# The MIT/Marine Industry Collegium

## Opportunity Brief #7

# CLOSED-CYCLE AQUACULTURE

A Project of
The Sea Grant Program
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The MIT Marine Industry Collegium

# CLOSED-CYCLE AQUACULTURE

Opportunity Brief #7

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The opinions, errors, and omissions are the sole responsibility of the MIT Sea Grant Staff.

## 1.0 A BUSINESS PERSPECTIVE

Experiments in recent years have shown that high-quality oysters and clams can be grown with extraordinary efficiency in carefully regulated artificial environments. The efficiencies include more rapid growth, higher yields of edible meat per oyster, and greater utilization of nutrients than can be achieved either in nature or in primitive aquacultural systems. Additional efficiencies now appear to be possible through closed-cycle systems in which some portion of the nutrients, wastes, and heated water are recirculated for reuse.

Two general considerations make closed-cycle aquaculture of considerably more than academic interest today. First, there appears to be the opportunity for near-term entry into a small but potentially profitable market for oysters and clams raised in closed-cycle environments. Second, the research breakthroughs now occurring in the culture of algae used for oyster nutrition have profound implications as a source of protein not only for shellfish, but as a food supplement for other animals as well.

To explore the potential of a closed-cycle aquaculture as a viable and profitable business, we focus on a specific operation now underway at the University of Delaware. For several years now, Delaware has experimented with a partially recycled, environmentally controlled algae/oyster husbandry system. Inorganic nutrients introduced into the system combine through photosynthesis with sunlight and seawater to produce more algae. Algae are assimilated by the oysters. Oysters become food for human consumption.

From a technical standpoint, the Delaware system is of interest for two reasons:

(1) Single-cell photosynthetic algae are among the most efficient converters of the sun's energy and organic chemicals into protein for consumption by animals. Delaware researchers have made important advances in productivity in algae husbandry that are important to oysters at present, and vital to the profitable longer-term basic food business.

(2) The Delaware work is advanced enough to provide a clear framework for understanding the complexities and the potentials of other aquaculture systems. Analysis of the Delaware system permits breaking up the problems and issues into manageable, understandable subsystems that can be analyzed as factors of production.

In the shorter term, an oyster business based on the Delaware system seems to have a reasonable chance of success because:

(1) oysters have a high unit market value so that relatively small "factories" and concomitant small investment are required, suggesting possible early profitability;

(2) the natural supply of oysters has declined in recent years and the decline does not appear temporary. Thus, the long-term outlook for capital investment in aquaculture of oysters (and other bivalves as well) appears good;

(3) although the system has not yet been operated on a production basis, some important preconditions necessary for a profitable operation have been demonstrated. For example, the cost of

nutrients is quite low;

(4) the research and development for aquaculture of bivalves over the past few years has led to very promising results and clear identification of the remaining barriers to success;

(5) the species grown in the Delaware system can be subjected to a wide range of quality control measures to assure higher yields, more uniform size, shape, texture, and the like. Incoming inspection of nutrients and other raw materials, combined with on-line process control can assure freedom from pathogens, disease, and poisons (e.g., mercury);

(6) the "manufacturer" can control the output to track market demand.

In the longer term, the Delaware system may contain the seeds for commercial realization of protein production from algae. Should this prove to be the case, the ramifications of closed-cycle aquaculture could well be on a par with the revolution that occurred in agriculture due to mechanization, new fertilizers, and hybridization. Such developments might mean that a grower, instead of serving an approximately $10 million annual market for oysters, could be serving a market a thousand times that size.

The Delaware system offers profound insights into the rationale (and problems) of all cultured systems. It is now at a "preproduction prototype" stage, and cooperative inputs from industry are now needed to bring the potential of aquaculture to commercial fruition.

## 2.0 BACKGROUND

Aquaculture is the culture and husbandry of plants and animals reared in controlled or selected aquatic environments. In its simplest forms, aquaculture is probably as old as agriculture. People have been growing fish in estuaries, ponds, and tanks for many years. In the United States, public aquaculture of salmon was started a century ago and more than one quarter of our salmon (27,000 metric tons or 60 million pounds) originate in hatcheries.

About 40% of oysters consumed in the U.S. are grown by oyster farmers in quasi-natural environments. Half of our catfish and crawfish are commercially raised in ponds. Nearly all our trout are raised in hatcheries before being transferred to rivers, lakes, and streams.

Worldwide output from aquaculture has approximately doubled during the last five years and now amounts to some six million metric tons (13.2 billion pounds) of edible marine products, roughly 10% of the world fish production. Japan and several Southeast Asian countries rely upon relatively primitive aquacultural systems for a substantial amount of their total fisheries supply. In general, the forms of aquaculture in use today consist of relatively minor manipulations of natural systems, such as ponds, rivers, or bays. These efforts are a little more advanced than primitive agriculture. They are typically labor intensive, requiring relatively little capital investment, and are run as small businesses.

By contrast, the type of aquaculture that we focus on in the brief is capital intensive, with low labor requirements, and having the potential for serving as the foundation of a large new industry. This type of aquaculture is sometimes referred to as "closed-cycle," in which nutrients and wastes are recycled for efficient utilization and additional efficiencies are achieved through use of solar energy. Closed-cycle systems are characterized by rather complete environmental control, high food and product densities, and high yields.

We focus on oysters in a closed-cycle system for several reasons. The culture of oysters in natural environments is well understood and widely applied both here and abroad. Oysters and other mullosks are herbivorous and fall near the base of the food chain. They are very efficient utilizers of the sun's energy that is fixed in plants. In addition, they have high unit value.

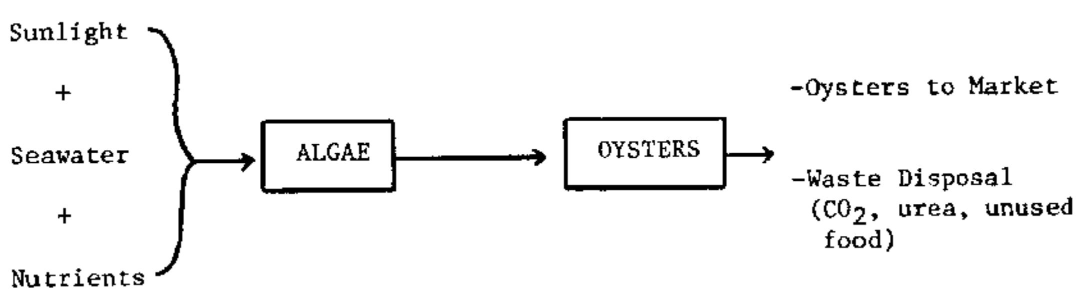
Oysters, along with many wild stocks of seafood, have declined substantially in the twentieth century. The once prolific grounds of Narragansett Bay and Delaware Bay have been decimated and do not appear to be recovering. Production of oysters decreased from a historical peak of 152 million pounds of meat in 1908 to about 50 million pounds due to a number of factors, all adversely affecting the environment for oyster production.

In the next section, we describe the closed-cycle system used for shellfish aquaculture by the University of Delaware. The long-range objective of Delaware's maricultural research is to produce fast-growing, palatable, nutritious oysters and clams, free of toxins and pathogens. Working with a controlled seawater environment, researchers are seeking to achieve reasonable production costs, using sunlight as a natural source of energy and recycling organic wastes. Introduction of new strains of shellfish and the successful exploitation of existing ones could provide the basis for the establishment of a new shore-based marine food industry.

## 3.0 CLOSED-CYCLE MARICULTURE AT THE UNIVERSITY OF DELAWARE

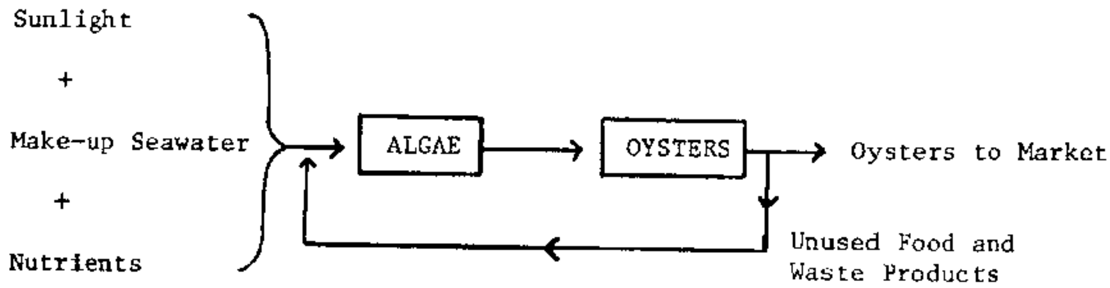
The philosophy of Delaware's closed-cycle mariculture system is to utilize sunlight and nutrients to yield the maximum amount of oyster meat as quickly as possible. Algae are grown as the photosynthetic intermediary to convert inorganic nutrients and sunlight into food for the oysters. The algae can be 5 to 10 times as efficient as land plants in fixing the sun's energy and are therefore the key element in the system.

To visualize the interrelationships, a series of block diagrams may be considered:




The diagram depicts a flow-through process system for the production of algae and oysters. The nutrients consist essentially of carbon, oxygen, nitrogen, sulfur, phosphorous, potassium, and various micronutrients (trace metals).

Through photosynthesis, nutrients and the sun's energy are converted to nutritious algae. A certain amount of the algae solution is fed to the oyster and an equal amount of waste water is disposed of. The system below depicts a recycled system.



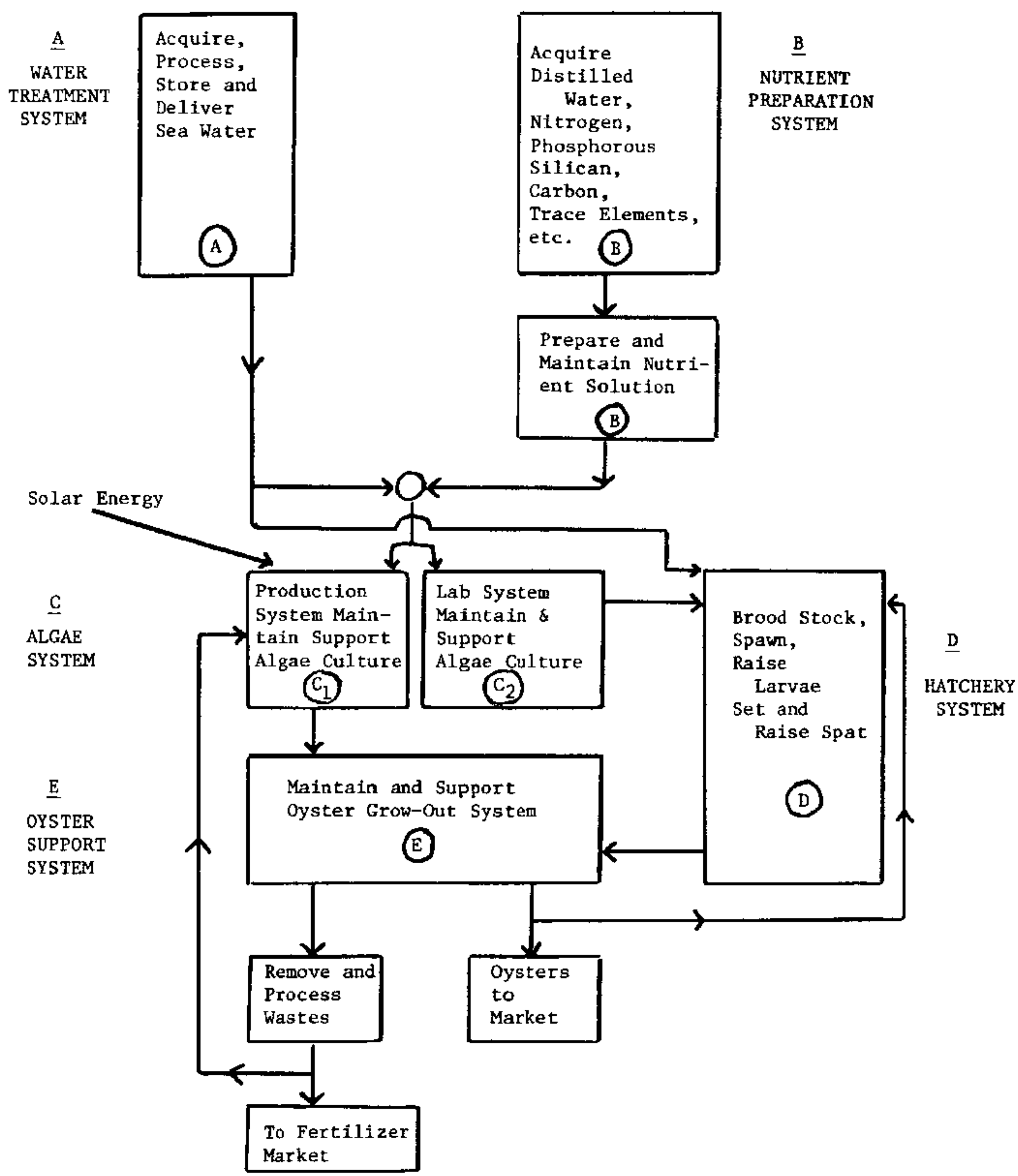

The water returned to the algae block contains unused food and waste products of the oysters. Some of the oyster wastes--such as nitrogen, carbon dioxide, and phosphorous--are nutrients for the algal culture. By recycling, nutrient costs are kept down and the capacity of the oysters to "lick the platter clean," or utilize a larger fraction of the nutritional inputs, is enhanced. Furthermore, energy needed to heat water is conserved.

At the University of Delaware, controlled environment systems, involving both flow-through and recycled processes, have been developed and are in operation. A recycled system is depicted in the system and activity network in Figure 1 (see page 9). Each block represents subsystems and activities required in operation of that subsystem.

The network is useful for two reasons. First, it makes understanding and talking about the system easier. Second, it gives valuable insights into the problems and opportunities in expanding the operation to commercial size.

The Delaware system is not completely closed (100% recycled) or completely flow-through (0% recycled). As indicated, some wastes and water are removed before recycling. Periodically, usually once a day, the water in the grow-out system (E in Figure 1) is processed to remove

FIGURE 1
SIMPLIFIED SYSTEMS AND ACTIVITY NETWORK
UNIVERSITY OF DELAWARE MARICULTURE SYSTEM



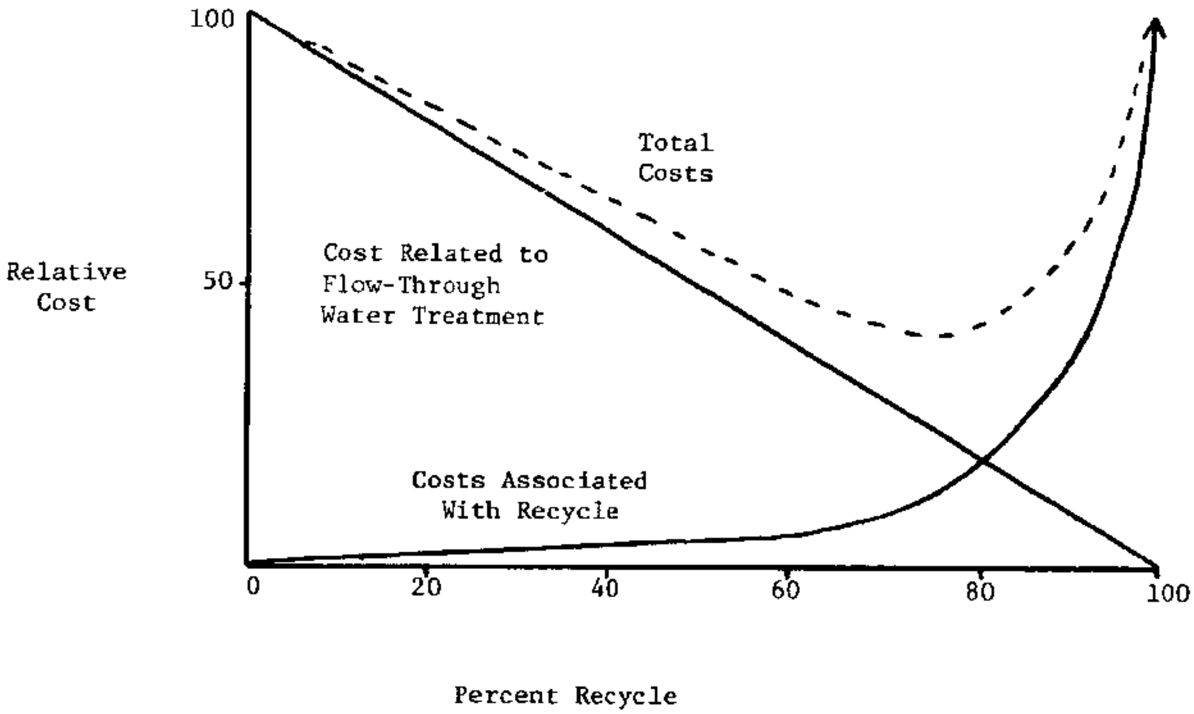
wastes. A fraction of the algae culture from (C) is drawn off and temporarily stored while water from the grow-out system is recycled to the algae culture (C). The temporarily stored algae culture solution is then added to the oyster grow-out system. Make-up water from (A) and nutrients from (B) are added to compensate for the waste water taken out.

Determination of the most economical or practical fraction of the total water to recycle is a nontrivial problem. For example, seawater may contain micronutrients that will be consumed but not resupplied in the nutrients provided, and thus the micronutrients must be provided from make-up water. Too much waste water per cycle causes loss of nutrients, heat energy, etc. The trade-off in the costs of recycling and the cost of the make-up water is reflected qualitatively in Figure 2 (page 11).

The work to date is being carried out on a number of parallel facilities and experiments. Many nutrient experiments, algae "mix" experiments, and growth rate experiments are carried out in small-scale (less than one bushel) completely flow-through facilities. Others are carried out in small closed-cycle facilities. At the same time, a larger closed-cycle system is being developed to investigate the effects of scale, to vary the recycle ratio and the like. This facility will have a capability of 50 bushels.

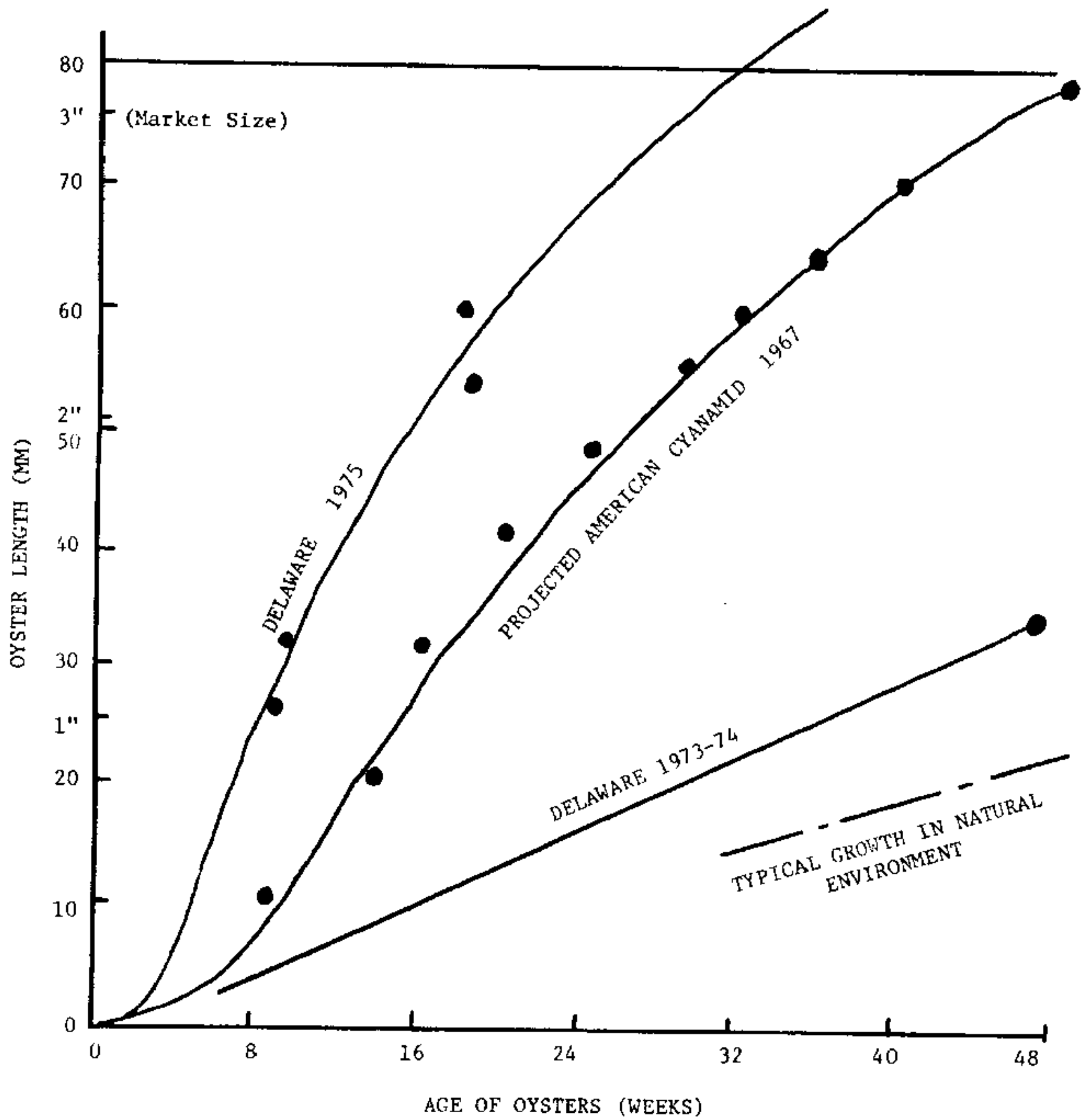
The University of Delaware has proved not only that bivalves can be grown in a closed system, but also that they grow faster than they would naturally. Oysters that take 36 months or longer to mature in natural seabeds and perhaps 24 months in open aquaculture systems are now growing to market size in only 36 weeks in Delaware labs (see Figure 3, page 12). The same degree of success has been achieved with clams, growing them to

FIGURE 2




Qualitative Recycle Optimization Curve

FIGURE 3
COMPARISON OF OYSTER GROWTH




The American Cyanamid projection (Goodrich, et al., 1968) is based on an intensive study of the costs and potential of a hypothetical 200,000 bushel plant (see Section 4.2).

The difference in Delaware oyster growth between 1973 and 1975 is due primarily to improved diets and denser algae production.

market size three to five times faster than in nature.

The most outstanding recent achievements have been made in increasing the density of the algae solution used to feed the oysters. Increased density of the algae solution means less water has to be treated, heated, stored, and circulated to provide a fixed amount of nutrients to a given amount of oysters. Also more oysters can be raised in a given space with higher densities of algae solution. Thus higher densities of algae culture imply lower costs. Since 1973 Delaware's mariculture scientists have increased the amount of algae grown in a given volume of water by a factor of ten.

Types of algae that promote fast growth rates of the bivalves have been determined, and investigation continues to find combinations of other algae which foster even faster growth. The exact biochemical basis for the varying food values of specific algal cultures is not yet fully understood, although it is under investigation.

Detection and control of potentially harmful bacteria are essential in any food-producing industry. The Delaware team operates a microbiology lab to detect bacteria which may be present in the system and to determine if their effects are deleterious, benign, or beneficial. So far, no threat to the health of either the oysters or their potential human consumers has appeared. Although monitoring continues, Delaware's system should meet the highest standards.

Another area of continuing research is the effect of trace metals. Some metals are introduced as micronutrients in the algal culture. Other metals, present in the seawater in varying and undefined quantities, are fed into the system. Experiments are underway to find out which of the trace metals build up, which are depleted, and in which parts of the system the changes occur.

Last, but by no means least important, the oysters have been taste-tested by laboratory personnel and pronounced excellent. Plans are being made for a formal taste-testing in the future. However, it seems safe to say that the combination of natural factors that produce the delectable flavor of clams and oysters has been reproduced in the laboratory.

## 4.0 MARKETS, COSTS, AND A MARKETING STRATEGY

### 4.1 Markets

#### 4.11 Current U.S. Markets*:

Total annual U.S. production of oyster meats is about 50 million pounds valued at $35 to $40 million. The range in market value is from about $0.50 to about $3.00 per pound of meat depending on quality. Gulf Coast warm-water oysters average about $0.50 per pound, Chesapeake oysters average over $0.75 per pound, and cold-water New England oysters are valued at about $3.00 per pound. These latter oysters have high meat and shell quality and command high prices for the "half-shell trade," but they comprise only 1% by weight of the total landings, i.e., around 500,000 pounds. Thus the half shell market is between $1 million and $2 million per year (500,000 lbs x $3.00/lb.). Note that U.S. imports of oysters were recently around 30 million pounds. If the majority of these imports are premium oysters, the U.S. market may be as much as $10 million to $20 million per year.

Total annual U.S. production of clam meat is about 110 to 115 million pounds, valued at $40 million to $42 million ($0.37 per pound). Fifty percent of the value or $20 million were hard clams (*Mercenaria mercenaria*) valued at approximately $1.40 per pound.

This fragmentary data suggest the total dollar market for hard clams is at least as big and possibly bigger than the market for oysters.

*Data are ex-vessel prices, that is, prices received by the producer from the wholesale buyer, as reflected in the National Marine Fisheries Service publication, Current Fishery Statistics, No. 6900, Fisheries of the United States, 1975 (Washington, D.C.: Department of Commerce, 1976).

4.12 Future Market Potential:

The NOAA Aquaculture Plan predicts that U.S. oyster consumption will approximately double by the year 2000 (from 70 to 125 million pounds) and that worldwide consumption will grow about 2-1/2 times (165 to 416 pounds). There are reasons to believe that these figures may be overly conservative, at least for the U.S.

Historically oyster consumption in the U.S. has been at much higher levels. In 1908, 152 million pounds of oysters were consumed in the U.S. Since the U.S. population was much smaller in 1908, per capita consumption of oysters was vastly greater than today. The figures become even more impressive in view of the fact that oysters were consumed only in the coastal regions in 1908.

The principal reason for the decline in consumption is most likely the decline in the natural supply of oysters. Data concerning imported oysters over the last 20 years indicate that increased supply could whet the public appetite for more oysters. Not only are there many more people in the U.S. (and the world) today, but refrigeration and transportation make it possible to reach inland markets not accessible in earlier times. In addition quality control, such as could be achieved with cultured oysters, could allay public health fears that seem to prevent some people from enjoying oysters today. A strong promotional program to inform the public that closed-cycle oysters are safe and tasty could also stimulate the per capita consumption to approach earlier consumption levels.

If our speculations are correct, many more people could be persuaded to eat many more oysters. But the supply will obviously not increase through natural sources. The natural oyster beds are likely to decline for environmental reasons outlined in Matthiessen (1970). In addition, many of these beds, especially the public beds, are not being managed for maximum yield. Only 13% of the total oyster beds are privately controlled and yet produce 50% of the market. Also, archaic state laws regarding wildstocks hamper the aquaculturist and impair efficient harvesting methods (see Brockrath and Wheeler [1975] and Agnello and Donnelley [1975]).

Closed-cycle mariculture would be free of legal and environmental constraints associated with natural beds and would be able to locate in favorable geographical locations to accommodate local markets. Closed-cycle aquaculture is in a better position than natural stock to satisfy future increases in demand.

## 4.2 Production Costs

Goodrich, et. al. (1968), have analyzed costs for a hypothetical manufacturing plant for rearing oysters. Their detailed and comprehensive study is a base line for any study of closed-cycle systems. Costs were totaled for each component of each subsystem and for alternative subsystems. They estimated production costs to range from $8.50 to $72.00 per bushel. The range reflects the alternative subsystems and the uncertainties that surround the critical parameters such as food requirements, stock density, and growth rates, etc. Due to these uncertainties, cost estimates must still remain tentative. Nevertheless it is instructive to look at the most recent breakdown of costs with a view to identifying the cost components and their relative importance.

Based on some extrapolation of engineering/economic data available from the experiences to date, Delaware provided us with information on total capital investment, labor costs, operation and maintenance costs, and nutrient costs for a facility to produce 8,000 bushels per year. Recognizing that changes in the technology may radically modify these estimates, we nonetheless have constructed a pro-forma income statement in order to estimate a profitable selling cost.

Cost of Goods Sold for a Hypothetical
8,000 Bushel/Year Facility

| COST ITEM | HIGH ESTIMATE $/Year | HIGH ESTIMATE $/Bushel/Year | LOW ESTIMATE $/Year | LOW ESTIMATE $/Bushel/Year |
|---|---|---|---|---|
| 1. Labor & FICA, etc. | $69,000 | $8.62 | $48,000 | $6.00 |
| 2. Operations & Maintenance | 9,000 | 1.13 | 9,000 | 1.13 |
| 3. Nutrients | 42,880 | 5.36 | 10,720 | 1.34 |
| 4. Depreciation (15 yrs) | 35,333 | 4.42 | 35,333 | 4.42 |
| 5. Cost of Goods Sold | $156,213 | $19.53 | $103,053 | $12.88 |

We looked at annual reports of four major food companies and determined a reasonable estimate for Sales and General Administration (S & GA) for food companies was about 17% of sales or about 25% of Cost of Goods Sold; in addition, Return on Investment (based on debt plus stockholders equity) was found to be about 20% on a pre-tax basis. Thus the more complete income statement would be:

| | | | | |
|---|---|---|---|---|
| Cost of Goods Sold | $156,213 | $19.53 | $103,053 | $12.88 |
| 6. S & GA @ 25% of CGS | 39,053 | 4.88 | 25,763 | 3.22 |
| Total Break-Even Cost | 195,266 | 24.41 | 128,816 | 16.10 |
| 7. ROI @ 20% of 530,000 | 106,000 | 13.25 | 106,000 | 13.25 |
| Selling Price | 301,266 | 37.66 | 234,816 | 29.35 |

This analysis makes several points more clear:

(1) Nutrient cost is relatively small and unimportant.

(2) Capital items (i.e., depreciation and return on investment) are about 50% of the selling price, hence the need to increase algae density and oyster density to reduce the amount and costs of tanks for water treatment, algae growth, oyster growth, and the size of the physical plant.

(3) Labor items are also relatively large, indicating the importance of process design to reduce the labor content to a minimum.

Not obvious perhaps is the suggestion that to keep labor and operation costs and structures to a minimum, one ought to move to tropical, lower labor cost areas.

Last, it should be noted again that forecasted costs have decreased with improvements in the system. If the proposed 8,000 bushel/year facility can be made to produce 16,000 bushels, the selling prices could be halved.

The difficulties of such a cost analysis are two-fold. First, different parts of the system "scale" in different ways and require different caliber of people to operate. For example, doubling the capacity of the water treatment system may require twice as much capital and labor, while doubling the capacity of the hatchery may require only 10% more capital and labor. Thus, scaling from a laboratory facility to a commercial plant is fraught with difficulties.

An analysis of the labor and capital costs and the changes in unit costs (with size) for each subsystem is needed to suggest the minimum cost business organization. The capital and technology intensive subsystems should perhaps be centralized, and the routine operations should be decentralized. But clearly, the strategy depends on a cost analysis which is not yet completed.

A second problem is that the required capacity of the various subsystems are strongly interdependent. Thus, an increase in algal density will strongly decrease the required capacity of the water treatment system. Similarly, the larger the fraction of water recycled, the higher the nutrient utilization. An appropriate economic analysis of subsystem interdependence will be useful to direct research to the areas for most effective cost reduction. The gross uncertainties in cost not withstanding, preliminary studies of the most expensive nutrient, nitrogen, are encouraging.

It has been determined experimentally that 380 grams of nitrogen are required to grow a bushel of oysters to market size in flow-through laboratory conditions. The cost to purchase inorganic nitrogen to supply this need depends upon the particular form selected.

| Material | Cost/100#* | Cost Elemental Nitrogen/$Kg | Cost Elemental Nitrogen/Bushel of Oysters |
|---|---|---|---|
| $NaNO_3$ | $22.00/100# | $3.00/Kg | $1.14 |
| $NH_4Cl$ | $12.75/100# | $1.08/Kg | $0.41 |
| $NH_4NO_3$ | $ 9.20/100# | $0.06/Kg | $0.23 |

*From Southern State Cooperative, Nassau, Delaware

It is clear that cost of the most expensive nutrient, nitrogen, is very small compared with the price of a bushel of oysters even in a flow-through system. In recirculated systems, the nitrogen costs could be reduced by a factor of two or three. Thus, we can say that nutrient cost is not a problem. This is a necessary, but not sufficient, condition for economic viability.

### 4.3 Marketing Strategy

Based on the more extensive work to date on oysters, a maximum profit, minimum risk strategy would be to start an oyster production facility aimed at the premium oyster market of about $1 million, where the unique higher quality cultured product could effectively compete.

The National Marine Fisheries Service estimates that the price elasticity of oysters is about 0.7, which means if mariculture production were to increase output by 10%, price would be about 7% less than it would be otherwise. But this does not take into account the positive attributes of manufactured oysters, such as immunity to natural and man-made disasters, uniform size and quality, high meat content, and control of production to track market demand.

If the product is successfully competitive and if production costs and market prices are reasonable, then the much larger world market could become accessible. Thus, in premium oysters alone, sales could grow from a several million dollar level to several tens of millions of dollars. Given larger per capita consumption, and lower prices, total markets between $50 and $100 million might be achievable over the next decade.

We obtained less information about costs for producing clams, but they should also be considered. While landings of both clams and oysters have remained relatively constant over the last 10 years, the price of hard shell clams has gone up half again as fast as oysters, with the price of clams doubling over the past decade. Clams are increasing in popularity and have entered the fast food chains, suggesting that the market size as well as the unit price will continue to rise.

In addition, the hatchery operations and prototype production operations seem less capital and labor intensive. Clams are generally hardier and can be fast growing. The relative profitability of clams vs. oysters should be more carefully scrutinized.

## 5.0 SOME SPECULATIONS ON THE FUTURE OF CLOSED-CYCLE AQUACULTURE

### 5.1 The Role of the FDA

The Food and Drug Administration regulations affect all shellfish (and other food) shipped in interstate commerce. Several points should be noted.

(1) The FDA administers the National Shellfish Sanitation Program (NSSP), which sets standards for the water quality from which shellfish are harvested. The standards concern mainly fecal coliform and heavy metal contaminates. We feel that the quality control exerted in a closed-cycle mariculture system would effectively clear this hurdle.

(2) The FDA's major regulations concern adulteration or misbranding of food products. Adulteration means the content of poisonous or deleterious substances either natural or added to the product, and any filth, putrid or decomposed matter in the product whether or not it is thence made unfit for food. "Added" means originating through the acts of man; therefore, closed-cycle mariculture would be affected by the laws regarding "added" substances. The terms filthy, putrid, decomposed have been interpreted by the courts in their ordinary rather than their scientific meanings.

In addition, even if a substance is pure, it can be interpreted as "otherwise unfit for food." The courts have used this phrase to protect the aesthetic feeling and sensibilities of the consumer even when there is no threat to health. It is conceivable that consumers could exhibit attitudes of repugnance or disgust for closed-cycle cultured mollusks and thereby open the door for FDA intervention.

The FDA, while a regulatory agency, has been accused of being susceptible to political pressure. The established shellfish growers could conceivably induce the FDA to take a hard look at new "artificial" shellfish procedures.

These imprecise adulteration provisions have been discussed in Kildow and Huguenin (1974) with particular regard to mariculture systems employing recycled domestic waste as a nutrient. To them the future of such "waste"-based mariculture systems appears definitely clouded by the spector of the FDA.

(3) Closed-cycle mariculture is quite different from mariculture based on domestic waste. The closed-cycle system is a tightly controlled emulation of the natural processes in the life cycle of shellfish. If anything, it is cleaner than nature. However, the impreciseness of the regulations could conceivably affect recirculated closed-cycle systems, particularly in regard to the "otherwise unfit for food" provision. Also, as closed-cycle mariculture is a new concept, the initial commercial facility will most likely face more scrutiny than succeeding plants.

While the prospective investor in closed-cycle mariculture would be well advised to study the regulations of the FDA and perhaps to discuss the acceptability of the operation with the FDA in advance, it is our opinion that closed-cycle mariculture will have less trouble with the FDA than many other forms of mariculture.

## 5.2 The Future Role of Algae Culture

Although Delaware's current research has shown that growing shellfish in closed or recycled systems is technically possible and that economic feasibility is within reach, a substantial amount of research and development in a number of disciplines remains to bring maricultural systems to the level of productivity that has been achieved with agricultural systems.

The key issue technically and economically at the present appears to center on increasing algae productivity. As noted earlier, most of the important capital costs and many of the operating costs are related to the support of the algae growth which in turn supports the oyster growth: increases in algae density directly reduce costs.

Research supportive of this goal includes the study of:

(1) increasing photosynthetic efficiency obtainable from single cell marine algae including utilization of intense solar illumination;

(2) production of favorable mutant algae; and,

(3) the role of bacteria, viruses, yeasts, fungi, protozoa, and other microorganisms in closed systems; their beneficial effects in breaking down wastes into basic nutrients; and their potential danger as pathogens.

The significance of the advances in algae production to date and the potentialities of further advances must not be underestimated. The implications are more profound than simply oyster production. The techniques and lessons learned in the algae/oyster system may be extended to other mollusks and to other useful marine organisms.

If the algae production techniques show continued increases in efficiency and economy in the basic process of converting sunlight and inorganic nutrients into plant life, then harvesting algae as a food or food supplement for animals such as cattle and chickens becomes a very real possibility. In fact, the markets for algae may be similar to those of our best-known land crops, such as soybeans--measurable in the billions of dollars.

Thus, the algae/oyster system at Delaware holds interesting promise both as a potentially profitable oyster and clam business and as a speculation in tomorrow's food production systems.

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