.28	.89

[a]Assumes whey powder yield = 5.80 lbs per cwt raw milk
[b]Assumes WPC yield = 1.64 lbs per cwt raw milk

Effects of Permeate Handling Situation

In the cost/profitability analysis of WPC manufacture reported thus far, it has been assumed that all costs of handling the large volume of permeate once it leaves the UF equipment are covered by revenues received for the permeate (i.e. breakeven). Permeate is a dilute solution (5 to 6% solids) of milk lactose and minerals in water. Milk lactose accounts for most of the solids content of permeate. Because of the low solids content, high volumes, and perishability of UF permeate, any further processing of permeate to recover the milk solids is costly. In most cases the value of low purity lactose (i.e. dried permeate) is relatively low, while drying costs can be quite high. However, further processing and purification of lactose (at additional cost) can substantially increase the value of lactose for use in specialized pharmaceutical applications. Unfortunately, the supply of lactose exceeds the commercial demand, particularly in the higher value methods of utilization.

If a cheese manufacturer is to manufacture WPC, it is important to find some method to utilize UF permeate that will breakeven or even provide a gain. This is not an easy task. The profit or loss on permeate could be influenced greatly by the plant location. The possible profit or loss on permeate may be the most important factor in deciding whether to build a plant to make whey powder or WPC.

The assumption that the WPC plants breakeven on handling permeate is very important to the profitability estimates for manufacture of WPC. The impacts of three net loss scenarios for permeate handling ($.02, .06, and .12 per pound of permeate solids) on total WPC profitability at a WPC price of $.72 per pound are shown in Table 13. The $0.02 loss per pound of solids was selected to reflect the loss per pound of permeate solids that would be incurred if the permeate were land spread. The loss of $.12 per pound of solids reflects a scenario where full permeate drying costs are incurred and very little revenue is realized from the sale of the dried permeate. When the breakeven scenario is compared to the loss of $.12 per pound of permeate solids for the medium size (960,000 lbs of milk per day) Cheddar cheese plant, it can be clearly seen that profitability in the WPC business depends on the minimization of loss on the handling of permeate solids. The down side risk is very large in WPC manufacture and therefore having a reliable and low cost alternative for permeate disposal is extremely important. In most cases this alternative has been land spreading of liquid permeate. However as environmental regulations become more limiting, land spreading of permeate will be only a temporary solution.

As shown in the example of a $.02 per pound of permeate solids gain (Table 13), any small net gain on the handling and sale of permeate solids is attractive. Future technological research needs to focus on finding new commercial uses (food or nonfood) for milk lactose that can at least recover the permeate handling and processing costs.

The profit or loss on handling permeate greatly influences the profitability of a WPC operation (Table 13) and thus the prices of WPC that yield the same profitability as various whey powder prices (Table 14). For example, at the average price of whey powder (i.e. $.18) for the 2 year period ending December 1989, the price of WPC that provides equal profitability if you breakeven on permeate is $.53 per pound. This is well below the $.72 per pound average for that period. However, if you lose $.06 per pound of solids on permeate, then the WPC price necessary to have equal profitability with whey powder increases to $.71. This demonstrates the extreme sensitivity of WPC profitability to loss on permeate.

TABLE 13. Sensitivity of WPC Operating Profits to Costs of Handling Permeate, Six Model Plants Operating 21 Hours Per Day, Six Days Per Week, Fall 1988. Note: Assumes no charge to whey operation for raw whey.

Cheddar Plant Capacity Lbs Raw Milk Received Per Day	WPC at $.72 per Pound[a]				
	Permeate Handling Loss or Gain Per Pound of Solids				
	Loss			Breakeven	Gain
	$.12	$.06	$.02		$.02
	dollars per cwt of milk				
480,000	-.23	-.05	.07	.13	.19
720,000	.06	.24	.36	.42	.48
960,000	.20	.38	.50	.56	.62
1,440,000	.34	.52	.64	.70	.76
1,800,000	.41	.59	.71	.77	.83
2,400,000	.47	.65	.77	.83	.89

[a]Assumes WPC yield = 1.64 lbs per cwt raw milk

TABLE 14. Whey Powder and WPC Prices that Yield the Same Profitability Regardless of Plant Size, Under Various Permeate Handling Situations, with All Plants Operating 21 Hours Per Day, 6 Days Per Week, Fall 1988. Note: Assumes no charge to whey operation for raw whey.

Whey Powder Price[a]	Price of WPC Yielding Same Profit per Cwt of Milk Received[b] — Permeate Handling Loss or Gain Per Pound of Solids				
	Loss			Breakeven	Gain
	\$.12	\$.06	\$.02		\$.02
	Dollars Per Lb				
.13	.72	.54	.42	.36	.30
.18	.89	.71	.59	.53	.47
.23	1.07	.89	.77	.71	.65
.28	1.25	1.07	.95	.89	.83

[a]Assumes whey powder yield = 5.80 lbs per cwt raw milk
[b]Assumes WPC yield = 1.64 lbs per cwt raw milk

Conclusions on Profitability

The profitability of manufacturing either whey powder or WPC is very sensitive not only to the market prices of the products but also, because of the significant economies of scale, to the size of the whey product plant.

The prices for whey powder and WPC averaged approximately $.18 and $.72 per pound, respectively, during the two years ending December 1989. At these product prices, and assuming no charge to the whey plant for the raw whey and a breakeven situation on permeate in the WPC operation, it would have been profitable (operating 6 days, 21 hours) to produce either whey powder or WPC in all of the model operations studied, except the smallest whey powder plant which would have lost almost $.18 per cwt of milk received for cheese. In fact, for a whey product plant serving a Cheddar plant receiving 960,000 pounds of milk per day or more, the manufacture of either whey powder (at $.18/lb) or WPC (at $.72/lb) would contribute an operating profit of from $.25 per cwt of milk to $.83 per cwt of milk received for cheese manufacture, depending on the size of plant and the product produced (Table 11).

During the two years ending with December 1989, the price of human food grade whey powder was as low as about $.12 per pound and that of WPC as low as $.60 per pound. Even assuming no charge for the raw whey, the sale of whey powder for a price of $.12 per pound would be unprofitable in plants associated with cheese plants with capacities handling 960,000 pounds of raw milk per day or less. On the other hand, assuming a breakeven situation on permeate, the production of WPC at prices of $.60 per lb would have been profitable except in the smallest plant studied (Table 11).

Results suggest that at the average prices prevailing from January 1988 to December 1989, namely $.18 for whey powder and $.72 per pound for WPC, the manufacture of WPC was more profitable than whey powder unless the plant lost more than 6 cents per pound of solids in handling permeate (Tables 11 and 13). The profitability of manufacturing WPC relative to whey powder is very sensitive to whether the plant makes a gain, breaks even, or loses on handling permeate as well as to the relative prices of WPC and powder. Yields of WPC are also very important.

With plants handling relatively small volumes of whey, it is very difficult to produce either whey powder or WPC competitively because of high manufacturing costs per pound. For small plants the possible options for minimizing costs or losses on handling whey, rather than producing either whey powder or WPC, include the following alternatives, none of which was studied in this research:

1. Field spreading, if land is available, where costs of $.02 to $.04 per pound of solids will be incurred .

2. Hauling whey back to farms for animal feeding, for which costs may be similar to field spreading but without the possible environmental concerns.

3. Drying the whey for animal feed.

4. Condensing the whey and selling the condensed whey to an ice cream manufacturer or to a larger whey plant for processing into whey powder.

APPENDIX TABLES

TABLE A1. Building Areas and Land Requirement Factors for Model <u>Whey Powder</u> Plants of Different Sizes.

Plant Size (Pounds of Milk per Day)	Building Area (Square Feet)	Land Factor[a]
480,000	9,951	3.023
720,000	11,694	2.672
960,000	13,178	2.443
1,440,000	15,334	2.186
1,800,000	18,270	1.929
2,400,000	22,361	1.677

[a]Land acres per 10,000 square feet of building area.

TABLE A2. Building Areas and Land Requirement Factors for Model <u>Whey Protein Concentrate</u> Plants of Different Sizes.

Plant Size (Pounds of Milk per Day)	Building Area[a] (Square Feet)	Land Factor[b]
480,000	8,138	3.537
720,000	8,504	3.416
960,000	9,052	3.253
1,440,000	9,984	3.015
1,800,000	10,353	2.932
2,400,000	11,257	2.750

[a]Does not include building area for permeate storage or processing.
[b]Land acres per 10,000 square feet of building area.

TABLE A3. Selected Equipment Specifications for Model Whey Powder and Whey Protein Concentrate Plants of Different Sizes[a]

	Cheese Plant Size (1000 Pounds of Milk Per Day)					
Technology & Equipment	480	720	960	1,440	1,800	2,400
WHEY POWDER:						
Evaporators	1	1	1	1	1	1
Crystallizing Tanks	3	3	3	3	3	3
Spray Dryer	1	1	1	1	1	1
WPC:						
UF System	2 stage	2 stage	3 stage	4 stage	4 stage	5 stage
Membrane Modules	42	60	72	112	144	180

[a]Whey powder equipment increases in size in conjunction with plant capacity.

TABLE A4. Total Initial Capital Investment for Model Whey Powder Plants of Different Sizes.
Note: Includes investment in land, building, and equipment for model whey powder plants. Does not include any investment for accompanying cheese plants.

Capital Investment	Cheese Plant Size (1000 Pounds of Milk Per Day)					
	480	720	960	1,440	1,800	2,400
	(Dollars)					
Land	111,822	115,794	119,131	124,044	130,428	139,948
Building	1,862,996	2,125,749	2,302,730	2,496,510	2,997,492	3,692,153
Equipment	3,244,048	3,743,347	4,190,124	4,956,822	5,394,609	6,176,772
Total Invest.	5,218,866	5,984,890	6,611,985	7,577,377	8,522,529	10,008,873

TABLE A5. Total Initial Capital Investment for Model Whey Protein Concentrate Plants of Different Sizes.
Note: Includes investment in land, building, and equipment for model WPC plants. Does not include any investment for accompanying cheese plants or for permeate handling.

Capital Investment	Cheese Plant Size (1000 Pounds of Milk Per Day)					
	480	720	960	1,440	1,800	2,400
	(Dollars)					
Land	106,470	107,452	108,919	111,344	112,281	114,506
Building	1,170,746	1,191,420	1,225,973	1,282,338	1,302,946	1,355,930
Equipment	3,067,031	3,217,366	3,429,007	3,739,248	3,895,630	4,026,914
Total Invest.	4,344,247	4,516,238	4,763,899	5,132,930	5,310,857	5,497,350

TABLE A6. Daily Labor, Electricity, Natural Gas, Water, and Sewage Requirements for Model Whey Powder Plants of Different Sizes Operating 24 Hours Per Day

Input Items	Units	Cheese Plant Size (1000 Lbs Milk per Day)					
		480	720	960	1,440	1,800	2,400
Labor							
Supervisory	Hrs/Day	8	8	8	8	8	8
Fixed	Hrs/Day	8	8	8	8	9	9
Variable	Hrs/Day	128	128	128	128	151	151
Electricity							
Fixed	KWH/Op. Hrs	16	17	18	18	20	21
Variable	KWH/Million Lbs Milk	11,774	11,112	10,282	9,775	9,366	8,981
Natural Gas							
Fixed	Therms/Hour	0	0	0	0	0	0
Variable	Therms /Million Lbs Milk	2,044	1,797	1,897	1,697	1,684	1,603
Water	Gallons /Day	19,978	23,505	24,270	26,630	35,270	40,210
Sewage	Gallons /Day	63,804	89,955	113,673	161,179	204,009	265,592

TABLE A7. Daily Labor, Electricity, Natural Gas, Water, and Sewage Requirements for Model Whey Protein Concentrate Plants of Different Sizes Operating 24 Hours Per Day
Note: No permeate handling is assumed

Input Items	Units	Cheese Plant Size (1000 Lbs Milk per Day)					
		480	720	960	1,440	1,800	2,400
Labor							
Supervisory	Hrs/Day	8	8	8	8	8	8
Fixed	Hrs/Day	9.5	9.5	9.5	9.5	9.5	9.5
Variable	Hrs/Day	122.5	122.5	122.5	122.5	122.5	122.5
Electricity							
Fixed	KWH/Op. Hrs	18	19	21	22	23	24
Variable	KWH/Million Lbs Milk	718	508	413	306	245	214
Natural Gas							
Fixed	Therms/Hour	44	56	59	81	85	106
Variable	Therms /Million Lbs Milk	2,478	2,412	2,380	2,430	2,243	2,220
Water	Gallons /Day	17,616	20,024	22,489	28,789	33,858	35,086
Sewage	Gallons /Day	26,994	34,927	42,918	62,136	70,751	84,547

TABLE A8. Whey Powder Manufacturing Costs for Six Model Plants Operating 21 Hours Per Day, Six Days Per Week, Fall 1988[a]

Cost Item	Cheddar Plant Capacity (1000 Lbs Milk Per Day)					
	480	720	960	1,440	1,800	2,400
	cents per pound of whey powder					
Labor						
Supervisory	0.6	0.4	0.3	0.2	0.2	0.2
Direct Fixed	0.4	0.3	0.2	0.1	0.1	0.1
Direct Variable	5.9	3.9	3.0	2.0	1.9	1.4
Total Labor	6.9	4.6	3.5	2.3	2.2	1.7
Capital Costs						
Depreciation and Interest	6.5	5.0	4.2	3.2	2.9	2.5
Utilities						
Electricity	1.3	1.2	1.1	1.0	1.0	1.0
Fuel	1.3	1.2	1.2	1.1	1.1	1.1
Sewage	0.4	0.4	0.3	0.3	0.3	0.3
Total Utilities	3.0	2.8	2.6	2.4	2.4	2.4
Materials						
Production	0.1	0.1	0.1	0.1	0.1	0.1
Packaging	1.0	1.0	1.0	1.0	1.0	1.0
Cleaning	0.4	0.3	0.3	0.2	0.2	0.2
Total Materials	1.5	1.4	1.4	1.3	1.3	1.3
Repair & Maintenance	0.7	0.5	0.4	0.3	0.3	0.3
Property Tax and Insurance	2.3	1.7	1.4	1.1	1.0	0.9
Other Expenses	0.1	0.1	0.1	0.1	0.1	0.1
TOTAL	21.0	16.1	13.6	10.7	10.2	9.2
Million Lbs of Whey Powder Per Year	7.2	10.9	14.5	21.7	27.1	36.2

[a]Assuming a whey powder yield of 5.80 pound per cwt of raw milk.

TABLE A9. Whey Protein Concentrate Manufacturing Costs for Six Model Plants Operating 21 Hours Per Day, Six Days Per Week, Fall 1988[a]
Note: Assumes breakeven on permeate. No costs associated with permeate handling included.

Cost Item	Cheddar Plant Capacity (1000 Lbs Milk Per Day)					
	480	720	960	1,440	1,800	2,400
	cents per pound of WPC					
Labor Supervisory	2.2	1.5	1.2	0.8	0.7	0.6
Direct Fixed	1.9	1.2	0.9	0.6	0.5	0.4
Direct Variable	20.1	13.4	10.0	6.7	5.3	4.0
Total Labor	24.2	16.1	12.1	8.1	6.5	5.0
Capital Costs						
Depreciation and Interest	19.8	13.8	10.9	7.9	6.5	5.1
Utilities						
Electricity	0.6	0.4	0.3	0.3	0.2	0.2
Fuel	6.0	5.8	5.7	5.8	5.4	5.3
Sewage	0.6	0.5	0.4	0.4	0.4	0.3
Total Utilities	7.2	6.7	6.4	6.5	6.0	5.8
Materials						
Production	0.3	0.3	0.3	0.3	0.3	0.3
Packaging	1.0	1.0	1.0	1.0	1.0	1.0
Cleaning	1.7	1.2	1.0	0.9	0.8	0.8
Total Materials	3.0	2.5	2.3	2.2	2.1	2.1
Repair & Maintenance	3.0	2.3	1.9	1.6	1.5	1.3
Property Tax and Insurance	6.3	4.4	3.4	2.5	2.0	1.6
Other Expenses	0.5	0.4	0.3	0.3	0.2	0.2
TOTAL	64.0	46.2	37.3	29.1	24.8	21.1
Million Lbs of WPC Per Year	2.0	3.1	4.1	6.2	7.7	10.3

[a]Assuming WPC yield of 1.64 pounds per cwt of milk

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