The Commercial Potential of New Dairy Products from Membrane Technology

John W. Siebert, Alejandro Lalor, and Sung-Yong Kim

Membrane filtration technologies are capable of creating entirely new, more functional food products. In this regard, potential new dairy products include high-protein, low-lactose fluid milk, high-protein, low-lactose ice cream, and nonfat yogurt made with fewer stabilizers. An initial survey of membrane manufacturing companies determined the added cost to produce such functional food products to be two to six percent of the existing retail price for similar standard dairy products. A subsequent survey of milk processors found that the most likely adopters of such membrane technologies were yogurt manufacturers.

Membrane filtration technologies, such as ultrafiltration and reverse osmosis, are capable of the molecular fractionation of fluids. Milk is ideally suited for processing by membrane filtration because it is a fluid consisting largely of water, lactose, butterfat, and protein molecules. Separation at the molecular level means that butterfat, lactose, and protein can be isolated from one other. Through the use of cellulose filters and high pressure pumps, membrane technologies take the two-dimensional concept of the venerable cream separator (i.e., milk in, cream and skim out) into the third dimension and even beyond.

Membrane technologies have brought about substantial change in the dairy industry (International 1991). However, because of the rapid pace of innovation many new dairy products created by membrane technology have not yet gained effective consumer demand. As David Hettinga, Vice President and Chief Technical Office of Land O' Lakes, stated, "one of the problems with this technology is we have a product or a technology chasing the market" (Berry 2000, p.32). The purpose of this research is to introduce readers to the membrane process and then attempt to assess the consumer demand for a few such new products.

The traditional dairy manufacturing paradigm has been to separate whole milk into cream and skim milk using a centrifuge. The skim milk is then often evaporated to produced condensed skim. Most dairy products are made using various combinations of milk, cream, skim, and condensed skim. The shortfall of this traditional technology approach is that protein and lactose (the main ingredients of skim) are bound to one another. A key value of membrane technology is that it enables a separation of these two ingredients. With membrane technology, protein, butterfat, and lactose can be used to manufacture dairy products more directly. Should sales of milk increase due to the development of new products, total dairy-farmer income would be likely to increase as well. With approximately 590,000,000 pounds of nonfat dry milk currently in government warehouses, research into demand expansion remains a high priority for dairy farmers (USDA 2001).

Technology Review

The most widely accepted dairy applications of membrane technology have been cost-reducing in nature. For example, most modern cheese plants use membrane technology to extract valuable protein isolates from the whey stream (Sienkiewicz and Riedel 1990). Whey-protein concentrate is currently an important source of income to all large cheese makers. The portion of a modern cheese plant devoted to whey-product manufacturing and storage can be almost as large as that devoted to cheese. Due solely to the ability of membrane technology to extract protein from whey, whey is no longer a disposal problem—it is now a profit center.

In New Zealand, membrane technology is used to produce a powdered dairy product consisting largely of butterfat and protein. Due to its func-

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tionality, this ingredient—called dry ultrafiltered milk or milk protein concentrate (MPC)—can be used to make cheese. MPC is imported to the United States for the purpose of boosting cheese-plant yields. In this regard it is a substitute for domestic nonfat dry milk, and for this reason has been viewed as a threat to the U.S. milk price support program (U.S. General Accounting Office 2001; NMPF 2000).

Dairy farmers in remote regions of the United States have used membrane technology to reduce raw milk transportation costs. At the farm, ultrafiltration is being used to remove lactose and water from milk. Also at the farm, reverse osmosis is being used to remove water from milk (Halladay 2000).

Membrane technology will likely replace the traditional cheese vat in the future. The traditional cheese vat is a large kettle (e.g., 5,000-gallon capacity) that uses calf rennet, heat, and agitation in order to yield cheese curd and whey from milk. The curds are then pressed into blocks of cheese and aged. Membrane technology has the potential to produce cheese by molecular separation of lactose from the butterfat and protein. This would allow the design of equipment that accepts milk as an input and produces liquid cheese and whey as outputs. The liquid cheese stream could then be poured into forms for hardening and aging.

The objective of this research was to determine if membrane technology has the potential to create new commercial dairy products for direct purchase by consumers. The key questions investigated concern the capabilities of membrane technology, the economics of producing new consumer products, and the consumer market potential of any such new products.

Before new consumer dairy products such as these can be found and evaluated, the technology must first be understood. Figure 1 provides a membrane technology diagram. This figure shows a fluid being pumped across a membrane under high pressure. Smaller particles pass through the membrane and are termed permeate. Larger particles cannot pass through and are denoted as retentate.

The membrane filtration process can be performed at progressive levels of molecular selectivity. Reverse Osmosis (RO) is a term denoting a very fine membrane-filtration process. To understand filtration in its application to dairy, consider that raw milk consists largely of water, lactose, butterfat, protein, and minerals. Applying RO to milk would thus produce a permeate which consists mainly of water and a retentate which consists of water, lactose, butterfat, protein, and minerals. Ultrafiltration (UF) allows somewhat larger molecules to pass through the membrane than does RO. In this case, not only water but also lactose molecules will pass through the membrane. Thus, applying UF to milk produces both a permeate consisting of water and lactose and a retentate consisting of water, lactose, butterfat, and protein. (Cheryan 1998)

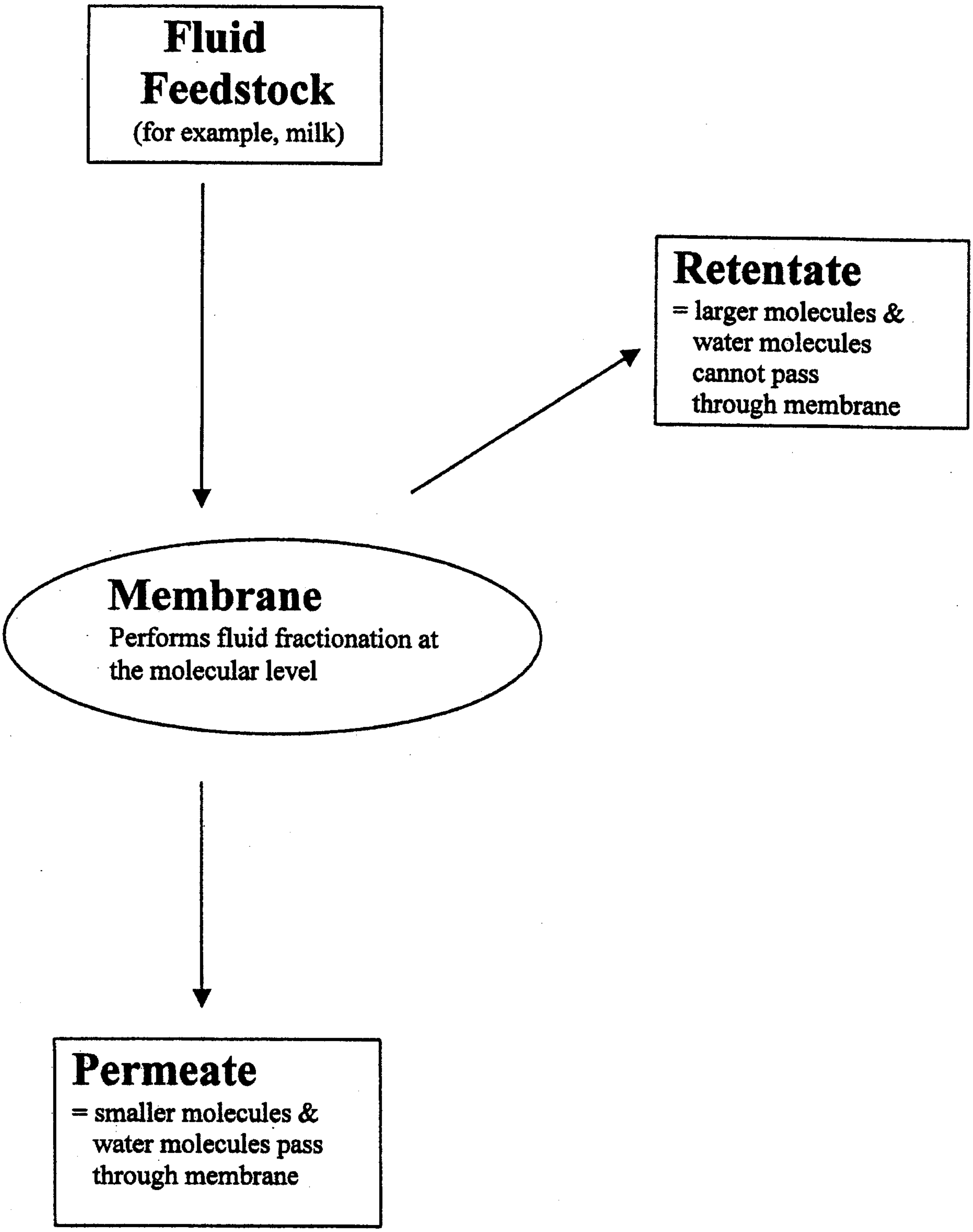
Equipment Industry Survey

To gain an understanding of the current status of membrane technology in the dairy industry, the authors made an initial survey of the membrane-equipment industry. Our objective was to learn about potential new consumer dairy product applications of membrane technology. We contacted nineteen firms involved in various combinations of equipment manufacturing, facilities and/or equipment design, and equipment installation.

The authors found these nineteen firms through advertisements in the dairy trade press, through suppliers listed in the International Dairy Foods Association Membership Directory, and through attendees at a Texas A&M University Short Course on Membrane Technology. The authors do not know what percentage of the dairy membrane manufacturing industry was contacted through their survey but the percentage is believed to be high, as all known firms were contacted. Also, the supplier industry is relatively concentrated. Thus, despite the small number of firms involved, this sample should be considered representative of the dairy membrane equipment industry during 1999. The firms contacted served the entire United States. Nine of the thirteen firms were headquartered in either Minnesota or Wisconsin. Several of the firms were subsidiaries of international companies.

Thirteen of the nineteen firms contacted participated, a response rate of 68 percent. The responding firms viewed membrane technology as advancing rapidly in terms of fractionation selectivity, methods, and reliability. Technological advances usually originate in Australia, New Zealand, or Western Europe. Consequently, U.S. firms often employ technology after it has proven its value elsewhere. Two dairy industry forces, when taken

Figure 1. The membrane filtration process is initiated by a fluid being pumped over a membrane. This causes fractionation at the molecular level.



in combination, likely explain why New Zealand, Europe and Australia have historically taken the lead in the development of membrane technologies. First, the U.S. Food and Drug Administration has restricted dairy manufacturers from using membrane technology in the production of traditional dairy products such as cheese. The FDA must approve on a firm-by-firm and case-by-case basis that the product manufactured with membrane technology has no compositional or organoleptic differences when compared to a product made in full conformance with regulatory Standards of Identity (Mohr et al.1988, p.64, 65). Second, the U.S. price-support program only offers stand-by purchasing authority for cheese, butter, and nonfat dry milk; therefore, membrane-based dairy products such as milk protein concentrate powder would not qualify for the program. As a result, U.S. dairy-industry investment is often made in traditional production technology in order to reduce exposure to price risk.

Manufacturers were asked about the future of membrane technology. The consensus was that by-product extraction at the dairy processing plant would be the main area for the future impact of membrane technology. Specifically, eight of twelve manufacturers who responded to a question concerning whether the biggest impact of membrane technology would be at the processing plant or at the farm felt the biggest impact would be at the plant. Ten of eleven manufacturers who responded to a question concerning whether the biggest impact of membrane technology would be upon dairy products or dairy by-products (e.g., on cheese as opposed to cheese whey) felt that the biggest impact would be in the by-product area.

Three New Product Concepts

Seven of ten manufacturers who responded to a question concerning whether membrane technology would be better at producing new dairy products or existing dairy products felt that the biggest impact would be upon new products. The following new consumer product ideas were gleaned from the membrane industry: [1]

[1] Equipment manufacturers often work under confidentiality agreements. As a result, some of the most advanced new dairy products, such as the extraction of lactoferrin or immunoglobulin, were beyond the scope of this research.

1. Protein-fortified, 2% reduced-fat milk can be made by a combination of whole milk, skim milk, and skim milk retentate. This product recipe had 18 percent more protein than regular 2% reduced-fat milk without increased lactose levels.
2. High-protein, low-lactose ice cream can be made by a combination of sweet cream, skim milk retentate, and nonfat dry milk. The desirability of this product results from substituting protein for lactose. The recipe evaluated had 48 percent more protein and 32 percent less lactose than regular ice cream.
3. Nonfat yogurt can be made with more protein and therefore less stabilizers. This product can be made by a combination of skim milk, skim milk retentate, and nonfat dry milk. The particular product recipe evaluated had 15 percent more protein and 21 percent less lactose than regular nonfat yogurt.

These products all substitute protein for lactose. The addition of protein can bring more product body, better mouthfeel, and higher product viscosity. The reduction of lactose brings little in the way of reduced sweetness as lactose has only one-sixth to one-third the sweetness of sucrose (Chandon and Shahani1993). Any such loss of sweetness can easily be countered by the addition of a small amount of sugar.

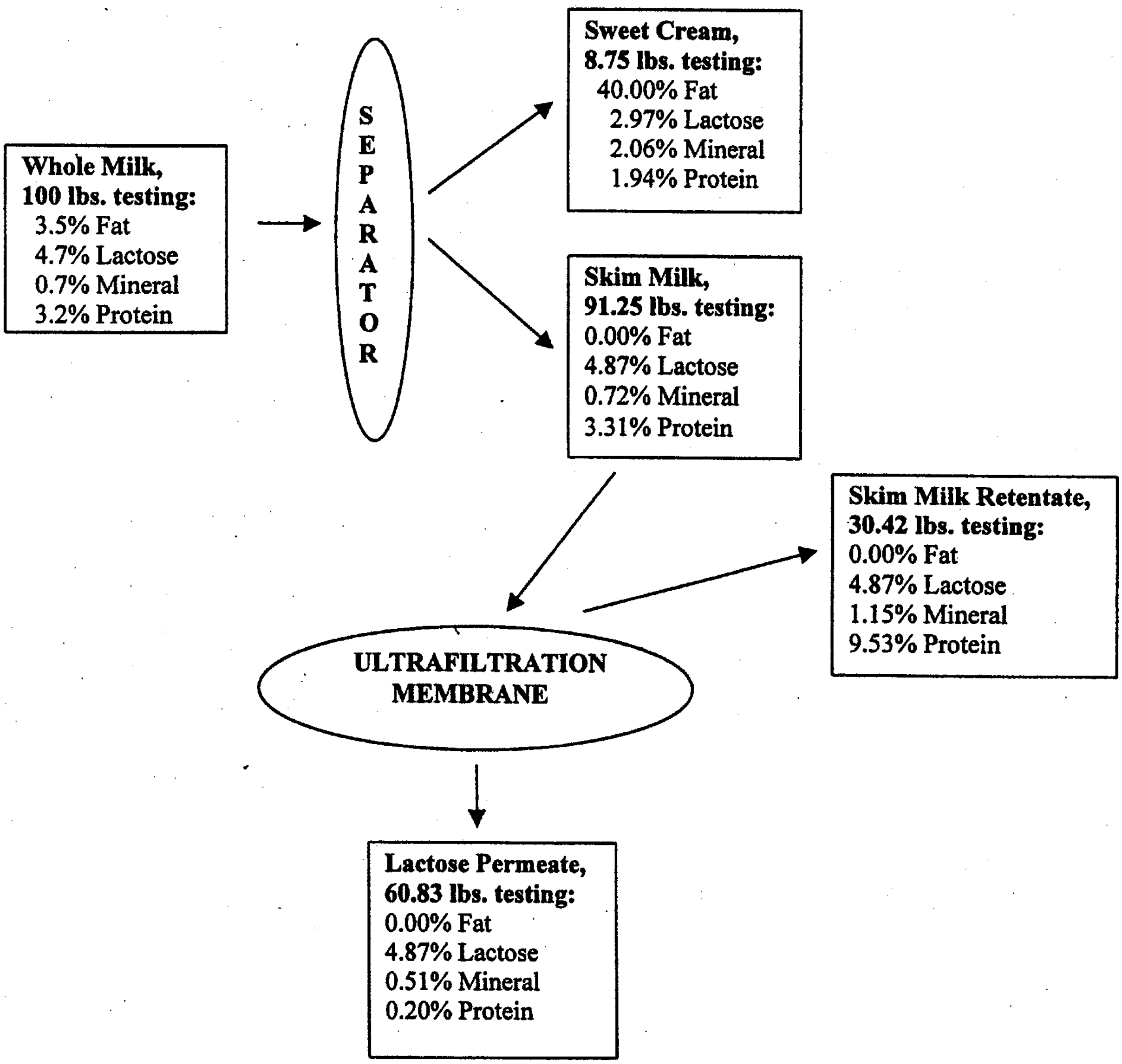
Focusing just on yogurt, the major benefits are two-fold. First, less product separation will occur. In other words, less liquid whey will form and separate from the yogurt curd. Second, if yogurt is made using non-dairy stabilizers, then product label-purity is compromised. The non-dairy stabilizers which might be used for this purpose could include any of the following ingredients: starch, pectin, gelatin, vegetable gums (carboxymethyl cellulose, locust bean, or guar), or seaweed gums (such as alginates or carrageenans) (Chandan and Shahani1993, p.29; Robinson and Tamime 1993, p.4).

To understand the important role of protein and why increased protein content is beneficial, consider the properties of two well-known dairy products, cheese and butter. The major difference between cheese and butter is that butter contains 80 percent milkfat, while cheddar cheese contains approximately 32 percent milkfat and 31 percent protein. Even though butter contains less moisture than cheddar cheese, it remains a softer product. In addition, butter's weak texture makes it unsuitable for eating out of hand while a substantial amount of cheese is eaten in this fashion. Finally, even though many different varieties of butter can be made, only one basic style is popular. In contrast, many different styles of hard cheese exist because protein is capable of conveying the tastes associated with different starter cultures and manufacturing methods.

Can substituting protein for lactose reduce lactose levels enough to be beneficial to lactose intolerant consumers? The enzyme lactase is responsible for the digestion of lactose in the small intestine. Individuals whose bodies produce insufficient lactase are said to be lactose intolerant. The severity of such lactose intolerance can vary from one individual to another. For individuals with only mild intolerance, the reductions achieved by a protein-for-lactose substitution could be beneficial. This would be particularly true for yogurt, which contains other beneficial bacteria to aid digestion (U.S. National Institutes of Health).

To make each of these products, skim milk

Figure 2. Flow and mass balance for the manufacture of skim milk retentate, the building block of new dairy products*



* Protein includes true protein as well as non-protein nitrogen.

retentate (SMR) is needed. As Figure 2 shows, SMR is produced by ultrafiltering skim milk to create a fluid isolate with a high protein-to-lactose ratio. As a result, SMR can reduce lactose content while increasing protein content. This means that protein can be substituted for lactose, improving the nutritional profile of dairy foods as well as their taste and texture. Further, it means that protein can substituted for the texture, functionality, and mouthfeel of butterfat.

Cost of Concepts

U.S. dairy processing firms evaluate the purchase of new equipment very carefully due to budgetary constraints. Detailed system-cost information was provided by four equipment manufacturers and is shown in Table 1. Capital costs pertain to the membrane system and system hardware but exclude the cost for connection to utilities such as water, steam, and electricity. Specific capital costs include assembly, balance tanks, design engineering, electrical wiring, flow meters, gauges, installation, membrane housing, membranes, pipes, pressure gauges, process control computer, pumps, temperature recorders, and valves. Capital costs were $455,000 for the fluid milk and yogurt membrane systems and $1,240,000 for the higher-capacity ice cream system. Membrane systems are relatively small and can usually be installed within an existing building; therefore, no cost for a building has been included. Capital costs were depreciated on a straight-line basis over ten years. Operating costs include those for membrane replacement, replacement of other parts, electricity, water, steam, sanitation materials, and labor. The third and final cost area pertains to the extra cost of the milk itself. This results from inexpensive lactose being replaced by expensive protein. Note that although the ice cream system was more expensive, since it re-

Table 1. Estimated Costs to Manufacture New Dairy Products

Characteristic	High-Protein 2% Butterfat Fluid Milk	High-Protein, Lower-Lactose Ice Cream Mix	High-Protein Nonfat Yogurt Mix
System Production / Day	375,000 lbs. milk	200,000 lbs. mix	100,000 lbs. mix
System Capital Cost [a]	$455,000.00	$1,240,000.00	$455,000.00
10-Yr. Depreciation (312 day basis)	$145.83/day	$397.44/day	$145.83/day
Operating Cost [a]	$675.00/day	$2,025.00/day	$675.00/day
Daily Capital & Operating Cost	$820.83/day	$2,422.44/day	$820.83/day
Capital & Operating Cost per Unit	$0.22/cwt.	$1.21/cwt.	$0.82/cwt.
Added Milk Cost [b]	$1.62/cwt.	$3.59/cwt.	$1.40/cwt.
Total Added Cost	$1.84/cwt. (or $0.16/gal.)	$4.80/cwt. (or $0.41/gal. Mix)	$2.22/cwt. ($0.19/gal. Mix)
Average Retail Price [c]	$2.50/gal.	One gallon of mix will make four half-gallons of ice cream selling for $3.00 each.	One gallon of mix will make 17 eight-ounce cups of yogurt selling for $0.50 each.
Total Added Cost / Average Retail Price	6.4%	3.4%	2.2%

Sources:
[a] Membrane manufacturers' estimates
[b] Milk Market Administrator, Southwest Marketing Area, April 1999
[c] Authors' estimate

quired greater capacity due to its greater substitution of protein for lactose, only one system-cost alternative was examined for each product. Debt was not included in the cost calculations.

The total added cost to make high-protein fluid milk was $0.16 per gallon. Using an average retail price of $2.50 per gallon, the resulting cost increase relative to retail price is 6.4 percent. The added cost for the high-protein, lower-lactose ice cream mix was estimated at $0.41 per gallon of mix. Because of the incorporation of air, one gallon of ice cream mix will make four half-gallons of frozen ice cream. This equates to a cost increase of $0.1025 per half-gallon of frozen ice cream. Using an average retail price of $3.00 per half-gallon of ice cream, the resulting cost increase relative to retail price would be 3.4 percent. The added cost for high-protein nonfat yogurt was estimated at $0.19 per gallon of mix. One gallon of yogurt mix will make 17 eight-ounce. cups of yogurt. Using an average retail price of $0.50 per cup, the resulting cost increase versus retail price would be 2.2 percent.

Survey of Milk Processors

In order to estimate the potential success of these new product concepts, a survey instrument was sent to U.S. dairy processors. Participants were informed of the particulars of the new product concept and supplied with the estimated cost of manufacturing the new dairy product. Background information was requested in a variety of areas including the respondent's opinion as to why customers purchased their existing dairy products, the importance of private-label products, the size of the firm, and the frequency of the respondent's contact with end-customers. The survey also asked whether the firm presently employed any membrane technology for dairy purposes (only 10 percent did so), whether the respondent thought consumers would buy the new product, and requested suggestions for increasing the probability of the new product's commercial success.

A total of 179 firms were contacted, of which 63 completed the survey for a total response rate of 35 percent. These 63 firms included 26 fluid milk processors, 21 ice cream manufacturers, and 16 yogurt manufacturers. The individuals surveyed were plant managers and/or those designated by each firm's receptionist as being most likely to make new product and/or new equipment decisions.

The survey instrument presented the new product idea, the equipment needed, the capital cost, the operating cost, and the increase in milk-component cost. Most of the interviews were initiated with a telephone call and then carried out by fax communication. Copies of the survey instruments are available from the authors upon request.

Statistical Findings

Table 2 presents the results of t-tests on mean differences. These compare the characteristics of firms which predicted consumers would be willing to buy the new products (SUCCESS = 1) versus firms which predicted consumers would not be willing (SUCCESS = 0). The first three lines of Table 2 pertain to firm type, which includes fluid milk bottling (FLUID), ice cream manufacturing (ICECR), and yogurt manufacturing (YOGURT). Among firms predicting new product failure (SUCCESS=0), 50 percent are fluid bottlers. In contrast only 28 percent of firms predicting new product success are fluid bottlers. P-values pertaining to this particular mean difference test are below 0.10. This indicates with greater than 10-percent certainty that these means are statistically different. In the case of ice cream (ICECR), the means are too close to make a generalization regarding ice cream makers and their predictions of new-product success. However, almost 16 percent of those predicting new-product failure are yogurt makers (YOGURT) whereas 40 percent of those predicting new-product success are yogurt makers. The p-values pertaining to this mean difference test are below 0.05 indicating with greater than 5-percent certainty that such means are different. Thus we conclude that being a fluid bottler is negatively associated with a prediction of new product success, whereas being a yogurt maker is positively associated with such a prediction.

Table 2 reveals, on the basis of high p-values, that current users of membrane technology (USENOW) are no more likely than non-users to make a prediction of new product success. The same can be said of a host of variables associated with why respondents felt consumers presently purchased their firm's existing dairy products. These variables include brand identity (BRAND), price level (PRICE), product quality (QUAL), packaging (PACK), private label (PVLAB), and other reasons (OTHERY).

The percentage of a milk processor's sales attributable to private labels is also examined in Table 2. In this section, only processors with private label sales greater than zero but less than one-third (PL<1/3) showed evidence of a relationship between the degree of private label manufacturing and the prediction of new product success. In this case, those in the PL<1/3 category are less likely to view these products as being successful.

Table 2 reveals on the basis of high p-values

Table 2. Mean Difference Tests Comparing the Responses of 25 Firms Predicting New Product Success Versus 38 Firms Predicting New Product Failure.

Variable Name	Group Means SUCCESS = 0 (n=38)	Group Means SUCCESS = 1 (n=25)	p-values Unequal Variance	p-values Equal Variance
	Type of Milk Processing Firm:			
FLUID	0.5000	0.2800	0.0794*	0.0852*
ICECR	0.3421	0.3200	0.8582	0.8584
YOGURT	0.1589	0.4000	0.0442*	0.0310*
	Presently Using Membrane Technology:			
USENOW	0.0789	0.1600	0.3569	0.3244
	Why Consumers Buy Company's Product:			
BRAND	0.2513	0.2436	0.8605	0.8650
PRICE	0.2316	0.2212	0.8550	0.8549
QUAL	0.3461	0.3732	0.5784	0.5992
PACK	0.1013	0.0780	0.3825	0.4301
PVLAB	0.0329	0.0300	0.8920	0.8941
OTHERY	0.0368	0.0540	0.5297	0.5071
	Importance of Private Label Sales:			
PL=0	0.1842	0.2800	0.3953	0.3791
PL<1/3	0.3158	0.1200	0.0577*	0.0764*
PLMID	0.3421	0.2800	0.6079	0.6113
PL>2/3	0.1579	0.3200	0.1570	0.1342
	Frequency of Consumer Contact:			
LOCALL	0.0789	0.1600	0.3569	0.3244
MECALL	0.5000	0.3200	0.1582	0.1629
HICALL	0.3684	0.4800	0.3919	0.3870
VCALL	0.0526	0.0400	0.8169	0.8214
	Best Thing to Make New Dairy Product Succeed:			
TASTE	0.3947	0.6800	0.0222*	0.0242*
ADVERT	0.2455	0.1000	0.1128	0.1423
NOPREM	0.3245	0.1800	0.1831	0.2021
LESSFT	0.0350	0.0400	0.9184	0.9154
OTHERS	0	0	N/A	N/A
	Size of Raw Milk Receipts by Firm:			
SMALL	0.1316	0.1200	0.8941	0.8947
MED	0.2632	0.1200	0.1501	0.1750
LARGE	0.1842	0.3600	0.1398	0.1206
VLARGE	0.4211	0.4000	0.8708	0.8707

* If p-value is less than 0.1 we reject with 90-percent confidence the null hypothesis that means are equal between the two groups.

that variables in the frequency-of-consumer-contact group are not related to the prediction of new product success. Variables in this group include respondents hearing from consumers less than ten times per year (LOCALL), from ten times per year up to ten times per month (MECALL), from ten to one hundred times per month (HICALL), and finally more than one hundred times per month (VCALL). Consumer contact was determined by asking survey participants, "How often do you hear from the final consumers using your product?" This question was developed for the purpose of trying to understand how accurately an individual might be able to perceive consumer preferences. Of course, consumer contact could come from any number of sources such as complaints, calls on a toll-free number, letters, or any other possible source. Consumer contact would be expected to increase with firm size. This was mildly in evidence as the correlation coefficient between firms in the highest call bracket (i.e., receiving more than 100 call per month) and firms in the largest size bracket (i.e., processing over 60,000 gallons of farm milk per day) was 0.26.

Variables associated with the question, "What one thing would make the new dairy product succeed?" included taste (TASTE), advertising (ADVERT), no price premium (NOPREM), less butterfat content (LESSFT), and other (OTHERS). Among these only taste produced highly significant mean differences. As evidenced by p-values well below 0.05, respondents viewing taste as important were much more likely to view membrane technology dairy products as being successful.

The size of a firm's daily milk intake is unrelated to prediction of new product success. SMALL firms were those processing less than 6,000 gallons of raw milk per day. MED firms were those processing 6000 to 30,000 gallons per day. LARGE firms were those processing 30,000 to 60,000 gallons per day. VLARGE firms were those processing over 60,000 gallons of milk per day.

In summary, on the basis of mean difference tests we conclude that yogurt manufacturers and those manufacturers feeling that taste is important are much more likely to view membrane technology dairy products as becoming successful. In contrast, fluid milk bottlers as well as those with private-label businesses in the PL<1/3 category are less likely to view these new dairy products as becoming successful.

Anecdotal Findings

Anecdotes reported by survey respondents are presented below. In all product areas, these comments illustrate a high level of cost and price sensitivity. Based upon the results discussed above one would expect this to be true for fluid milk. However, price sensitivity is also evident in the case of ice cream and even in the case of yogurt. Comments received included:

- *"Our current business is price-driven, thus the supplier would have to absorb any cost increase."* (From a bottler in the State of Washington.)
- *"This product would have acceptance from only a small group of consumers."* (From a bottler in Texas.)
- *"We make a NFDM [Nonfat Dry Milk]-fortified product. At standard retail price it sells well. However, with a $0.05/gal. premium it does not sell well."* (From a bottler in the State of New York.)
- *"It takes a lot of consumer education and advertising to market a value-added product at a premium price."* (From a bottler in Kentucky.)
- *"Adds cost. Our market area could not support this."* (From an ice cream maker located in the North Central U.S.)
- *"I am not sure customers would understand or care."* (From an ice cream maker located in Wisconsin.)
- *"This would take advertising."* (From an ice cream maker in the High Plains.)
- *"Customers currently love indulgence."* (From an ice cream maker in California.)
- *"Superior flavor and texture at a competitive price will be a new product requirement."* (From a yogurt maker in Ohio.)
- *"I do not think you can produce a product with enough improvement in taste/mouthfeel to justify cost increase to the consumer."* (From a yogurt maker in Michigan.)
- *"Shelf placement is critical."* (From a yogurt maker in Illinois.)

Study Implications

These anecdotal findings reveal extreme concerns from dairy food manufacturers regarding highly elastic demand as well as the ability of consumers to perceive and/or pay for product differentiation. Because of cost, membrane technology investments for the purpose of producing a new product are likely to be scrutinized with great caution. Among the three types of processors studied, statistical findings indicate that yogurt manufacturers are the most likely to consider a new functional-food formulation involving membrane technology. Concern about enhancing taste would likely be the motivation for making such a new product investment.

This study has simply scratched the surface of an evolving industry process. Should membrane manufacturing technologies for new consumer dairy products become more widespread in the future, opportunities will then exist for economists to gain a greater understanding of this technology and its associated cost.

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