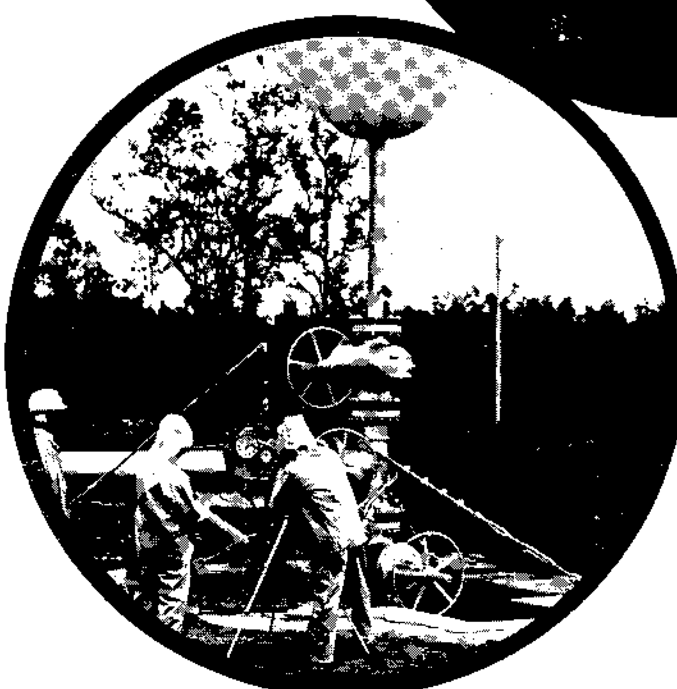
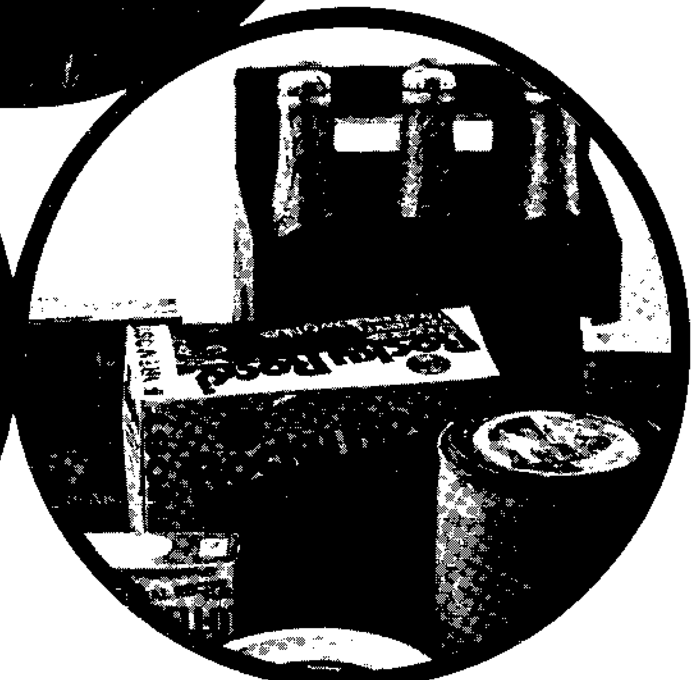
Establishing a SEAWEED INDUSTRY IN HAWAII: an initial assessment

by James R. Moss and Maxwell S. Doty

Harvesting



Processing - Geothermal Energy



End Products

A study produced for the Aquaculture Development Program of the
Hawaii State Department of Land and Natural Resources
Honolulu, Hawaii • January 1987

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EXECUTIVE CHAMBERS

HONOLULU

JOHN WAIHEE
GOVERNOR

MESSAGE FROM GOVERNOR JOHN WAIHEE

Aquaculture is one of Hawaii's fastest growing new industries. In 1985, the value of commercial production and research and technology transfer activities reached $12 million, and 1986 promises substantial progress for the State's farmers, researchers, scientists and consultants. Seaweeds, the subject of this report by Dr. James M. Moss and Dr. Maxwell S. Doty, have demonstrated the potential to become a leading aquacultural crop.

The worldwide value of seaweeds now exceeds $2 billion annually. Most seaweeds are used for human consumption, but a significant amount provides a source of extracted chemicals which are found in such products as cosmetics and pharmaceuticals. In recent years, the percentage of total seaweed production from aquaculture has rapidly increased.

Hawaii currently has six seaweed farms, but no extraction plant. According to the authors, there are excellent possibilities for expanding seaweed farming in the Islands and processing that production locally, especially if low-cost geothermal energy can be utilized.

We welcome those persons wishing to establish a seaweed venture in Hawaii and trust that Establishing a Seaweed Industry in Hawaii: An Initial Assessment will offer important and highly useful guidance.

JOHN WAIHEE

PREFACE

The first version of this report was prepared by Mr. James R. Moss, a highly successful developer of seaweed industries in the United States, and the owner of the California company, AGRO-MAR, Inc. He completed a draft of the report in 1983, concentrating on the relevant marketing, processing, and financial matters, but he died without completing a final version. The general nature of the seaweeds and their production was to be completed as a joint venture between Mr. Moss and Dr. Maxwell S. Doty, University of Hawaii botanist. Dr. Doty is an internationally recognized authority on seaweed culture. In spring, 1985, Doty, though unable to update most of Moss's materials, was able to edit the manuscript, add needed information, and so produce this volume.

We call the reader's attention to the fact that Mr. Moss's tables were compiled in 1983; although the information in the tables is correct for that date, anyone intending to make a more detailed investigation of the possibilities of a seaweed industry in Hawaii should be aware that quoted prices, etc., have changed.

This publication is a result of funding by the University of Hawaii Sea Grant College Program under Institutional Grant No. NOAA NA85AA-D-SG082 from NOAA Office of Sea Grant, Department of Commerce, and by the State of Hawaii Aquaculture Development Program. Claire Ball assisted with the editing.

ESTABLISHING A SEAWEED INDUSTRY IN HAWAII:
AN INITIAL ASSESSMENT

INTRODUCTION

Throughout recorded history, man has used seaweeds for food and other purposes. Starting in about 1900, substantial industries began to develop, based on the use of seaweeds as sources of extracted chemicals. The worldwide wholesale value of the foods and extractives now substantially exceeds $2,000,000,000 annually. The current value of the seaweeds used in foods in Japan, alone, falls just short of $1,000,000,000, and the value is increasing there and in other countries.

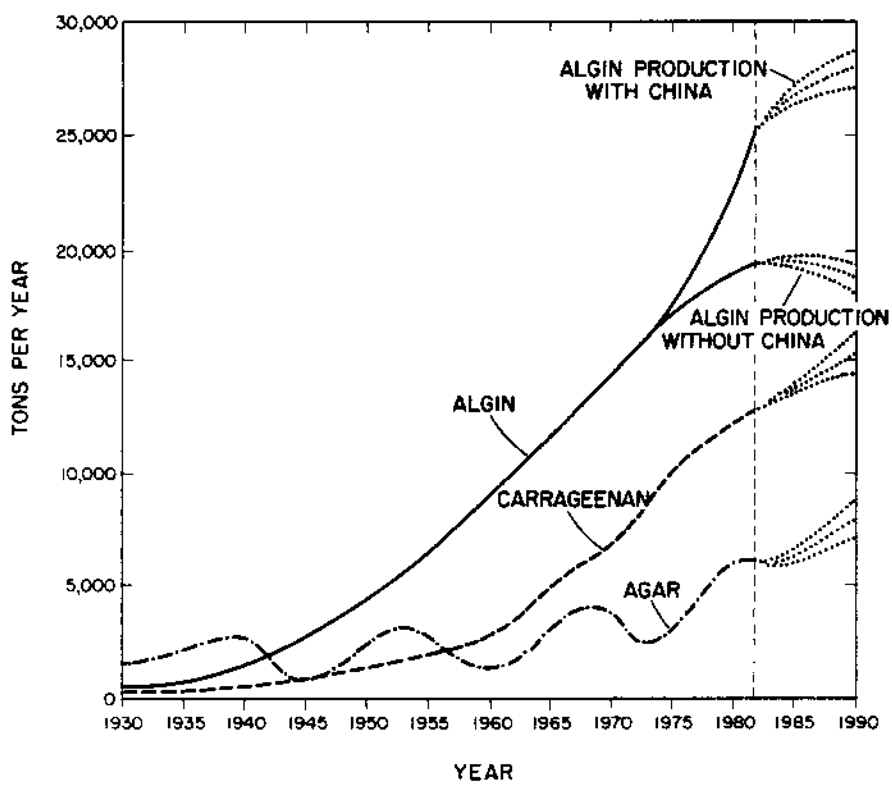

Figure 1. Estimated World Production of Seaweed Extractives through 1990. Source: James R. Moss in R. W. Krauss (Ed.), "The Marine Biomass of the Pacific Northwest Coast." Oregon State College Press. Corvallis, Oregon, 1978.

No significant seaweed extraction or farming industry has yet been developed in Hawaii, though the use of seaweed as a table vegetable in this area dates from the ancient Hawaiians. Hawaii appears to have the resources for seaweed farming, and locating an extraction industry in Hawaii may be economically feasible.

Unfortunately, budgetary constraints have limited this study to an assessment, rather than an in-depth feasibility evaluation. Nevertheless, an effort was made to include sufficient information to provide an overall understanding of the state's potential for this industry. This report should enable prospective investors to determine whether an in-depth feasibility study would be justified. In this context, the authors attempted to identify those areas where the data are insufficient, and where further research may be needed to round out a complete feasibility study.

Anyone considering the establishment of a new seaweed venture in Hawaii must know something about the industry's recent history. Such information includes the size, growth, and stability of markets, competition, availability of raw materials, costs, processing techniques, Food and Drug Administration requirements, etc. A prospective investor will also need to identify and evaluate the advantages and disadvantages that may be encountered by a seaweed industry located in Hawaii.

At the present time, Hawaii has six farms growing seaweed. A need exists to assess whether seaweed farming in the sea around Hawaii or the nearby island groups may be technically possible, economically feasible, and politically acceptable. The possibility of expanding land-based seaweed aquaculture must also be examined. And finally, the economic advantage that would accrue to the Hawaiian economy through seaweed farming and processing should be considered.

Each of these areas is addressed broadly in the sections that follow.

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FOREWORD

In June, 1985, the Department of Land and Natural Resources published Algal Natural Products in Relation to Hawaii's Seaweed Populations by Drs. Gertrudes Santos and Maxwell S. Doty. This historic state-funded study listed 1047 natural algal products found in Hawaii and identified the Hawaiian seaweeds from which they are obtained. Establishing a Seaweed Industry in Hawaii: An Initial Assessment by Dr. Doty and Mr. James R. Moss follows up on this study by assessing the economic feasibility of raising and processing the most commercially valuable seaweed species found in the State.

Hawaii possesses abundant resources for the aquaculture of seaweeds. Both warm- and coldwater species can be grown here, and technical expertise is available at the University of Hawaii and in the private sector. Seaweed biotechnology is opening the door for organic production of a host of valuable industrial chemicals and pharmaceuticals. Moreover, there is a tradition of using the fresh product in poke and other Island dishes. Without doubt, Hawaii leads the nation in per capita seaweed consumption.

There is, then, a solid foundation upon which to build an industry. How that industry is to be developed will very much depend on this study.

The authors set out to determine "whether seaweed farming in the sea around Hawaii or the nearby island groups may be technically possible, economically feasible, and politically acceptable." (page x). What they discovered leaves much room for optimism. Namely,

1) There are at least 2,500 hectares (6,175 acres) of reef flat that could be used for seaweed farming.

2) There are indications that thousands of hectares of lava rock surfaces on the western side of the Big Island could be utilized for growing seaweed. The newly-established 547-acre Hawaii Ocean Science and Technology (HOST) Park is a possible site for commercial production.

3) The Micronesian Islands and Line Islands could produce thousands of tons of product that could be processed in Hawaii.

4) The availability of low-cost geothermal energy and abundant fresh water at Pahoa on the Big Island make this site ideal for a seaweed processing plant.

5) Large-volume sales of seaweed extractives can be expected to continue for many years. "Nowhere in the world is there an opportunity such as is found in Hawaii for developing the economic production of commercial seaweeds for drugs or other new uses." (page 71).

There are, however, uncertainties which must be resolved before an industry can be developed. Substantial quantities of seaweed could be produced from farming in Hawaii's ocean waters, yet despite recent legislation that has opened up the possiility of leasing subtidal lands, the acquisition process for a lease remains to be tested. Also, the feasibility of importing raw material must be demonstrated.

Also needed is the continued development of Hawaii's geothermal resource--the key to a successful seaweed extraction industry. Applied research will be necessary to determine the most cost-effective ways to apply geothermal energy to the processing of algin, agar, and carrageenan.

Lastly, Dr. Doty and Mr. Moss recommend attracting the attention of international corporate processors to the cost advantages of siting seaweed production and extraction in Hawaii. Establishing a Seaweed Industry in Hawaii: An Initial Assessment represents an important first step in stimulating interest in this exciting economic development opportunity.

SUSUMU ONO, Chairperson
Board of Land and
Natural Resources

SEAWEEDS - A GENERAL OVERVIEW

Recent textbooks on seaweed classification and occurrence indicate that several hundred species grow along the Pacific Ocean's shores. Comparatively few are now economically exploited. Table A lists the genera of major international value that grow in the Pacific region.

Table A. Principal Seaweed Hydrocolloid Sources in the Pacific.

ASCOPHYLLUM	GELIDIUM	LAMINARIA
CHONDRUS	GIGARTINA	LESSONIA
DURVILLEA	GRACILARIA	MACROCYSTIS
EUCHEUMA	IRIDAEA	

Among the above eleven genera, at least two dozen species are involved. In the case of *Gelidium*, some species are often treated as *Pterocladia* species. Two nonscientific names, "spinosum" and "cottonii," are used respectively for the iota and the kappa carrageenan-producing *Eucheuma* species. In this report, the species are not otherwise distinguished.

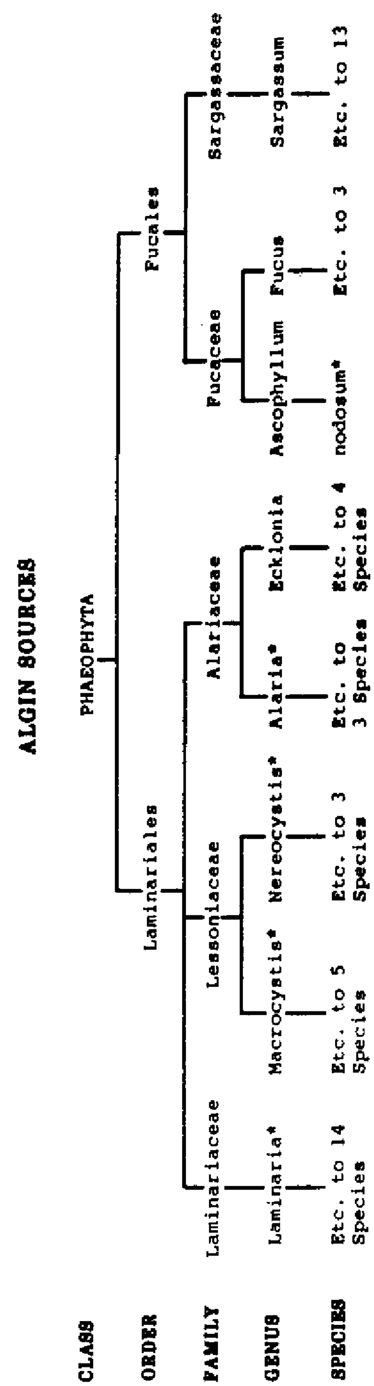
Marine scientists, however, are finding additional species which are excellent candidates for sea farming. Many natural products of seaweeds have potential applications of economic value. Examples are those seaweeds that are effective against viruses.

Santos and Doty (1985. Hawaii Botanical Science Paper No. 42) provide a list of 1047 natural seaweed products, giving references to the literature and naming the species of seaweed from which they are derived. Forty-three of these species already grow in Hawaii. Another 251 are represented in Hawaii by closely related species and genera (Table B). A great many of the natural products derived from seaweed are physiologically active in humans or have other known values, often pharmaceutical. Even a cursory perusal of this list will reveal many industrial seaweed products that are in demand and have the potential to be farm-produced and processed within the state.

Table B. Economic Seaweeds in Hawaii

Seaweeds	Number	Percent of Total Seaweeds of Economic Value
Species growing in Hawaii	43	11
Genera, but not the species, growing in Hawaii	251	64
Families, but not the genera or species, growing in Hawaii	90	23

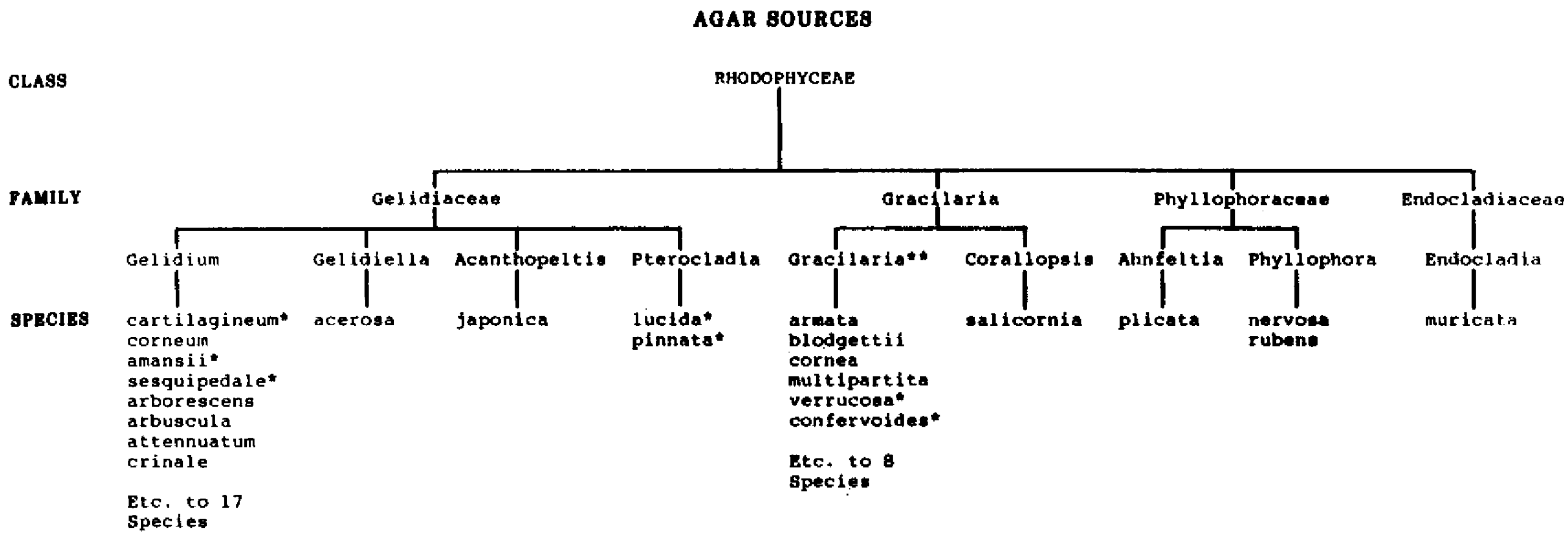
Laymen find it convenient to classify seaweeds according to their color--the "brown," the "red," and the "green." Throughout this report we will frequently refer to these classifications. As the reader progresses, he will notice that seaweeds of a given color possess certain broad characteristics and properties in common. For example, the various red and brown seaweeds covered in this assessment are the raw materials of the algal hydrocolloid industry and are botanically classified and listed in Figures 2, 3, and 4.



*Indicates extensive commercial utilization.

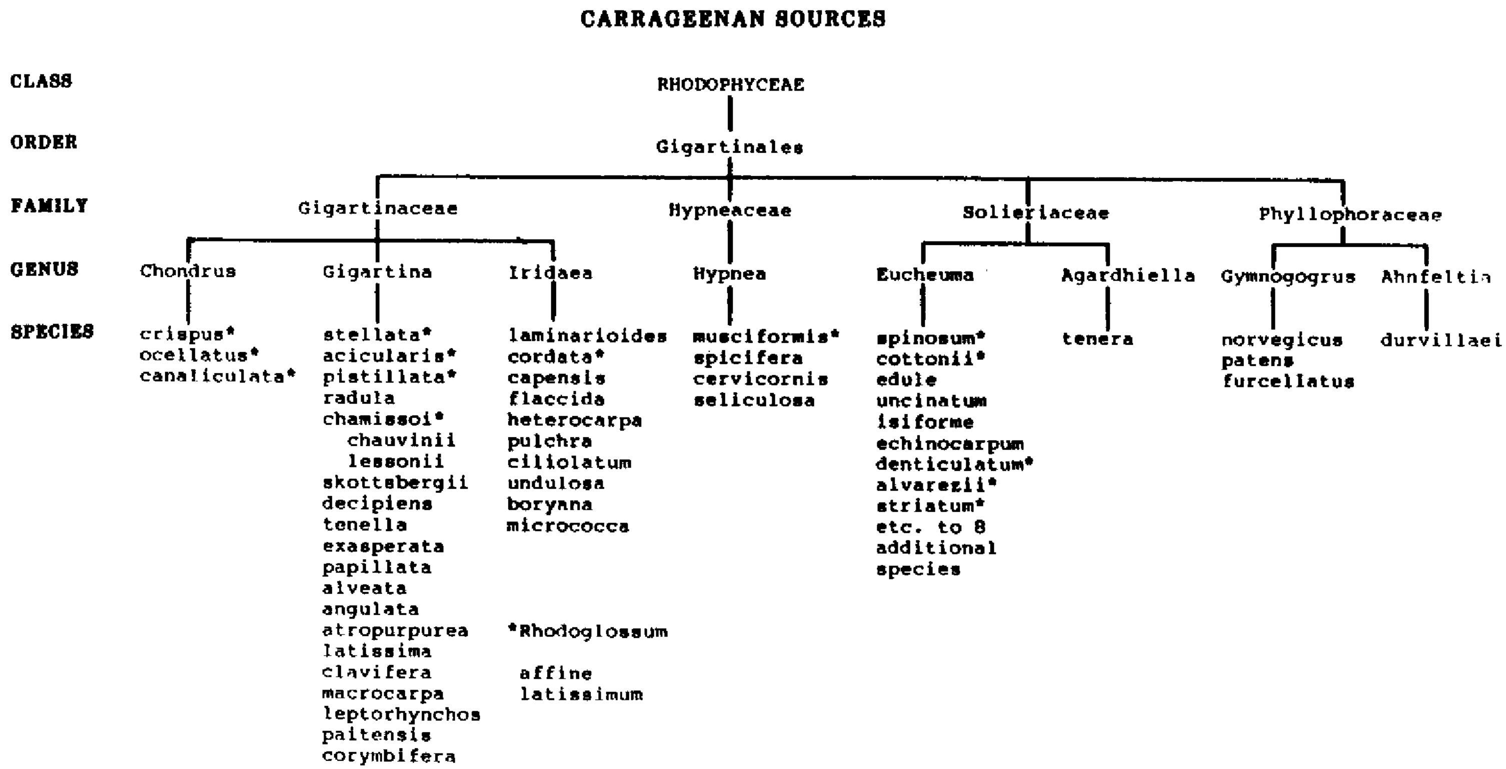
Figure 2. Algin Sources

Figure 3. Agar Sources



*Indicates extensive commercial utilization.
**The nomenclature for Gracilaria remains unresolved. For purposes of this report it may be better to classify it as "the species" from either Argentina, Chile or Taiwan.

Figure 4. Carrageenan Sources



*Indicates extensive commercial utilization.

Until comparatively recent times, the seaweed supply came from harvested wild growth. The economic feasibility of harvesting wild seaweeds, in turn, depended on the density of the growth in the ocean, the weather, ocean currents, waves, the availability of harvesters, etc. As we will show later, there are obvious problems in depending on wild sources. Consequently, within the past 40 years, sea farming of useful species has developed, with significant potential for Hawaii. This potential will be considered in subsequent sections of this report.

The world's principal sources for wild seaweed occur largely along the shores of the Pacific Ocean. Large concentrations occur in Chile, Mexico, the United States, the Philippines, Japan, China, Malaysia, and Indonesia. Other producing areas include Argentina, eastern Canada, western Europe, and several localities in Africa. Table C shows the distribution of significant wild seaweed harvesting areas by type of seaweed and use.

If a processing plant were established in Hawaii, the surrounding ocean areas would be capable of supplying a far greater volume of seaweed than the minimum amount needed to make the operation profitable. The role of farming and the opportunity for access to the raw materials for a seaweed extraction industry sited in Hawaii are discussed in a later section.

Preliminary pilot farming has successfully grown two seaweeds which are in good demand for their hydrocolloid content. One of them, Eucheuma of the cottonii variety, has been grown readily in Hawaii and in two nearby areas, Christmas and Ponape Islands. Both Christmas and Ponape have direct shipping contact with Hawaii. This particular seaweed, cottonii, is the target of a current industry-wide effort to expand and stabilize the raw material supplies. The effort includes encouraging farming in areas economically and politically independent of the present sources. Christmas Island, Ponape, and Hawaii would meet those specifications.

Seaweed is priced and sold either dry or wet. For example, kelps may be used wet or dry for extraction purposes. Porphyra (nori) is generally processed wet immediately after harvesting. Gracilaria is processed from dried material. The others are handled in various ways. Prevailing prices for wild and farmed sources of the seaweeds traded in international commerce are shown in Tables D and E.

Many seaweeds are among the fastest-growing macroscopic organisms in the world. They obtain their mineral nutrients from ocean water and their energy from sunlight. Commercial seaweed grows along the shores and on reefs from the high-tide line to depths of a hundred feet or so. Seaweeds do not possess an absorptive root structure such as would play a role in mineral nutrition, but they anchor themselves to the ocean floor by means of a holdfast attached to any solid surface or, rarely, to objects on sand or mud bottoms. Very few seaweed species will propagate and grow while free-floating. However, Sargassum, of the Sargasso Sea, and Gracilaria, the source of the best sugar-reactive agar, have this capability.

Seaweeds may be broadly classified according to use. In the first category, we include those that are harvested and used directly for human or animal consumption. These constitute the largest world market for seaweeds, a market which appears to be developing rapidly, especially in the southwest Pacific and southern and eastern Asia. This report provides only a brief discussion of these; in Hawaii, however, this market is significant.

In the second category, we place those seaweeds which are used as sources of extracted natural products, another segment of the seaweed industry that has experienced rapid growth in recent years. The extracts are largely hydrocolloids.

The third category, "other products," has significant potential, particularly in the cosmetic and pharmaceutical worlds.

The wholesale value of the hydrocolloids is estimated to be many hundreds of millions of dollars per year. The prospects for their processing in Hawaii are the primary target for this report.

Table C. Countries that Harvest Seaweeds

	Brown Seaweeds			Red Seaweeds		
	For Algin	For Food	For Other	For Carrageenan	For Agar	For Food
NORTH AMERICA:						
Canadian Maritimes	X			X		
New England				X		
California	X					
Mexico	X			X	X	
SOUTH AMERICA:						
Peru				X		
Chile	X			X	X	
Argentina	X			X	X	
Brazil					X	
AFRICA:						
South Africa	X				X	
Tanzania	X					
Angola	X					
Morocco				X	X	
EUROPE:						
Spain	X			X	X	
France	X			X		
England	X					
Denmark				X		
Norway	X		X			
Iceland	X		X			
ASIA:						
Philippines				X	X	X
Korea		X		X	X	X
Malaysia		X		X	X	X
China	X	X			X	X
Japan	X	X		X	X	X
Indonesia		X		X	X	X
Taiwan		X			X	X
AUSTRALIA	X				X	
NEW ZEALAND					X	

Table D. Estimated International Shipments of Dried Seaweed, 1981.

EXTRACTIVE	EXPORTING COUNTRY	DRY TONS EXPORTED	PRICE/TON FOR EXPORT COUNTRY	$ VALUE TO EXPORT COUNTRY
ALGIN				
Kelps	Mexico	4,000	200	800,000
	Australia	2,000	225	450,000
	Chile	6,500	225	1,462,500
	Argentine	500	240	120,000
	So. Africa	2,500	225	562,500
	Ireland	7,000	225	1,575,000
	Misc.	3,000	225	675,000
Ascophyllum	Norway	3,000	200	600,000
	Iceland	3,000	200	600,000
CARRAGEENAN				
Chondrus crispus	Ireland	500	600	300,000
	Canada	5,500	750	4,125,000
Other Gigartina	Mexico	400	600	240,000
	Peru	200	500	100,000
	Morocco	300	750	225,000
	Portugal	300	600	180,000
	Korea	800	600	540,000
	Chile	3,600	550	1,980,000
E. cottonii	Philippines	14,000	325	4,550,000
	Malaysia	3,300	325	1,072,500
	Indonesia	3,000	325	975,000
	Misc.	300	325	97,500
E. spinosum	Philippines	2,200	450	990,000
	Malaysia	1,000	450	450,000
	Indonesia	3,000	450	1,350,000
AGAR				
Gelidium	Korea	400	1,000	600,000
	Mexico	400	1,000	600,000
Gracilaria	Argentina	1,200	750	900,000
	Brazil	500	750	375,000
	Chile	4,000	750	3,000,000
	Taiwan	8,000	600	4,800,000
	Misc.	1,000	700	700,000

Table D. (continued.)

DRY TONS IMPORTED

EXTRACTIVE	EXPORTING COUNTRY	ENGLAND	FRANCE	DENMARK	JAPAN	SPAIN	U.S.	MISC HUMAN & ANIMAL FOOD
ALGIN								
Kelps	Mexico						4,000	
	Australia	1,000					1,000	
	Chile	2,500			2,000		2,000	
	Argentina	500						
	So. Africa	1,500					1,000	
	Ireland	7,000						
	Misc.	2,000					1,000	
Ascophyllum	Norway	1,500						1,500
	Iceland	1,500						1,500
CARRAGEENAN								
Chondrus crispus	Ireland	200	300					
	Canada			4,000			1,500	
Gigartina	Peru						200	
	Morocco		200				100	
	Portugal					200	100	
	Korea				700		100	
	Chile		600		500		2,500	
E. cottonii	Philippines		2,500	4,000	2,500	1,000	4,000	
	Malaysia		1,000	1,000	800		500	
	Indonesia		1,000	1,000	1,000			
	Misc.				300			
E. spinosum	Philippines		200	500	500		1,000	
	Malaysia		200		500		300	
	Indonesia		600	1,000	500	400	500	
Other	Mexico						400	
AGAR								
Gelidium	Korea				200		200	
	Mexico						400	
Gracilaria	Argentina				800	400		
	Brazil				500			
	Chile				3,200	800		
	Taiwan				8,000			
	Misc.				500	500		

Table E. Japanese Seaweed Harvest and Consumption in Foods and Industry.

	1971		1981	
	TONS (Metric)	VALUE U.S. $(000)	TONS (Metric)	VALUE U.S. $(000)
LAMINARIA JAPONICA				
Kombu - wild	110,780	45,589	112,178	106,000
- cultured	718	293*	45,000*	42,500*
TOTAL	111,498	45,589*	157,178*	148,500*
UNDARIA				
Wakama - wild	45,574		13,993	
- cultured	76,360		91,272	
TOTAL	121,934	27,945	104,265	55,000
PORPHYRA SPECIES:				
TOTAL	231,464	324,030	340,510	541,000
GELIDIUM AMANSII	12,314	9,851	8,988	6,528
OTHER SEAWEEDS				
Misc. - wild	55,406	15,760	31,356	24,400
GRAND TOTAL - ALL PRODUCTION	532,616	485,906	642,297	739,528

*Estimated

PRODUCTION AND SALES OF EDIBLE SEAWEEDS OF THE PACIFIC

Principal Markets

The principal markets for seaweeds used directly in foods are found in a zone along the western Pacific that includes Japan, Korea, China, the Philippines, Malaysia, and Indonesia. Obviously, the establishment of the first markets was based on wild sources. When market demand grew beyond the capabilities of the wild sources, major efforts were made to increase production by sea farming. Today, seaweeds sold for foods are still derived from both wild and farmed sources.

Although seaweed is used as food in Europe, the total for that area is insignificant when compared with the volumes used in Japan and China. However, there is a growing awareness in Europe and America of the nutritional values of seaweeds. When used as nutritional supplements, they can provide a broad profile of essential vitamins, proteins, and expecially trace elements. Tables F, G, and H show FDA definition, nutritional values, and composition for this type of product.

Table F. FDA Definition and Approval of Kelp Powder for Use in Foods. Source: Food Chemicals Codex

KELP: DESCRIPTION

The dehydrated seaweed obtained from the class Phaeophyceae (brown algae) of the genera *Macrocystis* (including *M. pyrifera* and related species) and *Laminaria* (including *L. digitata*, *L. cloustoni*, and *L. saccharina*). The seaweed may be chopped to provide coarse particles and/or it may be ground to provide a fine powder. It is dark green to olive brown in color and has a characteristic salty taste.

KELP:SPECIFICATIONS

Ash (total): Not more than 35 percent.
Iodine content: Between 0.1 percent and 0.5 percent.
Loss on drying: Not more than 13 percent.
Limits of Impurities:
- Arsenic (as As, inorganic). Not more than 3 parts per million (0.0003 percent).
- Heavy metals (as Pb). Not more than 40 parts per million (0.004 percent).
- Lead. Not more than 10 parts per million. (0.001 percent).

Table G. Basic Nutrients in Seaweeds.

Calcium	Magnesium	Selenium
Iron	Manganese	Chromium
Iodine	Copper	Nickel
Phosphorus	Zinc	Tin
Potassium	Cobalt	Vanadium
Sodium	Molybdenum	Silicon
Chlorine	Fluorine	

Summarized from Los Angeles Times, March 16, 1978.

Table H. Typical Analysis of *Macrocystis* Kelp Powder.
Preliminary data of June 15, 1982

TYPICAL NUTRITIONAL ANALYSIS	%
Protein	8.0 - 10.0
Fat	0.5 - 1.0
Carbohydrates	32.0 - 35.0
Fiber	6.0 - 8.0
Ash	36.0 - 38.0
Moisture	12.0 - 14.0

TYPICAL MINERAL CONTENT	
Arsenic	less than 3 PPM
Lead	less than 10 PPM
Total Heavy Metals	less than 40 PPM

	%
Iodine	0.20 - 0.40
Calcium	1.00 - 1.60
Phosphorus	0.28 - 0.34
Iron	0.03 - 0.04
Manganese	0.001 - 0.002
Magnesium	0.70 - 0.90
Zinc	0.002 - 0.003
Sodium	3.00 - 3.50
Potassium	11.00 - 15.00
Sulfur	1.00 - 1.60
Silicon	0.30 - 0.50

Present In Trace Amounts:
- Aluminium
- Barium
- Boron
- Chromium
- Lithium
- Nickel
- Silver
- Strontium
- Titanium
- Vanadium

Table H. (continued) Typical Analysis of *Macrocystis* Kelp Powder.
Preliminary data of June 15, 1982.

TYPICAL AMINO ACID CONTENT	mg/g
Leucine	6.0 - 7.0
Isoleucine	3.5 - 4.0
Methionine	1.0 - 1.2
Cystine	0.4 - 0.5
Lysine	4.4 - 5.0
Phenylalanine	4.0 - 4.5
Histidine	1.5 - 2.0
Tyrosine	1.0 - 1.5
Valine	5.0 - 6.0
Tryptophan	0.2 - 0.3
Threonine	4.0 - 4.2
Aspartic Acid	10.5 - 12.0
Serine	3.5 - 4.0
Glutamic Acid	17.0 - 20.0
Proline	3.5 - 3.8
Arginine	3.6 - 3.9
Glycine	6.0 - 6.2
Alanine	12.0 - 13.5

This powdered kelp is prepared from the large brown kelps that grow in the Pacific Ocean. It is light brown to yellow brown and has a slight salty and seaweed flavor.

As will be indicated later, there is good reason to believe that the markets in North America and Europe will continue to develop. However, it is too early to estimate future volume.

Table E shows that the wholesale value of seaweeds eaten by the Japanese will normally fall between $700,000,000 and $900,000,000 annually. The additional consumption in China and other countries in that area easily pushes the total value over $1,200,000,000 per year. Table E shows that the major seaweeds contributing to this volume in Japan are *Laminaria japonica* and the *Porphyra* species. In China the major seaweed consumed is also *Laminaria japonica,* while in the Philippines and Indonesia it is *Eucheuma*.

Porphyra, *Laminaria japonica*, and the other seaweeds listed in Table E must be processed for wholesale distribution and use by other processors or consumers. Processed seaweed is made available in thin sheets, flakes, powders, or tablets. This processing is usually done by the "processor/broker" to whom the farmer sells his product. Table E indicates the price and value which the farmer receives for his bulk product. However, once the seaweed passes this point, specific prices become blurred.

The use of seaweed for food increased steadily to its peak just before the recession of 1981-83. As this recession period now appears to be phasing out, it is anticipated growth will resume.

It is obvious that the western Pacific countries constitute a substantial market for processed edible seaweeds. Areas or countries having good ocean environments and other natural growing advantages may be able to establish a substantial farmed edible seaweed industry exporting to these markets. This possibility is evaluated with reference to Hawaii in various sections that follow.

Wild Seaweeds

Originally, seaweed utilization in foods was tied to the availability of wild seaweeds and the capability of shore populations to harvest and transport them. Commercial harvesting of wild seaweeds has become a major source of income for some fishermen and other people who live near the ocean. Such sources are variable, influenced by political and economic conditions and by winds, currents, temperatures, water quality, etc. Therefore, efforts are being made to develop stability for the farmer and the processors. For the processors, this means future developments in politically and economically stable areas, where there would be some control over continuity of supplies, quality, and quantity. A discussion of farming in these respects appears in the next section of this report.

Substantial quantities of wild seaweeds are still used for food in western Pacific countries such as Japan, Korea, China, etc. As seen in Table E, the Japanese Department of Marine Statistics tries to separate the sources of seaweeds in their annual reports on marine harvests. However, the reliability of these figures is questionable.

Costs for harvesting wild seaweeds vary according to density of growth, rate of growth, nature of the species, post-harvest treatment, labor costs, and other factors. Payment to the individual harvester is generally not above 75% of the price FOB port. The remaining 25% goes to the middlemen who assemble the crops, warehouse them, give them one treatment or another, and export them. Farmed sources are developing where labor and markets are available, and these appear to be displacing wild seaweed sources in all cases where both sources are available.

There is little or no difference in the qualities of wild and farmed seaweeds, provided equal care is given to their harvesting, processing, and delivery to the market. Seaweeds of equal quality will command an equal price. Generally in this report the statistics quoted pertaining to prices and properties cover both wild and farmed seaweed. Although wild seaweed may be equal to farmed seaweed, customers are increasingly attracted to the farm-raised products due to their availability, quality (due to greater care), and stable prices.

About ten species of seaweeds are found in the fish and fresh vegetable markets in Hawaii. Two species of the genus Gracilaria, G. coronopifolia and G. bursapastoris, are the principal seaweeds sold. Until recently, the market offerings were all from wild crops; but seaweeds produced by Hawaii's two Gracilaria farms are now appearing in the markets. There are ragged statistics on the "landings" of Gracilaria, but not of the other species. Interestingly, Eucheuma, which has occurred in minor amounts, presumably as a result of people innocently spreading it from experimental plantings, is appearing in the markets. Its market names have changed from "tambalang," the Philippine name for the particular strain, to "giant ogo" (derived from a Japanese name for a Gracilaria) to "big ogo."

Farmed Seaweeds

The technology and methods required for cost-effective seaweed farming evolved gradually over the past 50 years, and accelerated progress has been achieved within the past 20 years. Ocean farming of important species of seaweeds is now a substantial and growing business. It is reasonable to expect that within the next decade, cost-effective farming methods will emerge for other seaweeds not now used in foods.

Japan made the first completely controlled commercial farming breakthrough about 25 to 30 years ago with the highly desirable red seaweed Porphyra. Porphyra farming has increased almost steadily until the present and is now being attempted in other parts of the world. The Japanese kelp, Laminaria japonica, has been farmed in Japan since 1949, when details of its life cycle were clarified. It is now also extensively farmed in China. The technology for farming several Eucheuma species was developed about 1971, initiating its current large-scale use in foods. The uses of these farmed seaweeds are summarized as follows:

Porphyra

The largest producer and consumer of Porphyra is Japan, where the seaweed is called nori. Table E shows the extent of the Porphyra industry in Japan.

Data appearing in the Japanese statistical yearbooks (Fisheries and Aquaculture Production) published by the Japanese Agriculture, Forestry, and Fisheries Ministry, clearly show that annual sales of Porphyra have peaked at about 325,000 ± 25,000 tons over the past 5 to 6 years. During this time, sea farmers have consistently overproduced, forcing the surplus into lower-priced livestock feed or fertilizer uses. Intense competition and reduced prices have caused financial problems for many sea farmers.

Reports differ on current prices paid to the sea farmer for Porphyra processed into sheets of nori. Some reports fix this at $1,200-$1,400 per wet metric ton. Others state that most farmers obtained $1,600-$1,800 for the same weight. Calculations based on Table E indicate that the $1,200-$1,400 price is correct, but it is believed this must include the surplus sold at lower prices.

Under normal conditions the sea farmer makes about 20% profit on Porphyra production. This margin is maintained if the sea farmer processes his nori into sheets for sale to the retailer. Costs for Porphyra and nori are invariably calculated on a per-sheet basis. Under normal economic conditions, sea farmers sell their nori to wholesale food distributors for about 12 to 13 yen per sheet. From 1981 to 1983, the combination of over-production and economic depression caused prices to decline. During this period some sea farmers were forced to sell their nori at about 10 yen per sheet, which is below production cost.

Other considerations aside, the continuing Japanese over-production of Porphyra and the intensely competitive market situation eliminate Japan as a market for Porphyra grown in Hawaii. Additionally, in 1977 the Japanese government established import embargos on Porphyra and other edible seaweeds. Although Japan is a GATT Treaty nation, we do not believe that the Japanese government can be persuaded to revoke this embargo.

However, several modest but developing markets are available to Porphyra producers. The most interesting possibility is in the United States. In 1980 the Japanese exported about 1,400,000 lbs. of Porphyra to the United States, of which 190,000 lbs. was consumed in Hawaii. U.S. import dealers believe that most of the imported volume for 1980 and prior years was consumed by people of

Japanese ancestry. Since 1980, other ethnic groups in the United States have begun to consume seaweed in various forms, especially Porphyra. An example is the expanding popularity of sushi, in which Porphyra is used as a wrapper around the basic rice component.

The 1,400,000 lbs. of nori imported from Japan into the U.S. in 1980 was priced at about $4.00 per pound FOB Japan, with a total value of about $5,600,000.

It is estimated that since 1980, imports have increased by 35 to 40%, giving a current market value of $7,500,000 to $8,000,000. A check with importers revealed that prices have remained steady since 1980.

Porphyra is also sea farmed in Korea. Apparently neither the Korean government nor any private organization maintains production or consumption figures. It was verified that although production was substantial, it was far less than Japan's. Although most of its production is used internally, Korea supplies about 30% of the U.S. consumption. The Korean price is about 50 cents per pound lower than Japanese imports, but the quality is lower. Like the Japanese, the Korean sea farmers have been overproducing during the past three or four years.

Recently the state of Washington has strongly supported the development of Porphyra production in Puget Sound.

Summarizing the Porphyra market picture, it is concluded that if the seaweed were grown in Hawaii, the United States would offer the best and only reliable potential market. However, it is difficult to formulate an estimate of future Porphyra consumption in North America, particularly in the United States. There is no question that the increased usage of Porphyra is tied to the growing acceptance of Japanese foods by American families. Current consumption in the U.S. supports a substantial farming operation; at this point there is no basis for estimating how much further the trend will progress. It is not anticipated that the situation will change from year to year, so anyone interested in sea farming Porphyra in Hawaii should evaluate the U.S. market before committing funds.

Laminaria japonica

China has replaced Japan as the largest producer and consumer of this seaweed. Dr. C. K. Tseng, head of the Institute of Oceanology, Qingdao, China, stated at the Eleventh International Seaweed Symposium that production for 1983 would be between 300,000 and 325,000 metric tons, dry weight. Of this amount, about 40,000 tons are used for algin production; approximately 250,000 to 260,000 tons are consumed as food.

No specific data about the prices received by any of the Chinese sea farms is available. Dr. Tseng stated that costs to the processors are usually between $450 and $500 per metric ton. Further documentary proof was obtained that China was willing to export industrial-grade kelp in 1982 for $520 per ton FOB Chinese port. Also two reports, which were judged to be reliable, indicate that the Japanese are buying food-grade Chinese Laminaria for $1,200 per ton. Reliable information could not be obtained pertaining to the retail price of kelp to the Chinese consumer.

Table E indicates that approximately 150,000 tons of Laminaria japonica are consumed annually in Japan. Of this weight, about 100,000 to 110,000 tons are reported as originating from wild sources. As mentioned earlier, the figures shown in Table E are questionable. Individuals familiar with the Japanese kelp industry report that about 50% or more of the current

L. japonica supply originates from farmed sources. These statements were not verified. In any case, Table E clearly indicates that increasing quantities of L. japonica are being produced on sea farms and that sea farming is now well established.

Oral reports have been received that the sea farmer normally receives about $1,000 per ton for his Laminaria japonica. This is supported by Table E, from which one can calculate a per-ton price of $944.

Laminaria japonica may be prepared in strips, flakes, or granules. Costs could not be obtained for retail product preparation, nor could retail prices. Based on verbal communications with knowledgeable individuals, we estimate that the product processors receive their costs plus about 15%. The combined percentage of the wholesale and retail distributors amounts to between 30% and 40% of the retail price.

Undaria

Table E shows that roughly 110,000 tons of Undaria are consumed, of which about 90,000 tons are farmed; the remainder is from wild sources. Table E also indicates that the volume of Undaria is declining while that of Laminaria japonica is holding steady, even during the recession years. Japanese attending the Eleventh International Seaweed Symposium reported that farmed L. japonica is replacing Undaria in volume. This is partly because sea farmers are unhappy with Undaria's low price of between $500 and $600 per ton. Furthermore, consumers seem to have a growing preference for L. japonica. U.S. importers who handle these products stated that they are not currently importing any Undaria into the United States.

In view of its low price, declining market in Japan, and lack of an established market in other countries, Undaria is not considered a candidate for farming in Hawaii.

Eucheuma

The commercial Eucheuma species occur naturally in the western Pacific from the Philippines southward through Indonesia and eastward into the adjacent Pacific Islands area. Other background information is included under the sea farming sections which follow.

Eucheuma sea farming began increasing about 15 years ago, especially farming of the commercial forms known as cottonii and spinosum. Total annual production of cottonii now exceeds 25,000 tons (dry weight), while spinosum production from farming and wild crops is about 7,000 tons annually.

Personal correspondence has indicated that recently 5,000 tons or more of Eucheuma were imported into Japan. Apparently Japan does not prevent the importation of this seaweed because it is not farmed or grown in that country. It was estimated that about 2,000 tons of the 5,000 were used by the Japanese to produce carrageenan, and the remainder was used in foods. Food use in Japan is expected to grow rapidly, requiring increasing farming. This seaweed will come from the Philippines and adjacent areas. Because cottonii can be produced more readily, more economically, and in greater abundance than spinosum, it is preferred for human consumption. As far as we could determine, very little spinosum is consumed. Therefore, reference to edible Eucheuma pertains only to cottonii.

According to reports, the native populations of the Philippines and other Eucheuma-producing areas also eat this group of seaweeds. However, they are usually harvested and consumed locally. No volume data are available. No evidence was found that Eucheuma is used for food in North America, Europe, or other countries.

Currently high-grade, food-quality cottonii sells for prices ranging between $400 and $450, FOB Philippines port. The prices obtained for the exported food-grade Eucheuma depend on quality, which depends on whether the weed is washed and dried several times. It must also be dried in a manner to exclude sand and other contaminants. The Japanese frequently import industrial-quality cottonii for about $300 to $350 per ton; they wash and redry it in Japan and then sell it for food.

Several factors have led to an anticipation of increasing food usage for Eucheuma. First, production costs and prices are significantly lower than for other types of seaweeds used as foods. Secondly, sea farming is now well established, and this provides assured quantity and quality. Thirdly, Eucheuma lends itself well to any number of salad, pickle, baking, pudding, and other direct uses in domestic food preparations.

Sargassum

Sargassum is becoming more popular as a feedstock additive in the Pacific feedstock trade. It is merely dried, ground, and bagged for its bulk and carotin content. Various efforts to utilize Sargassum as a source of alginate have failed, largely due to low yield.

Edible Seaweeds

The use of seaweeds in foods is mentioned in ancient Chinese and Japanese literature, and since they were foods for centuries, there has never been any question about their suitability for direct consumption. Ancient and modern populations have recognized that the inclusion of small amounts of seaweed in their daily diet may contribute to overall health and well-being. Tables F, G, and H deal with the food value of seaweed. Important edible seaweeds are listed in Tables D and E. None of the leading government bodies, including the Food and Drug Administrations (FDA) of Japan, the United States, Canada, Germany, or France, or the World Health Organization has ever expressed any concern about the use of seaweed as food.

However, several FDAs have established standards that relate to moisture, impurities, content of arsenic, lead, total heavy metals, etc. Experience shows that these standards are sufficiently broad to impose few or no constraints on the use of seaweeds in foods. Table F shows the U.S. FDA standards for kelp. Generally, the brokers who import the seaweed into their countries will know the health regulations, and they are in a position to advise and guide the sea farmer/supplier.

Although no changes are anticipated in existing FDA regulations and practices, the possibility of new regulations that might change the food status of seaweeds cannot be ruled out. This uncertainty is created by the new understanding of the effects contributed by various food components and compounds, more sensitive test methods, etc. Therefore, before anyone commits a substantial investment to either seaweed farming or extractive production, it is recommended that he obtain a current status report pertaining to this subject.

SEAWEED FARMING: REQUIREMENTS, COSTS, AND POLITICAL CONSIDERATIONS

The Potential

It is estimated that within the next decade, cost-effective farming methods will emerge for other seaweeds not now used in foods. In the absence of harvestable concentrations of wild seaweed in Hawaii, the only logical way to establish local sources is through sea farming.

Preliminary study shows that some species may have a better chance for success than others and thus have a higher priority for evaluation. Based on experience, it is suggested that the species of Porphyra, Eucheuma, Gracilaria, and those of other genera can be farmed around Hawaii without adverse environmental impact.

Common Considerations for All Seaweed Farming

Only the broad aspects of sea farming are covered in this assessment; it is outside the scope of the study to include the specific, detailed techniques of the sea farming of each species. This information is readily available in the areas where seaweeds are being farmed. The marine science departments of universities in each country and the departments of fisheries of the local governments generally know where information is available concerning such farming activities in their areas. General information of importance to those who are considering introducing or developing seaweed farms is listed in the following discussion.

Determining the yield of harvested seaweed per unit of area is a planning necessity; e.g., often 15 to 30 tons/ha or 8 to 10 tons per farmer per year are produced. Exclusive rights to culture and harvest the planted farm are a prerequisite. Procurement of the exclusive rights in the U.S. usually requires the submission of applications for licenses to the appropriate governmental departments. Approval from the pertinent state, county, or city governments must also be obtained for the anticipated environmental impact, road use, zoning, etc. Various federal offices may also require permits. In Hawaii this can be a tedious process, for all subtidal lands have been classified for conservation use.

The exclusive farm plot should be located in a semi-protected area with high fertility. Transportation, labor, supplies, and a market should be available.

The following general observations about seaweed and seaweed farming are offered for guidance.

*On suitable substrata, some species of seaweeds could be harvested mechanically, though this is not often done. Labor-intensive hand harvesting is the rule. Generally, after harvesting, the seaweed is immediately dried on nearby beaches or special platforms.

*A pilot farm should be developed first. The size should be large enough and the duration of operation long enough to allow calculations of production costs, growing rates, quality of the seaweed, and evaluation of environmental impact. The seaweed, farm structures, and substrata should be tested for all-weather stability. Labor costs and availability should be ascertained and all equipment evaluated for efficiency and durability.

*When used for algin extraction, kelps may be processed either wet or dry. If wet, they must be delivered and extracted promptly after harvesting. If dried, they should have a moisture content of 15 to 18% of total weight. Extractors of red seaweeds generally prefer them dried with a moisture content of 16 to 21%.

*After drying, seaweeds are usually prepared for sale by pressing them into bales weighing about 150 to 300 pounds each. They are usually strapped and banded, and then shipped in containers.

*Dried seaweeds contain a substantial amount of salt. This, together with some of the other natural qualities of the seaweeds, renders them very stable in storage. Well-dried seaweeds will retain their extractives at full strength for several years. Rodents, insects, and similar life forms do not bother stored seaweed. As a result of this stability of the dried seaweeds, extractors often carry an inventory substantially in excess of annual requirements as protection against poor harvests, shipping or labor strikes, governmental interference, etc. A reliable farm source could reduce the need for such large inventories, with considerable saving to the extractor on capital costs.

*Depending on the species, properly harvested and dried seaweeds used by commercial extractors normally contain 20 to 40% extractive material. This high extractive concentration, the high prices obtained for the extractives, and seaweed's stability in storage enable the extractors to import seaweeds from almost any location in the world. Table D shows the international nature of the sources of dried seaweeds.

*Extractors have a standard method for calculating and comparing the costs of their raw materials. The standard used is determined by dividing the price paid for a ton of seaweed by the pounds of extractive in that seaweed. For example, if a metric ton of delivered _Eucheuma_ contains 30% extractive, the ton contains 660 pounds of extractive. If the ton costs $550 delivered to the extraction plant, the cost of the extractive in the seaweed, _before extraction_, is $0.83 per pound.

Special Considerations Related to Hawaii

Protection of Beaches

Hawaii's tourist trade is a major contributor to the Hawaiian economy, and the principal attraction for tourists are its people, sunshine, and beaches. A major concern immediately emerges when seaweed farming is discussed with responsible people in Hawaii: fear that seaweeds grown in that area, under either wild or cultivated conditions, will become detached during the growing process and drift onto the beaches, reducing their attractiveness. This might well occur if seaweeds are farmed in the vicinity of tourist beaches. However, there are areas where no beaches exist and the reef flats are generally unattractive to tourists. It would be possible to culture seaweed extensively in these areas. Also, remote islands or areas with little or no tourist trade and no conflicting other use may be suitable for sea farms.

Exclusive Harvesting Rights

The state government has the right to grant the underwater harvesting rights that are required for any sea farming venture. It seems impossible to determine what the state authorities might require or accept as proof that seaweed farming would not create intolerable problems. These requirements must be determined before any substantial pilot evaluation is undertaken; then data meeting the state's requirements can be obtained and incorporated as a part of the evaluation.

Methods and Costs

In the course of this evaluation it was concluded that three major questions must be considered with respect to sea farming in Hawaii:

*Are physical conditions suitable for maximum productivity?
*Is sea farming politically acceptable?
*Will sea farming in Hawaii be economically competitive?

Note that the cost of producing seaweed varies strikingly, depending on whether farms operate in an owner/manager situation, with the laborers who do the farming being paid on a time-spent basis, or whether the owner does the farming and is rewarded on the basis of his production, perhaps with unpaid members of his family assisting (a concept somewhat foreign to most American businessmen). Below, note that Porphyra and Laminaria farms are of the former (owner-manager) type and Eucheuma farms of the latter (family-operated) type. Gracilaria farming is too recent a development to be analysed at present. Probably, like the others, it will initially be of the family-type operation and in time change to the sophistication of the more capital-intensive state or communal farming operation.

As far as information is available, each of the above questions is discussed below along with the costs, etc., for the seaweeds covered in this assessment.

Porphyra

Experience shows that Porphyra will grow in a variety of climatic and oceanic conditions in nature or in tanks. While the waters around Hawaii are judged desirable in places, other factors make Hawaii less than ideally suited for producing this genus economically.

Phorphyra is used only in foods. It is not utilized as a source of extractives.

Laminaria and Other Kelps

Laminaria and other kelp plantings are initiated by causing the reproductive bodies to grow on string or small ropes. These and the juvenile thalli on them are then inserted in larger ropes. The larger ropes may be associated in a network or hung from a network of buoyed ropes anchored in appropriate places. The Chinese place such kelp ropes in long rows.

When the kelp is mature, the ropes are raised and quickly harvested. After obtaining a boatload of kelp, the fishermen bring it ashore and spread it on the beach for drying. Food-grade kelps are frequently dried on stakes, walls, or hard pads to prevent contamination with sand or other debris.

Hawaiian-farmed kelp might provide the raw material requirements for a locally situated algin extraction plant. However, the temperatures at otherwise-suitable sites are always above 22 degrees Centigrade, and this negates the possibility of growing such seaweeds as Laminaria in Hawaii, at least as far as the essential microscopic gametophytic stage in their life cycle is concerned. If a strain of any of the commercial kelps is found which has the macroscopic stage tolerant of the 22-to-26 degree surface waters of Hawaii, the microscopic stages could be produced elsewhere and the very young sporophytic macroscopic stages outplanted; in this way, kelp could be farmed in the state. Further background is needed to assess this possibility.

Four major algin producers and several smaller operations now exist. The largest companies are Kelco Company of San Diego and its large subsidiary, Algin Industries, Ltd., of England. Other sizable operations are Protan in Norway and CECA in France. Personnel of any sea-farming undertaking in Hawaii that is designed to supply an algin plant must have some understanding of the supply picture of these competitive plants.

Kelco Company currently obtains about 60 to 70% of its requirements by machine-harvesting nearby kelp beds. Depending on the distance to the bed, their costs for algin, in the weed before extraction, range between $0.25 and $0.42 per pound. Between 50% and 75% of the raw materials used by the other three major extractors also comes from fresh sources. However, their costs range between $0.45 and $0.60 per pound of algin, delivered as wet kelp, before extraction.

The remainder of their requirements comes from imported dried kelps, largely Lessonia, Macrocystis, and Undaria, as shown in Table D. The current price for sun-dried wild kelp imported from Chile or similar areas ranges between $225 and $275 per metric ton, FOB country of origin. Ocean freight and port charges total about $155 to $165 per ton, making a total per-ton cost of about $380 to $440. The algin in this kelp ranges between 18 and 22%. Therefore, the cost of the extractive in the kelp, before extraction, is between $1.73 per kilogram (380/(1,000 x .22)) and $2.44 per kilogram (440/(1000 x .18)), or $0.79 to $1.11 per pound.

China's impressive progress in the production and extraction of farmed Laminaria japonica is another development that must be considered in connection with any farming venture in Hawaii. Based on observations and two reliable verbal reports, it is quite apparent that the Chinese farms are delivering wet kelp to Chinese extraction plants at a cost of 45 to 50 cents per pound of algin in the weed before extraction. This is equivalent to about $300 to $325 per dry ton. This calculation does not include the costs of drying. In this instance, 28% was used as the algin content of the dried seaweed; note that 18 to 22% was the estimate used in the discussion in the paragraph above.

Information pertaining to the costs of producing the Chinese kelp is confusing. No empirical data could be obtained from the Chinese about their costs, although their costs for producing industrial-grade kelp were said to be between $450 and $500 per dry metric ton, and a lot of it was seen stored, at least in one extraction plant. Again, it was not determined if the price included any profit for the sea farm. We obtained invoices showing that the Chinese are exporting industrial-grade kelp at $520 per metric ton. They are selling food-grade dried kelp to the Japanese for $1,200 per dry ton. Although there is no supporting evidence, we estimate that their food-grade kelp probably costs $100 to $150 per ton more than the industrial grades, due to the added care required in drying and packaging.

One must also remember that within the past five or six years, the Chinese have increased their algin production to approximately 7,000 tons annually, all of which is extracted from seaweeds harvested from their sea farms (Figure 1). Due to the minimal amount of labor required for the extraction of algin and the fact that reagents and energy costs are roughly the same on a world-wide basis, it is estimated that there would be no significant difference between the Chinese extracting costs and those of the non-Chinese major extractors. It may be that the major western manufacturers named above have developed more sophisticated methods which give them a slight quality-cost advantage.

The major difference between the Chinese and other extractors is the allocation that must be made for income taxes and profits. No information could be found as to how the Chinese account for these two items. However, an acquaintance from Hong Kong has estimated that China imposes a tax of approximately five percent on business profits.

There is no firm basis for estimating the costs for sea-farming kelps such as *Laminaria japonica* around Hawaii. Based on observations and extrapolations taken from our Chinese trip and other experiences, an attempt to make a tentative operating statement appears in Table I. From this exercise, we estimate that *L. japonica* can be grown (if it can be grown in Hawaii at all), harvested, and delivered wet to a 1,000-ton-capacity Hawaiian extraction plant for between \$70 and \$90 per pound of alginate at a raw material cost of 68 to 70 cents per pound, in the weed, before extraction. This cost should average close the the costs of the combined wet and dry kelps now obtained by the major extractors.

Table I. Assumptions and Estimates re Production Costs of Seafarmed *Laminaria japonica* - Hawaii Vicinity - per 1,000 Metric Tons, Delivered

Production Costs	
2 men - \$5 hr + 20% fringe x 330 days	\$ 31,680
Maintenance	6,000
Depreciation	10,000
Miscellaneous	2,500
Hauling wet kelp to extraction plant	4,000
Loading & unloading	4,000
Total production costs	\$ 58,180
Administrative Costs (Based on 100 Ha Farm):	
Office & secretary, etc.	1,000
General management	3,500
Taxes and licenses	1,000
Miscellaneous	2,000
Total administrative costs	\$ 7,500
TOTAL ALL COSTS	\$ 65,680

Table I. (continued). Assumptions and Estimates re Production Costs of Seafarmed *Laminaria japonica*.

Cost of algin in the weed before extraction

At 750 ton level - 5 ha plot
Cost per ton = $ 87.60
Cost of algin = $ 1.08/lb.

At 1,000 ton level
Cost per ton = $ 65.68
Cost of algin = $ 0.76/lb.

At 1,125 ton level
Cost per ton = $ 58.40
Cost of algin = $ 0.68/lb.

The estimates show that energy to produce algin costs between 16 cents and 18 cents per pound. A kelp farm located along the coasts of Hawaii Island plus an extraction plant located at the nearby geothermal area (Figure 5) could make an economically feasible combination. Before further consideration can be given to this possibility, firm data must be developed through pilot evaluations, which we recommend accordingly.

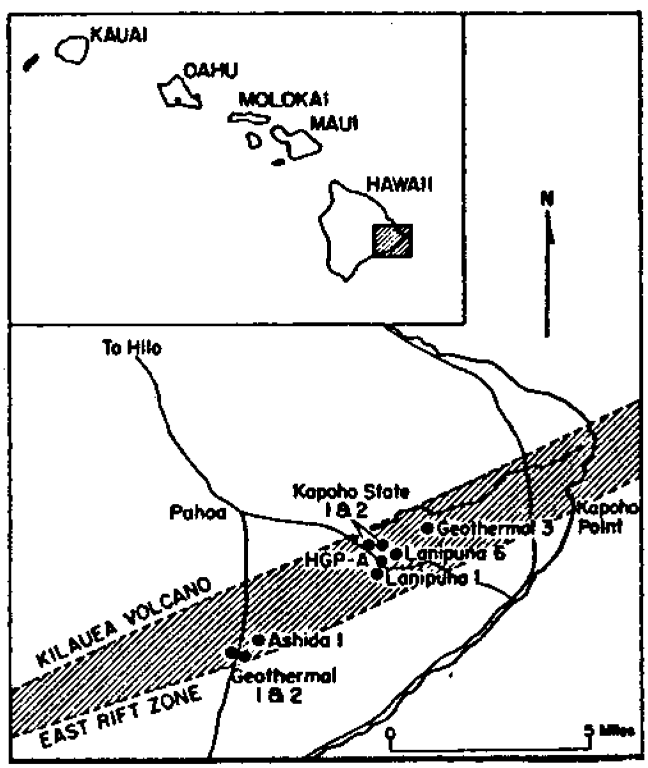


Figure 5. Location of Hawaii Geothermal Power Well "A" in relation to Hilo and Honolulu, respectively, some 20 and 150 miles to the north. Note private wells sited nearby.

Eucheuma

There are two Eucheuma species, referred to as cottonii and spinosum. They are becoming increasingly important to the extraction industries as sources for carrageenan. Until about 1970, only limited wild sources were available, and these were frequently overharvested and undependable. In 1973 and 1974, significant quantities of the farmed weed began to appear on the market. Dependability of the supply, better quality, and lower costs have induced extractors to buy increasing quantities from the farmed sources in the Philippines and Indonesia. Malaysia could become a producer.

The 24,000 tons of cottonii Eucheuma produced in 1982 and the total for both cottonii and spinosum, about 30,000 tons in 1983, were nearly all from farms. Today, little cottonii is harvested from wild beds. About 50 to 60% of the E. denticulatum, the spinosum type, is grown on farms, while the rest comes from wild sources.

Eucheuma farms are quite simple. Small pieces of Eucheuma are tied to nylon monofilament lines, which are then suspended appropriately in protected ocean water having good circulation. The seaweed produces rapid vegetative growth in all seasons. The mature growth is harvested by hand, and the younger branches are used for replanting. Several harvests are possible each year. One hectare will produce up to 30 tons annually, but half as much is commoner. The wet harvest is dried on nearby beaches or similar areas. After drying, the seaweed is usually packed into pressed burlap-wrapped bales weighing up to 300 pounds each.

It is hard to define precisely the costs for this type of operation. Capital requirements are very low. The sea farmer does not normally assign a cost to his labor, and farming is only a part-time occupation as a rule, allowing him to pursue his normal fishing or other farming. Thus one cannot deduct labor cost from profit.

In any case, the sea farmer currently sells the cottonii to the collector/broker for about \$275 to \$325 per ton, with prices dependent on moisture content (extractive content), quality, etc. The collector assembles the Eucheuma from several sources, moves it to port, and subsequently exports it for prices ranging between \$325 and \$375 per ton FOB point of origin. Freight charges to the United States and Europe are approximately equal at \$115 to \$135 per ton, giving total costs of about \$440 to \$510 per ton.

Because spinosum grows more slowly than cottonii and requires more care, it is sold by the sea farmer for about \$425 to \$475 per ton. The collector/broker gets about \$500 to \$550 per ton FOB port, which makes the delivered price to the extractor (after adding freight charges) between \$615 (\$500 + 115) and \$685 (\$550 + 135).

Based on current economic conditions, we find it improbable that in future years the sea farmer will receive less than \$300 to \$325 per ton for cottonii and \$375 to \$400 per ton for spinosum. Extractors have learned that if prices fall below these levels, volumes farmed decline rapidly. Once a decline in production has occurred, several years are required to bring it back to desired levels, and often premium prices must be paid to encourage sufficient production. At the current time, extractors are being very careful to obtain the volumes they desire by adjusting their prices (or allowable water content) as the market indicates.

The Department of Botany, University of Hawaii, Manoa, has provided positive evidence that Eucheuma seaweeds will grow economically on reef flats located in Hawaiian and nearby waters. It is visualized that Eucheuma farms would be located on reef flats which would be remote from those frequented by tourists and would be no problem to the tourist industry or the people who use the beaches.

It is impossible to estimate the costs of farming any seaweed without knowing the specific location. However, based on our experience with farming Eucheuma in other localities and first-order approximations from terrestrial crops, it is estimated that cottonii may be farmed on Hawaiian reefs such as those of Lanai and Molokai Islands at costs ranging between $350 and $450 per ton. Likewise, it is ventured that spinosum may be farmed at costs ranging between $450 and $500 per ton. These estimates take into consideration the higher Hawaiian labor costs compared with Philippine costs.

Such locally farmed Eucheuma seaweeds, at costs falling within the above ranges, would give a local extractor an assured supply and a definite cost advantage. An operation of this type would also contribute a significant number of jobs to the Hawaiian economy.

We can anticipate that the use of Eucheuma in foods will be accelerating and should continue to increase for some years. There is no limitation on the importation of Eucheuma into Japan or the U.S., the major developing markets. Between 3,000 and 5,000 tons are already being used as food, and it is estimated this will double or triple within the next 5 to 10 years.

Although the carrageenan industry leveled off during the recent recession, it is estimated that its historic pattern of growth will soon resume. There is also the possibility that the carrageenan industry may shift away from some of the other wild-crop seaweed species and toward the more readily available and economically attractive Eucheumas and those genera which can be farmed in the same way as Eucheuma. In any case, Eucheuma demand is expected to continue to increase rapidly, and this will require increased farming.

Area Requirements

Introduction

Seaweed extraction plants require a minimum of a few thousand tons of a given seaweed per year in order to be economic. Obtaining sufficient supplies for an extraction plant in Hawaii would not be a problem. In fact, such a plant could operate competitively today, using only imported dried seaweed. However, for two reasons, the plant would show a greater profit if it used seaweed grown at nearby Pacific islands: the freight charges would be lower, and the drying step might be eliminated. Establishing seaweed farms would also help to bring jobs and money to the Pacific islands involved.

In light of the above benefits, we will next consider which areas of the Pacific near Hawaii are suitable for seaweed farming, how large an area is needed, and the volume of seaweed that would be harvested.

Since the major products of extracting plants are hydrocolloids, the minimal farm areas are estimated with hydrocolloid extraction in mind. Lesser amounts of certain seaweeds could be utilized in the production of specialty chemical products, but the profits realized by such ventures would not be significant compared with profits from the standard hydrocolloid extraction plant.

In general terms, one acre of a sea farm produces 2 to 20 dry tons of seaweed for hydrocolloid extraction per year. Approximately five dry tons of seaweed are needed to produce one ton of extract.

Table J. Total Farm Areas Needed for Plant Support.

The hectarage needed to produce enough dried seaweed to support economic operation of a minimal-sized extraction plant. Weights are given in metric tons per year. (One hectare equals 2.47 acres.)

Hydrocolloid source	Dry tons per ha per year	Hydro-colloid yield %	Yield:Tons gel/ton seaweed	Tons/Min. plant size	Min. ha required per plant
Agar Gracilaria	10	25	2.5	125	50
Algin Macrocystis	40	18	7.2	1,000	139
Carrageenan Eucheuma	15	35	5.25	750	143

Table J indicates farm sizes and yields per year that would produce the seaweed required for an extraction plant of minimal size.

The figures for different seaweeds and different products vary widely, but it seems safe to say that sufficient areas for farming them are available. Table J may be misleading, for it does not take into account the economies of scale necessary for the pre-extraction plant portions of the industry, nor does it consider the range of products necessary to allow an extraction plant to meet market demands.

Suitable Areas in the Central Pacific

Hawaii, Micronesia, the Line Islands, and western Kiribati have many thousands of hectares of reef flat suitable for producing Eucheuma and other seaweeds. However, only a few thousand hectares scattered throughout these areas have been examined for the present study (Table K); there are probably more than 10,000 hectares suitable in just the part of the tropical Pacific that has shipping connections with Hawaii.

Eucheuma farming has been successfully introduced into the Line Islands, which are a combination of atolls and low volcanic islands. Some of these islands belong to the nation of Kiribati; others are U.S. unincorporated territory. They have a few thousand hectares of seaweed farm area.

Micronesia is also farming this seaweed, and Ponape, Micronesia, has Eucheuma farms and the promise of producing other seaweeds which are agar sources. A current joint project of the companies processing over 80% of one hydrocolloid is to develop large-scale farming of one seaweed in Micronesia soon.

According to Ryther, the maximum productivity of such areas should be on the order of 200 tons of algal material per hectare per year; there is an unpublished record of a 0.44 hectare Philippine farm area said to have produced Eucheuma at a rate of over 100 T/ha/year. In Indonesia, two other farms are said to produce around 75 T/ha/year of Eucheuma each. Many farmers produce 10 to 15 T/ha/year.

Table K. Total Estimated Reef Areas Apparently Suitable for Farming Eucheuma in Hawaii, or Connected with Hawaii by Surface Freight. The area is given in hectares. (One hectare is 2.47 acres.)

Location of Area	Hectarage, estimated
State of Hawaii	
Kauai Island	>22 - <222
Lanai Island	252
Molokai Island	2,043
Oahu Island (sample only)	>89
U.S. Unincorporated Territories	
Wake Island	<?100
Palmyra Island	?300
Kiribati	
Christmas Island	>500 - <1,061
Western Kiribati	?1,000
Federated States of Micronesia	
Kosrae	?250
Ponape Island	>500 - <940
Yap	>1,000
Belau	>1,000
Various locations anticipated from charts	>10,000

Thus it seems safe to say that the potential production for Eucheuma, alone, that would be available to a processing plant in Hawaii would be between 100,000 and 1,000,000 tons per year (10 to 100 tons times 10,000 hectares). This is vastly more seaweed than the world could consume as carrageenan in the forseeable future. Thus the known areas are far more than enough to produce the minimal amount of seaweed needed to support a processing plant.

The raw field data from which these numbers were derived were obtained for the project by a separate consultancy funded by the International Sea Grant Program and the Sea Grant College Program of the University of Hawaii.

The reef flat areas given in Table K for Hawaii and Christmas Island were estimated from random walking over the reef flats and then identifying, on aerial photographs, those areas suitable for Eucheuma or Gracilaria farming. The special walking was largely done by Mr. Vicente B. Alvarez, who is perhaps the world's most experienced Eucheuma farmer. Estimates of potential sea farms in other locations were obtained from a variety of sources. Those from Micronesia are from aerial observations, with some on-site inspections. Those marked with a question mark were derived from poor aerial photographs or from charts alone. The last category, "Various...", appears to be a conservative estimate, with 10,000 suitable hectares available.

The information derived from random walking and other procedures was transferred to tracing paper laid over aerial photographs or charts of known scale. Areas suitable for seaweed farming were cut out of the paper and weighed. The ratio of these weights to the weight of a piece of the tracing paper that represented one hectare gave us a figure for the area suitable for farming.

Detailed Analysis of Hawaiian Islands, Micronesia, and the Line Islands

Today there are six seaweed farms in Hawaii, and more could be developed. Experimental farming has been done successfully, and in general the types of suitable areas are known. In the state of Hawaii, there are at least 2,500 hectares (6,175 acres) of reef flat that could be used for seaweed farming.

In the case of Oahu, the population center of Hawaii, our study had to be confined to a small sample of the reef flats only, due to site competition. Thus for Oahu, which has the most reefs of any of the Hawaiian islands, only the term "greater than 89 ha" is indicated in Table K. A vastly larger area than this is present in the combination of the reefs and shallows of three Oahu areas: between Kahi Point at the west end of the Ewa Plain and Diamond Head; at Kaneohe Bay; and among the windward reefs both north and south of Kaneohe Bay. We concentrated more on the outer-island reefs of Kauai, Lanai, and Molokai, which are more practical areas for development. In addition, the Leeward Hawaiian Islands might very well be ideal for many species, but their remoteness and their status as wildlife preserves obviates their consideration now. With the Leeward Islands included, the area for seaweed farming within the state of Hawaii is certainly considerably in excess of the minimal 5,000 hectares required to support an extraction industry.

On the outer Hawaiian islands, people are interested in the idea of farming seaweed. As an individual family enterprise, farming could probably be successful without hired labor. Such farming is being encouraged for the genus _Gracilaria_ to the extent feasible in the sense of wild crop management. However, the site competition, the costs of labor, and the lack of legal backing from the state for producing anything from subtidal lands make it impractical at this time to recommend funding of subtidal seaweed farm development in Hawaii.

Fortunately, the situation is very different outside but near Hawaii. In this case, at least 2,000 ha (1 hectare = 2.47 acres) of reef flats in the neighboring countries of Kiribati, and much more in the Federated States of Micronesia, Belau, and the U.S. territories of Wake and Palmyra Islands are suitable and available. While the potentials for Wake and Palmyra are unknown, special surveys in the state of Ponape, the Federated States of Micronesia, and at Christmas Island in Kiribati have provided very favorable information (Table K).

Micronesia now has a series of _Eucheuma_ production areas under development; the most prominent are the sixteen states of Belau and three of the four states of the Federated States of Micronesia (Yap, Ponape, and Kosrae). Production of the genus _Gracilaria_ has been considered, and _Sargassum_ is abundant in places. There is certainly enough reef and mud flat area for the economic production and export of these three genera, which would provide Hawaii with the raw materials for a carrageenan extraction plant (using _Eucheuma_), an agar plant (using _Gracilaria_), or an alginate plant (using _Sargassum_).

The area estimates of Table K, above, are based not only on inspections but actual test plantings. The growth rate of over 3% per day in several of these areas indicates success is possible if management is good. The testing was done at a variety of sites, with a good many tons of _Eucheuma_ of the regular commercially farmed strain, tambalang, being produced at some of them. Successful Eucheuma farms produce 15 to 30 T/ha/yr, dry weight, and are capable of producing vastly more. Ponape and Christmas Island each have >500 hectares of available reef flat suitable for the farm production of Eucheuma. Thus the potential for these two islands alone is a minimum of 15,000 tons per year (15 T x 500 ha x 2 islands). This is about half of the current annual world production.

Frequent ocean freight connections between Hawaii and Micronesia have made that area especially attractive as a source of seaweed to be processed in Hawaii. Container service is readily available. A sailing schedule for one line is enclosed as an example (Table L).

Table L. Typical Route for Major Ships Connecting Pacific Ports with Honolulu and California.

Day 1	Honolulu
Day 9	Alameda
Day 11	Los Angeles
Day 24	Majuro
Day 25	Ebeye
Day 27	Kosrae
Day 28	Ponape
Day 29	Truk
Day 32	Saipan
Day 34	Yap and Koror
Day 37	Davao
Day 39	Lae
Day 41	Rabaul, Kota Kinabalu, and Muara (Brunei)
Day 42	Kieta
Day 44	Cebu
Day 46	Manila
Day 60	Lae
Day 61	Rabaul
Day 62	Kieta
Day 71	Honolulu

Three ships follow the schedule above, repeating the schedule each time the cycle is completed. The schedules of the three ships are staggered so that each port is visited by a ship approximately every 24 days. (Source: PM & O Lines, No. 5, issued 3/25/85)

The Line Islands (Figure 6) present a special situation. They are about 1,000 miles due south of Hawaii. The atolls and higher islands might be called a low-island complex. Two of them, belonging to the country Kiribati (formerly the Gilbert Islands), have had Eucheuma introduced and are very good potential sites for farming this genus. Christmas Island alone has about 700 ha of farmable sites and could begin export the first year of development. Some others to the south are U.S. unincorporated territory - a considerable tax advantage. Palmyra, one of these, is a privately owned, tropical, low-island complex. It has a number of resources in its favor, including energy, which offset its remote location. Its deepwater port, some hundreds of hectares of farmable reef flat, an abundance of fresh water, and other features make it an unusually attractive location for seaweed farming, pre-export treatment, and consolidation.

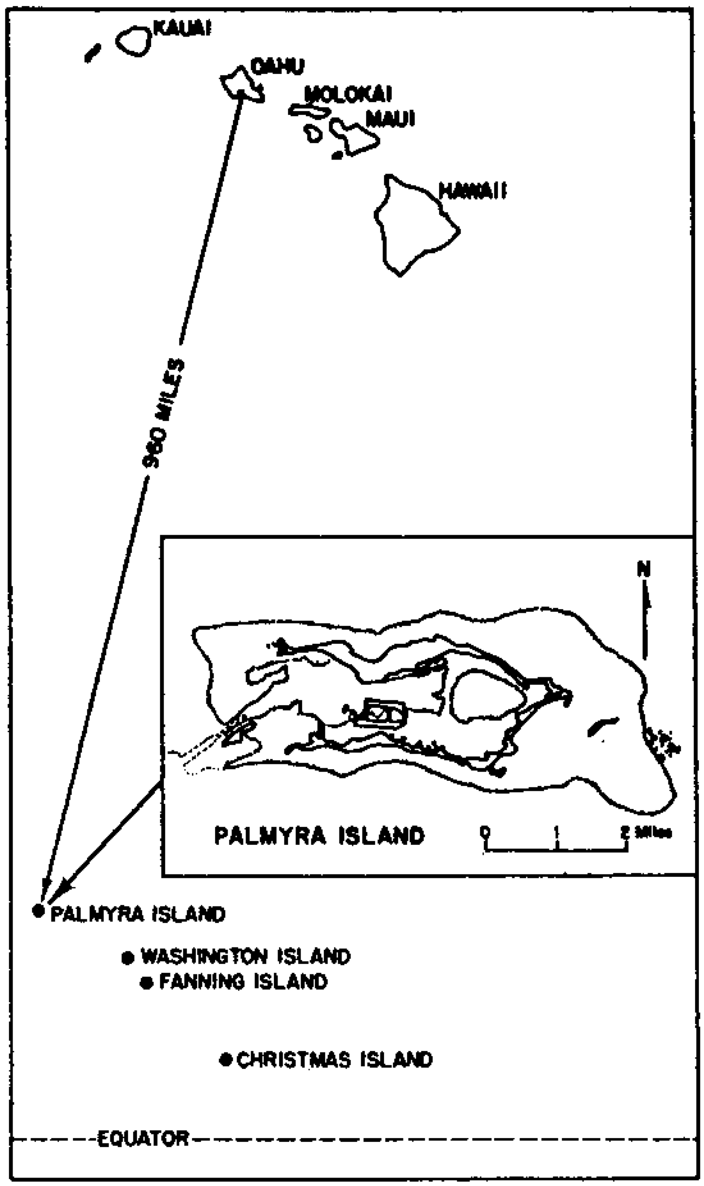


Figure 6. The Line Islands, About 1,000 Miles South of Hawaii

About two tons of Eucheuma have been exported to date from Christmas Island, and an effort is being made to expand farming to the more-western reaches of Kiribati. While no export beyond sample lots has been made from Ponape, more Eucheuma has been grown there than in Kiribati to date. There is currently a well-supported effort to develop a production and export industry on both islands. As the narrative and other records show, either of the two is ready for expansion; far more than 1,000 tons per year of the cottonii forms of Eucheuma could be obtained. Both the people and the farm seedstock are available to initiate the industry.

Palmyra (Line Islands) and Wake (Leeward Hawaiian Islands) also appear to have enough area to produce considerably over 1,000 tons per year. Unfortunately, no on-site survey has been made of either place. All information on them has been interpreted from verbal reports of visitors to these places (none of whom was phycologically competent), or from charts, or from a very few aerial photographs. Such U.S. territories have tax, legal, and other advantages. Palmyra is privately owned.

New Possibilities in Hawaii

Recently a reliable supply of cold, fertile water has become available with the development of ocean thermal energy. Large areas of barren lava surfaces in South Kona on the island of Hawaii (the largest island of the state of Hawaii) now have a potential for aquaculture. The state of Hawaii has established a 547-acre Hawaii Ocean Science and Technology (HOST) Park to promote development and commercial production utilizing this and surrounding land (Figures 7, 8, 9, and 10). There are thousands of hectares of barren rock surfaces in the area, mostly privately owned, that are available for lease. They were previously considered useless rocky land.

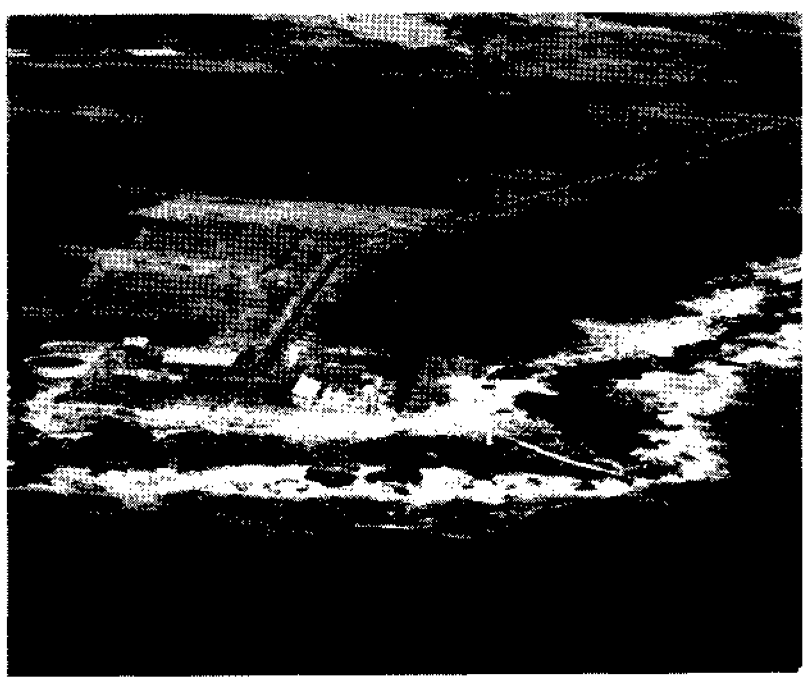


Figure 7. The State's Natural Energy Laboratory of Hawaii (NELH) is fast becoming one of the world's premier aquaculture sites. Located at Keahole Point on the Big Island, NELH offers both commercial farmers and researchers the opportunity to try new aquaculture technologies using deep ocean water pumped to the facility through long pipes. The water is clean and nutrient-rich.

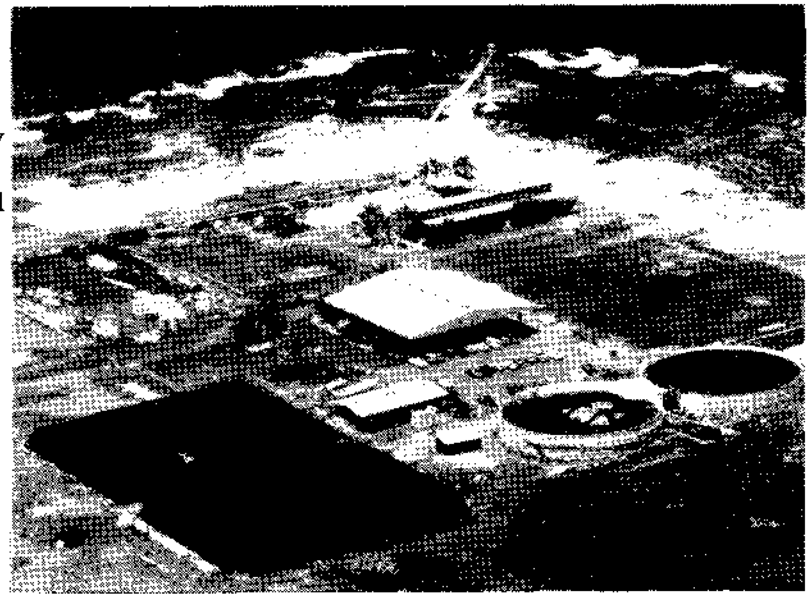


Figure 8. Closer view of the State Natural Energy Laboratory of Hawaii facility. The two largest circular tanks are used by Hawaiian Abalone Farms for growing kelp, which is fed to the millions of abalone in the largest rectangular construction.

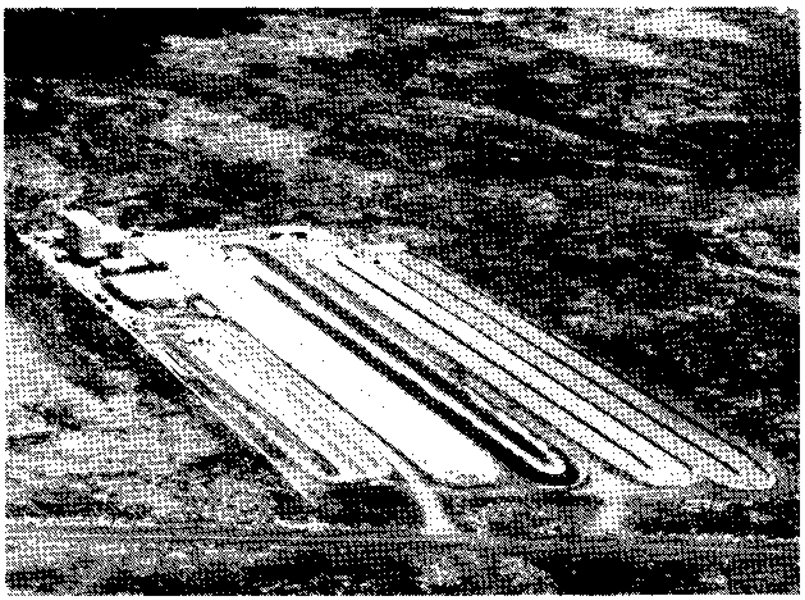


Figure 9. Cyanotech Corp. is raising spirulina (foreground) and dunaliella (back raceways) at the Hawaii Natural Energy Laboratory. Spirulina production is currently 2000 lbs. per month. Beta carotene is derived from dunaliella and is used in the production of food dyes and natural vitamins. The firm plans to produce a biofertilizer soon.

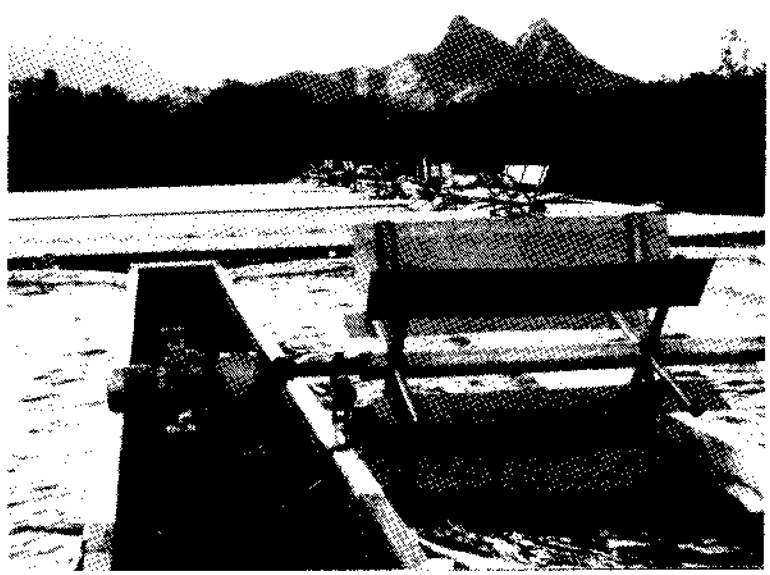


Figure 10. Unisyn of Hawaii's spirulina production raceways at Waimanalo, Oahu. The paddlewheels keep the algae in suspension. After harvest--approximately every three days--the spirulina is freeze-dried and sold for $8 to $10 a pound.

Figure 11. Hawaiian Marine Enterprises in Kahuku, Oahu, is raising *Gracilaria* (ogo) in raceways. The product is sold fresh to food stores.

Seafarming of seaweed could use the state's Keahole facility to adapt known methods and develop new ones. Research could be concerned with seaweeds that are in commercial demand, and additionally the most promising wild species that do not yet support an industry. Tank and pond culture are the conventional modes of cultivation. *Porphyra* has been shown to grow nearly optimally under these circumstances. *Macrocystis* grows well in the 16-foot-deep tanks (Figures 7 and 8) of the Hawaiian abalone farms. Though not explored at all, *Chondrus crispus*, which is now growing in the wild in Hilo Bay, might be developed as a crop in trenches the same way Cyanotech is now growing another alga, *Spirulina*. Alternately, the *Chondrus* might well be farmed subtidally along this same shore, as it is suspected that cold water would be necessary. *Chondrus* was at one time the world's principal source of both lambda and kappa carrageenan, and could be again, with appropriate farming.

Producing *Eucheuma* and other seaweeds of commercial value on relatively flat lava fields outside of tanks or ponds is a real, if unorthodox, possibility. This is about as novel to man's thinking as would be the idea of growing farmed crops on a reef flat under seawater. It is so novel that it takes more explanation than can be provided in detail here. The method involves growing the seaweed in the air on barren supratidal lava flats, and keeping it cool and moist under ordinary agricultural sprinklers. In 0.5 x 1 meter experiments, the growth rates of several Hawaiian seaweeds, including cottonii, have been normal or above-normal using this method.

In brief, it is envisaged that the crops would be grown, at least initially, in South Kona on barren supratidal lava rock. This appears biologically feasible and technically possible. To date, the method has never been tested in the field. Such pilot work could be done to develop the precise techniques, e.g. at the state's facility at Keahole.

Seaweed crops could be readily trucked, wet or dried, from anywhere in

South Kona directly to processing plants in the geothermal area 90-odd miles away. Ports handling ocean freight are only a few miles away and could easily receive imported seaweeds. The Kailua-Kona airport can handle the largest airfreighters; this airport is about a half mile away from the facility and is visible in Figure 7. The Kona area has exceptionally favorable weather and rather consistent gentle breezes across its barren rock sites; these would be appropriate for sun drying.

The state of Hawaii maintains and operates the 547-acre Hawaii Ocean Science and Technology Park and the Natural Energy Laboratory of Hawaii at Keahole to provide support to aquaculture and marine agronomic research. Two companies are now producing algae commercially at the site (Figures 8-10).

The Keahole facility provides both surface seawater at 24 to 27°C, at 2,000 gpm, and cold seawater at 10°C, at 1,500 gpm, with backup by three diesel generators and a backup pumping system (Table N). The quality and temperature of this water are desirable and adjustable. Cold deep water and warm surface water are available, and the flow of these is maintained at all times (Table N). The facility includes several kinds of shops, a seawater chemistry laboratory, 12,700 sq. ft. of industrial building providing warehousing, over 8,000 square feet of concrete experimental pad, and office and other spaces. Paved roads lead from the site to the surrounding retail and residential areas (about five miles away), to the airport, to the ports, and to the geothermal energy area.

Table M. Solar Radiation Received at Keahole Point. The values are "global", i.e., in terms of mean daily kilogram calories per square centimeter of light energy received by a circular flat plate collector under a hemispherical clear glass cover. (Source: University of Hawaii, Honolulu, Hawaii 96822 - Water Resources Research Center Natural Energy Laboratory of Hawaii, 10/84.)

Mo.	Yr:1976	1977	1978	1979	1980	1981	1982	1983	1984
JAN		406	410	390	348e	403e	350	403e	423
FEB		436	512	371	426e	413e	541	493e	510
MAR		451	525	556p	512e	498e	398	554	522
APR		527	552	540e	558e	553e	548	547	471p
MAY		500e	615	546e	527	561e	516p	605	
JUN		495	563	543e	516e	550e	539e	574e	
JUL		515	566	516e	522e	565e	552e	581	
AUG		543	544	623e	487e	537e	512e	545	
SEP		498	520	530e	469e	504e	518e	528	
OCT	458	406p	475	440e	470e	485	530e	475	
NOV	393	409	383	476e	423e	365p	379e	437	
DEC	397	364	360	419e	358e	387	308e	404	
AVERAGE		463	502	496	468	485	474	512	

Each value represents a monthly average of daily solar radiation in cal/cm^2/day.

p = partial data base
e = estimated by extrapolation from other station sites.

Table N. Quality of Available Seawater. The Natural Energy Laboratory of Hawaii facility at Keahole was established to supply such water reliably to marine agronomists for their research and development on seaweed production. (Source: The Natural Energy Laboratory of Hawaii)

Parameter & terms		Warm Seawater max	Warm Seawater ave	Warm Seawater min	Cold Seawater max	Cold Seawater ave	Cold Seawater min
Temperature	^{o}C	28.00		24.00	10.50		9.50
Temperature	^{o}F	82.40		75.20	50.90		49.10
Salinity	0/00	34.93	34.71	34.31	34.37	34.31	34.27
pH		8.34	8.24	8.04	7.64	7.55	7.45
Alkalinity	meq/1	2.36	2.32	2.25	2.43	2.38	2.34
NO_3 + NO_2	ug-at/1	0.50	0.20	0.05	41.70	40.00	38.20
NH_4	ug-at/1	0.70	0.50	0.20	0.76	0.42	0.06
PO_4	ug-at/1	0.20	0.14	0.03	3.16	3.04	2.85
Si	ug-at/1	31.00	4.21	1.80	72.00	79.00	85.00
TDN	ug-at/1	6.24	4.68	3.69	48.00	42.14	39.30
TDP	ug-at/1	0.50	0.34	0.19	3.26	3.07	2.91
D.O.	ml/1	10.09	7.25	4.85	3.93	2.38	1.33
TOC	mgC/1	1.20	0.91	0.51	0.99	0.58	0.07
POC		0.06	0.04	0.03	--	--	--

Intake Locations of the 12-inch Pipes

Warm Water: 320'(97.6m) offshore; water depth 65'(20m); 40'(12.2m) above sea floor; 25'(7.6m) below surface

Cold Water: 5,500'(1675m) offshore; water depth 1,995'(608m); 70'(21m) above sea floor; 1,925' (586m) below surface

The mean air temperature of any one day is probably not more than five degrees different from the mean of any other day. Within one day the variation is on the order of ten degrees. The average temperature is about 25^{o} Centigrade. Annual rainfall is approximately five inches; thus essentially every day is a day of clear sky and brilliant sunshine (Table M), approaching the maximum for this latitude of near 19 deg, 45 min, N.

Already in place and productive are two companies, both basically producing algae. One, a major investment, produces abalone, but it is dependent on tank production of the kelp Macrocystis as feed. The other company produces the planktonic, high-protein feed alga, Spirulina, in tanks. Both have long-term leases for space from the state under such terms that they are, or anticipate being, economic.

The state offers leases on the adjacent lava land that can be long term and at rates that make them attractive for growing seaweed. If research and development funds are made available for adaptation of the sprinkler method, perhaps a great deal of seaweed could be grown here inexpensively. We envisage "walking sprinklers," mechanical harvesting, and trucking the harvests directly to processing plants in the geothermal-well areas, a short drive away on the same island.

PRODUCTION AND SALES VOLUMES OF SEAWEED EXTRACTIVES

General Discussion

Because manufacturers jealously guard their extractive sales and distribution figures, it is difficult to arrive at accurate estimates regarding extractive production or the quantity of extractives in a given pharmaceutical, industrial, or food use. It is assumed that production volume is equal to sales volume.

The most reliable index to production is based on the amount of seaweed purchased by the individual extraction plants and also the average extractive content of each seaweed. These figures are generally available on both a plant and national basis. Extractors also have a good understanding of what their competitors are making. A cross check among major competitors resulted in good verification of the estimate derived from seaweed utilization figures. This approach was used in preparing the estimated production and sales volumes shown in Figure 1 and Table O.

It is estimated that each major producer of algin and carrageenan will have between 500 and 1,000 customers. About 50% of the producer's total volume will come from the top 50 customers. Furthermore, even though each company may make from 100 to 250 different products, about 40 to 50% of the sales volume will be derived from about 10 to 15 "standard" products. This concentration of the algin and carrageenan volume and customers simplifies the situation for anyone desiring to enter the seaweed extraction business. Agar is much simpler with respect to diversity of product line, uses, and customers. Because the production of extractives which are engineered for specific uses is closely tied to raw material sources and sales requirements, these aspects are covered under the respective algin, carrageenan, and agar sections of this report.

Excellent texts are available which go into detail regarding product properties and uses. Industrial Gums by R. L. Whistler and Food Hydrocolloids by Martin Glicksman are recommended. Additionally, major manufacturers freely distribute product description and specification bulletins together with an extensive array of use/formulation bulletins.

The markets for seaweed extractives are solidly situated in realms of food, pharmaceutical, and industrial uses. Large-volume sales can be expected to continue for many years. We estimate that agar and carrageenan will experience substantial additional growth on a world-wide basis. There are indications that algin utilization is in a moderate decline in the United States and Europe, but continues to increase in other areas of the world. Ramifications pertaining to each extractive's current and estimated future sales are discussed in some detail under subsequent sections specific to each extractive. Figure 1 shows growth history, and Table O shows the number of processing plants and production volumes by countries as of September 30, 1983.

Competition Among Seaweed Colloids

Algin, carrageenan, and agar have many common properties: all are water soluble; when dissolved, all can make viscous solutions or water-based gels. They can function as water stabilizers, suspending agents, and emulsifiers in many foods, pharmaceuticals, and industrial uses. However, each extractive also possesses its own range of advantages and limitations.

Table O. Estimated World Production of Seaweed Extractives in 1983

	No. of Plants			Production in Tons		
Producing Country	Algin	Carrageenan	Agar	Algin	Carrageenan	Agar
Canada	1			1,200	--	--
Argentina		1	1	100	--	400
Brazil			1	--	--	100
Chile	1		2	200	--	600
China	5(?)		1	7,000	100	300
Denmark		2		--	3,600*	100
England	1		1	6,500	--	100
France	2	1	1	1,600	2,400	100
India	1			200	--	100
Japan	2	2	10-20	1,500(?)	1,200	2,500
Korea		1	2	--	500	400
Mexico			1	--	--	100
Morocco			2	--	--	250
Norway	1			3,600	--	--
New Zealand			2	--	--	200
Philippines			1	--	--**	100
Portugal (& Azores)			2	--	--	400
Spain	1	2	5	500(?)	1,300	1,000
Taiwan				--	--	450
United States	1	1	1	5,000	4,000	100
USSR	Unknown	Unknown	Unknown	--	--	--
Totals	16	10	33-43	27,300	13,100**	7,075
Estimated average selling price per pound				$3.25	$3.50	$6.50 Std. $12.00 Bact

Estimated total annual sales:
(World Production $435,450,000)
Algin, $195,000,000
Carrageenan, $101,052,000
Agar, $114,387,000

*Includes furcellaran extractive now estimated to be under 1,000 tons annually.

**Does not include approx. 2500 tons alkali-modified E. striatum, "alkali-modified carrageenan".

***Estimate 6,000 tons standard agar @ $650/lb. and 1,075 tons bacteriological agar @ $12/lb.

For example, alginates are cold-water soluble, but require the presence of soluble calcium to form water gels, whereas carrageenan is hot-water soluble but can form gels when the temperature is reduced. There are many differences of a similar nature which allow each extractive to be used in its individual profile of uses at prices which commercial customers are willing to pay. However, if an extractive price becomes too high, users will endeavor to switch to a cheaper but less-desirable colloid or one that may have to be used in greater amounts to achieve the same result. Generally, the three extractives do not compete with one another under the normal and current conditions of prices, properties, and availability.

Competition with Non-seaweed Colloids

An all-purpose, water-soluble colloid has not been developed to date. Experts in colloidal chemistry estimate there is little or no prospect that such a product can be developed in the foreseeable future. However, numerous colloidal products have appeared in the past, each having a limited profile of chemical and physical properties; this enables each product to function in its special group of uses.

Water-soluble colloids available for use in food, pharmaceuticals, and industry can be broadly classified according to sources, i.e. seaweeds, seeds, fermentation products, and chemical products. Generally, the seed gums, such as locust bean or guar gum, are synergistic with the seaweed colloids. Although they have wide individual uses, they are frequently combined with seaweed colloids to achieve new effects and uses. Their properties rarely overlap those of the seaweed colloids, and for this reason, they rarely compete for the same uses.

During World War II it was discovered that certain bacteria produce useful colloids when cultured in a suitable fermentation process. The only important fermentation gum to reach the market to date is xanthan. An estimated 16,000,000 to 17,000,000 pounds of this product (manufactured by Kelco Company) is sold annually in the United States, with another 6,000,000 to 7,000,000 lbs. being sold in other parts of the world. Since it was first introduced about 10 to 12 years ago, xanthan has replaced an estimated 3,000,000 to 5,000,000 lbs. of alginate volume. However, it appears this erosion has stopped, and no further major loss to xanthan is anticipated.

Gellan, another fermentation product, is now being promoted by Kelco, but the company has failed to find significant markets to date.

Fermentation gums are capital-intensive and energy-intensive, qualities which dictate current and future high prices. This contrasts with presently declining costs and prices for seaweed extractives (due to seaweed farming and the resulting reduction in the cost of raw materials). We do not visualize fermentation gums as a major threat to seaweed colloids in the foreseeable future.

One of the principal chemical gums requiring consideration here is carboxymethyl cellulose (CMC). This gum also appeared during World War II. About 30,000,000 lbs. are used annually, with about 12,000,000 to 14,000,000 lbs. going into food uses and the remainder into industrial applications. Prices range between $1.20 and $1.80/lb. for food grades and between $.70 and $1.30/lb. for industrial grades. CMC has specific uses; it continues to compete with algin for some textile and paper uses and with carrageenan for use in toothpaste and pet foods.

Possibilities for Extractives Other Than Colloids

Many years ago it was recognized that seaweeds are potential sources for new and unusual drugs and other products. Substantial research has been devoted to identifying and isolating possibly useful compounds. An adjunct to the present report is the production of a report by Santos & Doty, "Hawaii Botanical Sciences Paper No. 42," in which are listed some 1,047 compounds produced by algae (mostly seaweeds), aside from those biochemicals rather universally present in algae and related organisms. Although there are numbers of promising suggested uses, significant production of drugs and other valuable extractives from seaweeds has not yet developed. It is urgent that research and development in this line be continued consistently.

After a prospectively desirable substance has been identified in a seaweed, two major problems face industry. Both must be solved before the new products can be processed in Hawaii and marketed. They are, first, the cost of meeting FDA requirements when the raw materials are on hand; second, getting enough raw materials for research now and for supplying the market in the future.

Hawaii's Keahole facility is readily available and could play a significant role in facilitating research and development involving seaweeds. It has two advantages at least: one is the possible availability of state funding, which could reduce all but the operational costs; the other is the availability of adjacent low-cost sites for the commercial production of the algal materials. The chances for success at each scale-up stage are greatly improved when all the R & D is done with the same water supplies, environments, and sites.

Use of this suggested Keahole phycological facility should be encouraged, for significant medical advances would be likely to develop from it. The endemic Hawaiian seaweeds should be cultured, and when physiologically active substances are discovered, the researchers should encourage culturing the seaweeds and should plan the steps to commercial production. The University of Hawaii is known world-wide for its natural-products chemists, algal ecologists, and pharmacologists who are recognized for their past and current innovative work with seaweeds. The facility might well provide academic support and free or low-cost facilities for research on Hawaiian seaweeds.

FDA Status of Extractives

Red and brown seaweeds, including those containing algin, agar, and carrageenan, have been eaten as food for many centuries. During the past 30 or more years, leading producers of these extractives have completed extensive toxicological tests, further verifying that these seaweeds and their extractives have not been found to cause health problems.

The FDA has classified algin, agar, and carrageenan as "Generally Regarded as Safe". This permits their use in all foods. Generally, one or more of the seaweed extractives is included as an optional ingredient in those "standardized" foods that contain water, if the quality can be improved through the incusion of a water-soluble colloid.

The Federal Register of April 1, 1980, Section 32, CFR, records the FDA's rulings and approvals as of that date regarding seaweed extractives as follows by paragraph:

182, 7133	Ammonium alginate
182, 7187	Calcium alginate
182, 7234	Sodium alginate
182, 7610	Potassium alginate
182, 7255	Chondrus extractive (carrageenan)
182, 1155	Agar

Currently there is no reason for concern about the FDA status of these three natural products. However, for reasons already explained, an up-to-date FDA evaluation is recommended before any substantial capital expenditure is committed.

In a subsequent section on carrageenan, we describe a product known as "alkali-modified carrageenan." The FDA questions whether this product conforms to the definition of carrageenan. This point should be evaluated and clarified before significant expenditures are committed to the production of this type of product.

PROCESSING SEAWEEDS FOR EXTRACTIVES

General Discussion

All seaweed extraction plants, whether processing algin, carrageenan, or agar, have a number of common requirements. They use large volumes of fresh water. They are energy-intensive and must dispose of large quantities of waste water and non-toxic solid wastes. When in operation, they generate a mild seaweed odor which may be a problem in urban environments, but is never a problem in sparsely settled areas. Most plants run 24 hours per day, 7 days per week, and produce some noise at all times; this could also become a problem.

The high concentration of valuable colloids in dried seaweed, i.e. the value per ton, makes it possible to transport them long distances before the cost becomes a serious economic factor. Similarly, the needed reagents can also be transported long distances. Thus, an extraction plant can be located in a rural or semi-rural area to utilize such advantages as lower taxes, cheaper land, reduced waste- and water-disposal costs, cheaper solid waste disposal, and reduced problems with environmental impact permits. Frequently labor costs in a more remote area are lower than in highly urban districts. No site was found on the island of Oahu which offered competitive costs and conformed to the requirements covered in the first paragraph.

Site Availability and Geothermal Energy

A promising potential plant site lies a few miles southwest of Pahoa on the island of Hawaii. This Pahoa area has several drilled geothermal wells which can provide the heat, energy, and water needed for the extraction of colloids from seaweed (Figure 5). The water issuing directly from the geothermal wells is a brine (Table Q); the water condensed from the steam is nearly distilled water. The geothermal wells are in an 80- to 100-inch rainfall area and, though there are no nearby streams, well water is readily available. Suitable plant sites having road access, ample fresh water, and waste water disposal capabilities are available. Solid waste can be placed in nearby dumps. Taxes are competitive, and environmental impact would be minimal.

Table Q describes samplings of the brine issuing under its own pressure from the state's experimental well, "HGP-A". In such young wells, the water quality changes with time, and different nearby wells in the same field yield different values. There are considerable differences in data depending upon where in the system the measurement or sampling was done.

Plant construction costs would probably be somewhat higher than on the mainland. The abandoned, or soon-to-be-abandoned sugar-cane processing mills within a few miles of Hilo were considered and inspected by air, but the idea of their conversion and use was rejected in favor of constructing a new plant at a geothermal energy site. The cost of a plant in the present geothermal area would probably not detract unduly from Hawaii's competitive position in the world market.

Geothermal energy and fresh water are both available at low cost on the island of Hawaii; taking advantage of these opportunities would result in substantial savings in the extraction of products from seaweed. Large amounts of water, steam, and electricity are needed. In general, the costs for water and energy for algin fall between 5.5 and 6.5% of the selling price (18 to 19 cents per lb. of extractive). Similarly, the cost of water and energy for agar is 10 to 12%, while carrageenan requires 20 to 25% (70 to 80 cents per pound).

The impact of geothermal energy on seaweed processing in the area below Pahoa is covered more fully in the processing discussion for each extractive. However, we should note that though several privately sponsored geothermal wells have been drilled and tested successfully, the data from them are held in confidence while proposals are being developed for their precise applications. The one operating state-owned experimental well, HGP-A, is one of the hottest geothermal wells in the world, with the brine at the mile-deep source level (1,966 meters) reaching a temperature of some 358°C, and the field possibly containing 50,000 megawatt years of energy.

At the well head, the hot water from HGP-A flows to the surface under its own power under conditions controlled for the production of electrical energy. Some 2.4 megawatts of this energy have been passing into the Hawaiian Electric Company's power grid for about three years, with a certain additional amount being used on site. This represents about half of the available energy; the rest is residual heat in a brine which is similar to 50% sea water. The brine is a waste product of the electrical energy production; it is discharged at the rate of 22,722 kilograms per hour at 187°C and 10.9 kg/cm^2, the 17.9 kilojoules per hour being the energy equivalent to about a million dollars of oil per year (Takahashi, Seki and Chen, 1985). Fresh hot water is also available from condensation of the power plant steam.

The island of Hawaii has an excellent port at Hilo, which could receive imports of seaweed. Good roads exist between the port and the industrially zoned area near the geothermal wells. An adequate supply of skilled and semi-skilled labor is available, due to the gradual reduction in sugar mill activity in the area.

Local wage rates appear to be 15% to 25% less than the rates for similar skills in Honolulu; San Diego (Kelco); or Rockland, Maine (Marine Colloids).

<u>Table P.</u> The Hawaiian Geothermal Applications Program

More than $30 million has been spent so far to develop geothermal energy on the island of Hawaii. The first well, completed in 1976 at Puna, has a bottomhole temperature of approximately 358°C, making it one of the hottest geothermal wells in the world. Conservative estimates indicate that the Kilauea East Rift zone has 50,000 megawatt-years of available energy. The geothermal power plant at Puna generates 2.4 megawatts of electricity, which is transmitted to the electric grid of the Hawaiian Electric Company. Following the success of the Puna geothermal power plant, several wells were drilled nearby by private companies.

Considerable heat is wasted when geothermal fluid is used only for generating electricity. For example, at the first Puna well, approximately 22,722 kilograms per hour of 187°C geothermal water are discarded. This hot water is available for experimental or business use.

In 1984, the state of Hawaii released $325,000 to build a facility at the Puna well to investigate applications of geothermal

energy; one area of research will be dehydration of aquacultural product.
(Summarized from a report with the same title by Patrick Takahashi, Arthur Seki, and Bill Chen, 1985.)

Table Q. Geothermal Energy and Water Supply Data. The data were provided by Dr. Donald M. Thomas, University of Hawaii, from work under State Department of Economic Development Contract #12892.

A. Measurements of the Brine, Dec. 1, 1984.

PARAMETERS

Temperature:	190 degrees	TDS:	15,800 mg/L
Pressure:	170 psi	pH:	6.6
Conductivity:	23,000 umhos/cm		

CHEMICAL CONSTITUENTS (mg/L)

Ag:	<0.010	Cr:	<0.001	Mg:	0.26	Sb:	0.6
Al:	0.1	Cu:	<0.002	Mn:	0.21	Si:	386
As:	0.09	Fe:	<0.010	Mo:	<0.001	Sn:	<0.020
Ba:	4.6	Hg:	<0.050	Na:	4927	Sr:	6.5
Ca:	358	K:	756	Ni:	<0.010	Ti:	≤0.003
Co:	<0.001	Li:	1.1	Pb:	<0.010	V:	0.002
B :	4.3			Zn:	0.016		

$CO_3^{=}$: <0.1 (as CO_2)	NH_3/NH_4: <0.01 (as N)
HCO_3: 18.5 (as CO_3)	
Br: 44(±4)	S^-: 5(±4)
Cl^-: 8968	SO_4: 24(±4)
Total Carbonate: 18.5 (as CO_2)	F^-: 0.25(± 0.10)

B. Noncondensable Gas Concentrations in the Steam

COMPOUND	CONCENTRATION (in mg/Kg)
Carbon Dioxide	1200
Hydrogen Sulfide	900
Nitrogen	125
Hydrogen	12
Helium	0.54

Table Q. (continued). Geothermal Energy and Water Supply Data.

C. Chemical Composition of the Geothermal Brine, 1984.

ELEMENT OR COMPOUND	CONCENTRATION (in mg/kg)	ELEMENT OR COMPOUND	CONCENTRATION (in mg/kg)
Antimony	<0.002	Niobium	<0.4
Barium	2	Phosphorus	0.2
Boron	2	Platinum	<0.006
Calcium	218	Potassium	600
Carbonate	75	Silver	<0.02
Chloride	7200	Silica	800
Cobalt	0.014	Sodium	3700
Copper	<0.004	Strontium	2.0
Gold	<0.00004	Sulfate	50
Iron	0.02	Sulfide	17
Lithium	0.034	Tantalum	<0.001
Magnesium	0.131	Tin	<0.2
Manganese	0.034	Titanium	0.006
Mercury	<0.001	Uranium	0.16
Molybdenum	0.067	Vanadium	0.016
Nickel	<0.02	Zinc	0.012

Table R. Minimal Requirements for Profitable Operation of an Extraction Plant. Estimated. (Assumes standard commercial-grade products.)

a. Minimal weights of seaweed (in tons)

	Algin-yielding		Carrageenan-yielding	
	Wet	Dry	Wet	Dry
Kelps	4,600-7,000	460-700	10,000-12,000	2,100-2,400
Eucheumas			9,000-10,000	2,200-2,500
Gigartina			9,000-10,000	2,100-2,400
			Agar-yielding	
			Wet	Dry
Iridaea			2,000-3,000	400-600
Gelidium			2,000-3,000	400-600

b. Extractive production: minimal range

	ALGIN	CARRAGEENAN
Tons - metric production	1,000 - 1,500	600 - 800
Pounds	2,200,000 - 3,300,000	1,320,000 - 1,760,000
Price per pound - range	$2.00 - 5.50	$2.60 - 6.00
Price per pound - average	$3.75	$4.00
Sales	$8,250,000 - 12,375,000	$5,280,000 - 7,040,000

	AGAR
Tons - metric production	100 - 150
Pounds	220,000 - 330,000
Price per pound - range	$6.00 - 7.00
Price per pound - average	$6.50
Sales	$1,430,000 - 2,145,000

(continued on next page)

Table R. (continued)
Minimal Requirements for Profitable Operation of an Extraction Plant

c. Minimal investment

	ALGIN PRODUCTION	CARRAGEENAN PRODUCTION
Land, Buildings & Utilities; Harvesting Equipment & Organization; Engineering; Product Development; Equipment; Start-up Costs; Raw Materials & Reagents; Finished Product Inventory; Accts. Receivable; Operational Cash; Miscellaneous	1,000 Tons @$5,00: $11,000,000 1,500 Tons @$4.50: $14,850,000	600 Tons @$8.00: $10,560,000 800 Tons @$7.10 $12,500,000

	AGAR PRODUCTION
Land, Buildings & Utilities; Harvesting Equipment & Organization; Engineering; Product Development; Equipment; Start-up Costs; Raw Materials & Reagents; Finished Product Inventory; Accts. Receivable; Operational Cash; Miscellaneous	100 Tons @$5.10: $1,120,000 150 Tons @$4.60: $1,518,000

Estimated Capital per Pound Capacity:

ALGIN	$4.50 - $5.00
CARRAGEENAN	$7.10 - $8.00
AGAR	$4.60 - $5.10

AGAR PROCESSING

Overview

Figure 1 shows that agar production has been subject to cyclical fluctuations. These up-and-down cycles were caused by variations in demand for, and supply of, the raw material. For example, agar production reached a cyclical low point of about 1,200 to 1,500 tons in 1960. This was caused by an increasing shortage of the seaweed Gelidium, which was the main raw-material source of agar during the previous years. The shortage of Gelidium caused a sharp price increase. The resulting high prices for both Gelidium and agar caused a sharp decline in demand, which reached a low point in about 1960. This, in turn, resulted in a surplus of agar, followed by a surplus of Gelidium during the years of 1959 to about 1963. There was a concurrent decline in agar prices during this period. This low price again attracted an increasing number of new customers, and the cycle was repeated.

Beginning in the mid- to early 1970's the red algal genus, Gracilaria, became an important source of agar, and within a few years it supplanted the traditional Gelidium. The new agar source also provided an additional agar grade, the sugar-reactive agar. Before this, only two grades had been available, the food (or standard) grade and the bacteriological grade.

The characteristics of the third, "sugar-reactive," grade are explained as follows: agar from Gelidium and from the common agar weed Pterocladia, often confused with it, loses gel strength with the addition of almost any significant amount of sugar, but it remains brittle. However, many Gracilaria species produce "sugar-reactive agars," agars that retain gel strength with the addition of sugar, at least up to 75 grams per 100 ml of 1 percent agar gel, and they become elastic. These latter Gracilaria species producing the sugar-reactive gel bring the highest prices of any agar-producing seaweed.

Gracilaria species producing sugar-reactive agar have created a demand in a number of areas, such as the baking industry. Thus Gracilaria relieved the shortage of the traditional seaweed sources of agar, induced the current high demand (Figure 1), and helped stabilize the market. Hawaii has wild Gracilaria species that produce sugar-reactive gels, a point favoring Hawaii as a site for processing agar if the production of this seaweed can be increased to an appropriate volume.

The list of uses for Gelidium agar continues to grow. Included in this group is the high-priority use for bacteriological analysis. Other substances requiring Gelidium agar properties are candies, dessert gels, canned meat, and various media for growing and culturing larvae used for controlling insect populations. These uses, particularly the bacteriological one, which now requires an estimated 1,000 to 1,200 tons annually worldwide, are growing at an estimated rate of 8 to 12% annually.

Historically, agar prices have generally reflected the fluctuations of supply (Figure 1). For example, the price of food-grade agar in 1966 to 1970 was about \$3.50 to \$4.00 per pound. In 1973 to 1974 prices declined to around \$2.25 to \$2.50 per pound. In 1980 to 1981 food-grade agar prices had increased to \$8.00 to \$9.00 per pound, whereas on September 30, 1983, food grade agar was selling for \$5.25 to \$6.25 per pound. Compared with 1973 to 1974, current agar prices have increased by 50 to 75% due to the effects of energy costs and inflation. Consequently, it is estimated that agar is now at the low point of a minor cycle.

However, due to the increasing availability of Gracilaria and the ability of processors to use it to produce extractives that are suitable for use in foods and industry, the world may have seen the last cyclic change in agar prices. Furthermore, it is estimated that agar sales will now move generally upward with little of the price cycling of the past, until the volume approaches that of carrageenan. It is estimated that the price of food-grade agar will stabilize at about $5.00 to $6.00 per pound based on the current economy, whereas bacteriological agar will probably stabilize at a price of $9.00 to $12.00 per pound, depending upon the availability of Gelidium and the degree of refinement of the agar.

Production

As mentioned in previous sections of this report, agar seaweeds do not occur in Hawaii in quantities sufficient for economic agar production. In all probability they can be "farmed" in suitable locations, but cost-effectiveness remains to be proved. Hawaii probably has sufficient area. Yet, of the agar weeds, satisfactory farming methods have been found only for Gracilaria. These promise to produce at least 1 kg dry weight per square meter of farm per year. However, meeting the demands of the agar market takes several kinds of seaweed, each producing a different quality of agar, and none of the bacteriological Gelidium-type seaweed sources has been farmed satisfactorily as yet, nor have the species producing sugar-reactive agar. Thus, at present no one knows how many hectares are required to support an agar industry other than for food-grade agar. That would be about 400 to 900 hectares, if the plant is to compete.

Any agar produced in Hawaii at present would have to be extracted from imported dried seaweeds from a variety of sources. As indicated earlier, most manufacturers of agar import their raw material from numerous, distant countries. Even though delivery to Hawaii might cost $75 to $100 more per ton, the increased price of the agar would only amount to about 17 to 19 cents per pound on a product that sells for $6.00 per pound. This would not impose a significant disadvantage on a producer located in Hawaii.

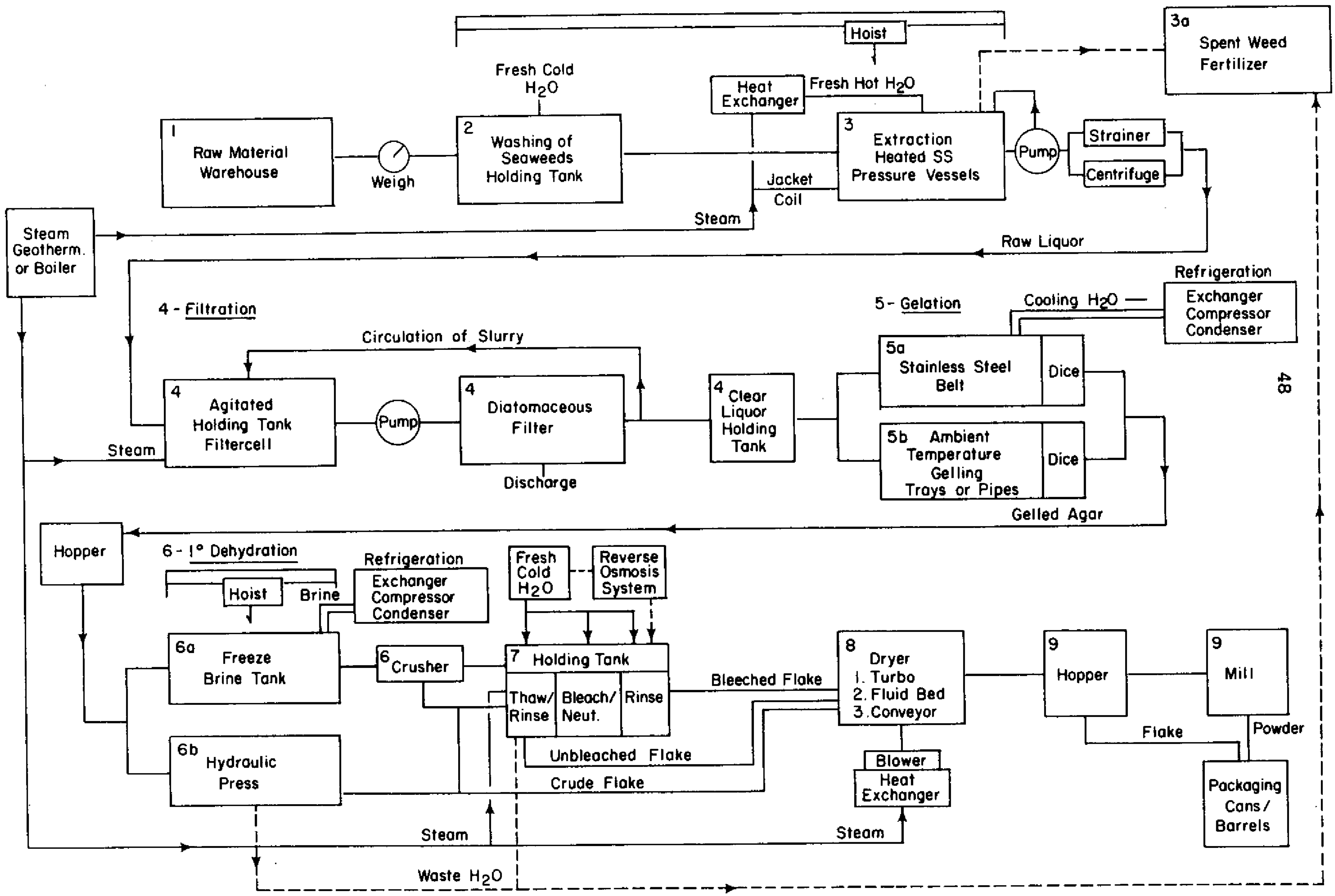
Agar for bacterial uses has rather formalized, rigid specifications relative to melting and, especially, gelling temperatures. There are also specifications with respect to clarity, syneresis, and residual salts. As with most products of narrow specifications, bacteriological gel is finally marketed as a blend. The current prices (1983) of $10 to $13 per pound in large wholesale lots are about twice those for food-grade agar.

The use of wet, freshly-harvested agar seaweeds is not advantageous. Atmospheric drying in sunlight enhances the extractability and quality of the agar. Manufacturers generally urge their seaweed suppliers to dry their seaweed in bright sunlight to a moisture content between 14 and 18%. The whole seaweed is normally baled before delivery to the manufacturer.

Processing Steps

Figure 11 is a flow sheet showing the sequential steps of agar processing. The numbers appearing by each of the following sections correspond to the numbers appearing in the flow sheet.

Figure 12. Steps in Agar Processing



1. The Inventory

The inventory is usually stored in dry, well-ventilated sheds located adjacent to the production line. The pressed bales are normally stacked to a height of 10 to 15 feet. Aisles are left between the stacked rows so that any stock is available.

An acceptable minimal inventory covers extraction requirements for six to twelve months. The agar content of well-dried seaweed is quite stable; this permits holding the inventory without degradation of the agar content.

Generally about 12 to 15 square feet of floor space are needed for each ton of seaweed inventory. This includes the space for the aisles.

2. Washing

It is essential to remove the high percentage of soluble salts contained in the seaweed before the agar is extracted. This may be done by placing the seaweed in open-mesh, stainless-steel baskets, which are then placed in holding tanks where rapidly circulating cold water removes the salt. At this point, some seaweeds may require treatment with a warm NaOH solution. Therefore, the rinse tanks should be equipped with steam jackets or other devices for heating the water.

3. Extraction

After salt removal, the baskets are transferred to stainless-steel pressure vessels filled with fresh water. A steam jacket or coil that can raise the temperature to between 100°C and 115°C is required. A steam-generating boiler is normally used as the source of the steam. A circulating pump is also needed to speed uniform heat distribution.

The pressurized hot circulating water removes the agar from the seaweed. Once the extraction is complete, the resulting liquor is pumped into a holding tank. The baskets of spent seaweed are then removed, using a track hoist. Under some conditions, the spent weed can be sold as a fertilizer or as a soil-building additive.

4. Filtration

As the liquor leaves the extracting tank, it is pumped through a basket strainer or a centrifuge to remove macroscopic matter. Next it goes into a heated holding tank proveded with an agitator. Again, a steam jacket or coil maintains the temperature of the liquor between 80° and 90°C. Once in the holding tank, a filter aid (diatomaceous earth) is added to the liquor under good agitation. The resulting slurry is circulated between the holding tank and filter until a clear filtrate is obtained. The clear liquor is then pumped to another holding tank.

5. Gelation

(a) Refrigerated-Water Method: Liquor is pumped or gravity-fed onto a moving stainless steel continuous belt with curbs at the sides. This belt is cooled from the underside by a spray of refrigerated water. A refrigeration system removes acquired heat from the cooling water and readies it for reuse. The hot filtered liquor has cooled and gelled by the time it reaches the end of the belt; there it is diced mechanically into a hopper below.

(b) Ambient Temperature Method: The liquor is gelled at ambient temperature in stainless steel trays or pipes. The gel is diced manually, and gel cubes are loaded into a hopper. In yet-more-primitive plants, the agar gel is caused to solidify and is then cut into narrow strips. These methods require manual labor, more time, and considerable space.

(c) Freezing Method: Agar coalesces and tends to separate from water when the gel is frozen. When the combination is thawed, the soft concentrated agar gel remains behind while most of the water drains away, carrying with it dissolved impurities such as sea salts, etc. The classic method took advantage of this phenomenon by preparing the agar gels during seasons of the year when the ambient temperatures at night were expected to fall below freezing. Alternatively the agar gel may be frozen by lowering cans full of gel into a tank of brine which is below 0° Centigrade. A refrigeration system produces and maintains the freezing temperatures of the brine.

When the cans or trays of liquor have been frozen throughout, they are removed from their freezing brine environments, artificial or natural. If the agar is frozen when removed from the containers, it may be coarsely ground in a crusher and accumulated for thawing, or the frozen block or strips may be sized one way or another, or thawed in bulk form.

This freezing-and-thawing method is slower, and if artificial or mechanical refrigeration is used, it is more energy-intensive. However, the resulting product is purer than that of the alternative methods. If a bacteriological-grade product is sought, this method is highly recommended.

6. Dehydration

The gelled or frozen-and-thawed agar is drained and dried after the above processes. The natural way of drying is the simplest: merely expose the strips or cubes of thawed, drained agar to hot sunshine. This method is often used in regions of the world where hot, sunny weather is usual. The roofs of the processing plant are sometimes used for drying, though racks on the grounds of plants are common.

The more modern alternative, using electro-mechanical drying methods, is more expensive, but it allows operation throughout the year and yields a cleaner, more predictable product. In this process the granules, cubes, or strips of drained, thawed, wet agar are loaded between leaves or coarse cloths and crushed in a hydraulic press to remove the bulk of their water. The resulting agar may be dried directly to produce a crude finished product, or it may be refined further to meet the customer's requirements. In any case the agar may be given its final drying in one of the following types of dryers:

Conveyor dryer
Hot air bed dryer
Turbo dryer

All of these artificial drying systems require hot air and blowers. A steam-loaded heat exchanger is best suited to produce the hot air, since steam is already the heat source for the rest of the process.

7. Purification

Rinsing and bleaching the agar gel during or before step 6, figure 11, help remove water-soluble impurities and decolorize the product. The nature of the desired final product dictates the degree to which this step is performed. An agitated holding tank is utilized for rinsing and bleaching.

The agar can be bleached by adding sodium hypochlorite solution to fill the rest of the tank. When bleaching is complete, the solution is neutralized and drained. A final rinse removes unwanted residual bleach and neutralizer. Fresh or reverse osmosis water is used for this final rinse, depending on the amounts of calcium or sodium desired in the final product.

8. Drying

This may be accomplished by means of a heat exchanger and blower.

9. Packaging

Once dried to an acceptable level, the agar can be packaged for sale or ground in a mill. The powdered product may be standardized by blending. In wholesale quantities, it is usually sold in fiber form or packaged in bags.

Estimated Operating Costs

Obviously, any estimate of operating costs is subject to variations in the costs of raw materials, chemicals, transportation, energy, depreciation of land and plant, construction costs, size of the operation and the degree and method of processing. Table S estimates costs based on 1983 conditions in Hawaii and Taiwan. These estimates cover one plant for 125 tons and another for 300 tons of annual production.

Table S. Estimated Production Costs of Agar, Based on Imported Seaweed.

	Existing Foreign Plant(a) Usually oil heat		Hawaiian Plants Oahu: oil heat(b)		Hawaii: geo-thermal heat(c)	
Cost Items	125 Ton	300 Ton	125 Ton	300 Ton	125 Ton	300 Ton
Raw Materials	$ 1.65	$ 1.65	$ 2.10	$ 2.10	$ 2.10	$ 2.10
Chem & Packaging	.53	.53	.53	.53	.53	.53
Variable Energy	.51	.48	.51	.48	.25	---
Water	.06	.06	.06	.06	.02	.02
Waste Disposal	.04	.04	.04	.04	.02	.02
Maintenance	.17	.15	.17	.17	.17	.17
Wages & Fringes	.61	.45	.61	.45	.61	.45
Depreciation:						
Equipment, etc.	.45	.38	.45	.38	.45	.38
Geothermal Plant	---	---	---	---	---	.16
Research & Quality Control	.20	.16	.20	.16	.20	.16
Sales	.44	.38	.44	.38	.44	.38
General Admin.	.44	.38	.44	.38	.44	.38
TOTAL COSTS	$ 5.10	$ 4.66	$ 5.55	$ 5.13	$ 5.23	$ 4.75
ESTIMATED WHOLE-SALE PRICE	$ 5.25-$ 5.40		$ 5.25-$ 5.40		$5.25-5.40	

(a) Cost of raw materials based on Gracilaria imported at $950 per ton FOB Taiwan, with estimated average yield of 26%.

(b) Cost of raw materials based on imported Gracilaria at $1,200 per ton, delivered, with a yield of 25%

(c) Estimated costs for drilling and utilizing a geothermal well are $1,250,000. The well will normally last 10 to 14 years, resulting in an annual depletion cost of about $100,000 per year. This depletion would cost the 125-ton agar factory about 36 cents per pound and the 300-ton agar plant about 15 cents per pound.

The estimated costs for bacteriological agar are not included, but this grade costs more because it requires more refinement than standard commercial agar. Although the processes are essentially the same, certain steps must be repeated to increase its purity. Bacteriological agar must be made from Gelidium to obtain, among other things, the capability of suspending in water at over 90°C and settling at about 40°C. It must have a very low residual salt content, and the gel must be transparent. Standardization of gel strength, solubility and other aspects of quality control must be more precise. To meet the specialized requirements and more rigid specifications, the cost of producing and marketing bacteriological agar generally runs 35 to 50% above that for other commercial agars.

In the cost analysis, Table S, two plant sizes (production volumes) have been used. The 125-ton operation is about the minimum size that can be economically viable. The 300-ton size is estimated to be close to optimum.

It appears that plants located near or at the existing government geothermal wells could purchase their heat and energy requirements at about 50% of the costs of an oil-based plant. Consequently, we assume that energy for the 125-ton geothermal operation is purchased at half the costs shown for the Honolulu or foreign plant. While no energy cost is included for the 300-ton geothermal plant, an increase in depletion by 16 cents per pound is included.

Discussion and Recommendations

American Agar Company in San Diego has already determined that it cannot import Gelidium or Gracilaria seaweeds and produce competitively-priced, standard-grade agar. It now produces only bacteriological grades for its internal fabrication into complex media formulations. The present survey revealed that costs in or near Honolulu are approximately identical with those in San Diego, Los Angeles, or other large U.S. cities for water, land, labor, building rent, oil for energy, taxes, waste disposal, etc. Reagent prices seem to range about 5 to 8% higher in Honolulu. Note that standard-grade agar could not be produced profitably in a 125-ton capacity plant in Hawaii using oil as fuel.

The labor and management costs shown in the foreign plant estimates may be incorrect. These costs will vary from country to country. It is almost certain that labor costs in Taiwan will be 15 to 20 cents per pound less than the 61 cents shown for California or Hawaii.

The low cost of the raw materials shown in the foreign plant estimates results from the low cost of Gracilaria farmed in Taiwan. Until some other area is able to produce the large volume of farmed Gracilaria required to supply a 125-ton plant (some 500 tons per year), establishment of a new extraction plant may not be justified.

As mentioned in other parts of this report, we believe that agar seaweeds, especially Gracilaria, can be farmed in Hawaiian waters. If this proves possible, it may enable a plant situated within the geothermal belt near Pahoa to be a significant success in the growing agar industry.

ALGIN PROCESSING

Overview

The cell walls of brown algal seaweeds, in addition to their cellulose fiber, contain complex mannuronic/guluronic salts separable as alginic acid. After these salts are extracted and refined, they are marketed under the generic name of algin.

Commercial algin was first produced in significant quantities in 1929 or 1930 in San Diego, California, by the Kelco Company. Initial development of technology and sales was slow until World War II, when shortages of other colloids created a demand for algin. In general, the demand for algin held steady after World War II and then grew with new uses for algin in fields such as ice cream, textile printing, paper sizing, etc. (Figure 1).

Shortly after World War II, other producers of algin began to appear, particularly in Maine, England, France, and Norway. Within the last 5 years, extraction plants have appeared in Japan and China. Competition among these plants has been reviewed in prior sections.

Algin extractors may use either wet or dry kelp as their raw material. In practice, all major kelp extractors rely on both sources. For example, when it is available, Kelco obtains 80 to 100% of its algin products from freshly harvested wet kelp. Their subsidiary plant in England, Algin Industries, Ltd., obtains an estimated 50% of its products from wet sources and the remainder from imported dry seaweed. In general, the algin extractors use as much wet seaweed as they can obtain from local sources and augment this with dry seaweed to meet their requirements. Obviously, the percentage of dry seaweed purchased varies from year to year, depending on the availability of wet weed.

All algin extractors, with the exception of the newly-starting Japanese and Chinese plants, depend entirely on wild sources of brown seaweed which abounds in many parts of the world. There have always been sufficient supplies for those manufacturers willing to use a combination of wet and dry seaweeds. Large untapped reserves are available from such countries as Chile, Australia, Iceland, South Africa, and Argentina. Each of these countries is capable of exporting hundreds of thousands of tons of dry kelp, and 2,500 tons contain roughly 1,000,000 pounds of algin.

Two factors have not been taken into consideration in speaking of the raw material supplies for algin extraction. First is the decline in the standing crops of the kelps providing the raw materials for most of the North American extractors. This decline has been very serious for Macrocystis in the eastern Pacific during the recent decades. The precipitous loss of most of the Lessonia standing crop in Chile during the 1983-84 period of el nino conditions has eliminated what was perhaps the principal back-up kelp supply. Second is the development of farming of Laminaria japonica off the coast of China, with a production of more than 250,000 dry tons per year. Shipments from this area have provided raw material filling the gap caused by the declines in the Macrocystis and Lessonia crops. This is such recent history that no evaluation of it has been possible for the present report.

At the present level of sales, there is no danger that the algin industry will be short of kelp in the foreseeable future. There is a substantial international trade in dry kelp, as shown in Table D. Although dry kelp purchases vary from year to year, the estimates shown in Table D may be regarded as typical.

The cost of one pound of algin in freshly harvested kelp, before extraction, ranges between 25 and 45 cents, delivered to the extractor's plant. The cost for one pound of algin in imported dry seaweed delivered to the plant ranges between 90 cents and $1.10 per pound.

Production

Algin is marketed in three major forms:
- Paste products
- Alcohol-washed or acid-precipitated products
- Modified alginates

These three products provide the highest market volume of any algal hydrocolloid product (Table T). The estimated sales total is about the same as the production estimate shown in Table O. The estimates do not take into account the Chinese production, of which 400 tons per year are now entering the U.S. and about 3,000 tons entering Europe and Third World countries. It is not yet possible to identify how all the Chinese algin is being used, since China only recently entered the market. The Chinese may have created some new uses, or their product may have displaced existing businesses.

Table T. World Uses of Algin in Tons

Algin type and use	U.S. & Canada	European Area	Japan	Other Countries	
Paste types					
Textiles		700	600	250	800
Paper	1,000	700	250	100	
Miscellaneous Other	800	900	300	400	
Alcohol-Washed or Acid-Precipitated					
Breaded Foods	500	100	-	-	
Food Gels	200	300	300	100	
Bakery Products	200	300	100	-	
Miscellaneous Foods	500	600	400	200	
Propylene Glycol Alginate					
Beer	900	300	?	-	
Salad Dressings	500	300	100	-	
Other Food Emulsions	200	100	100	100	
Flavored Drinks	200	100	100	-	
Miscellaneous Other	800	100	200	100	
	6,500	4,400	2,100	1,800	
Unknown (Required to balance estimated total usage of area)	600	2,400	600	1,200	
ESTIMATED TOTAL WORLD SALES (19,600 TONS)	7,100	6,800	2,700	3,000	

The flow sheet describing algin production (Figure 12) includes a segment showing the production of paste-type products. These were the first alginates made, and for this reason they have been generally considered the standard for quality. Paste products can also be divided into two sub-qualities—one designed for food and the other for industrial purposes such as textiles, paper, etc. Paste products are currently selling at $2.50 to $2.70 per pound, which is about $1.00 to $1.50 per pound cheaper than the alcohol-washed product.

Figure 13. Steps in Algin Processing. Plant I: Steps From Harvesting Through Serge Bin

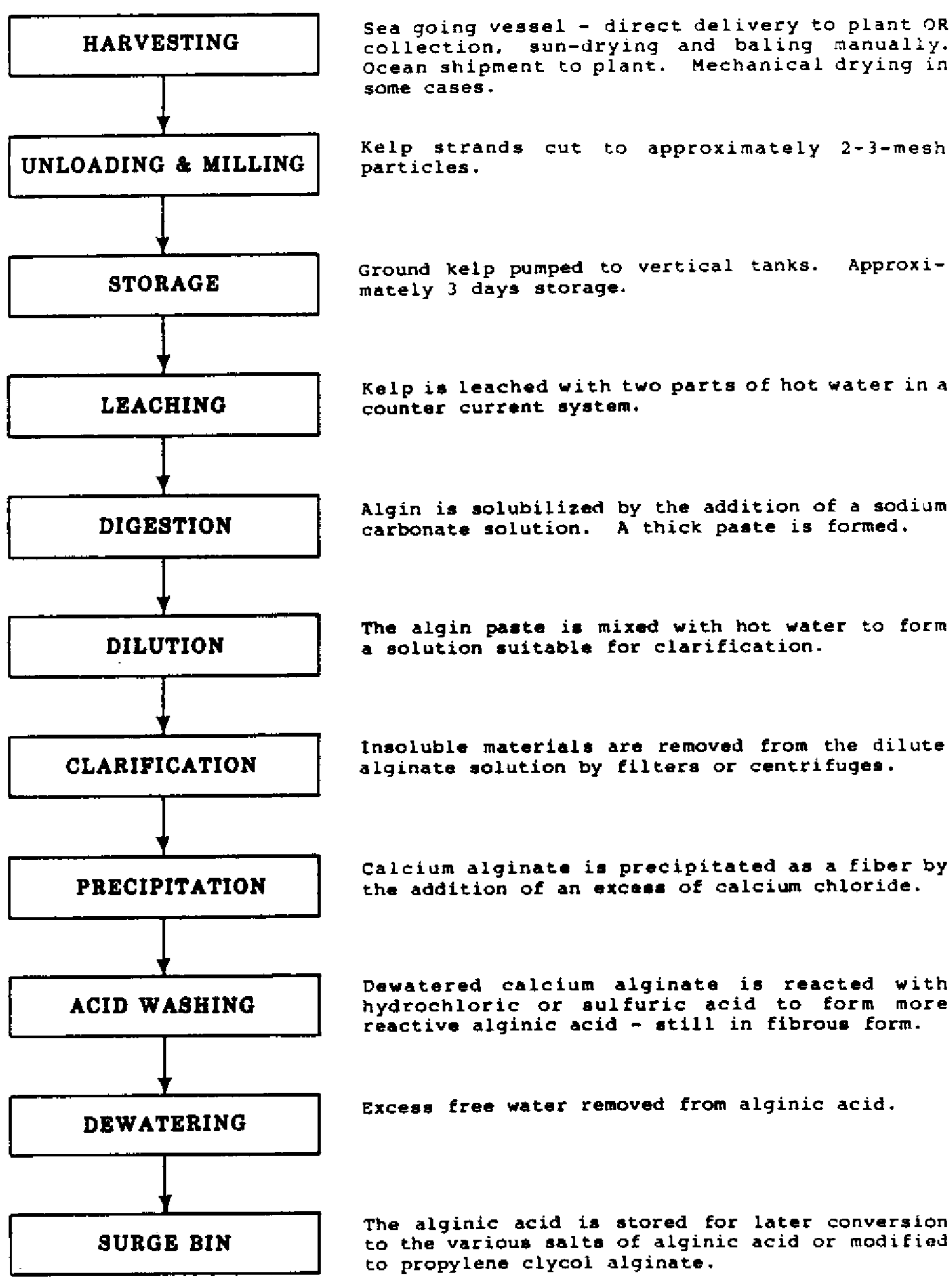


Figure 14. Steps in Algin Processing. Plant II: Product Reactions and Modifications

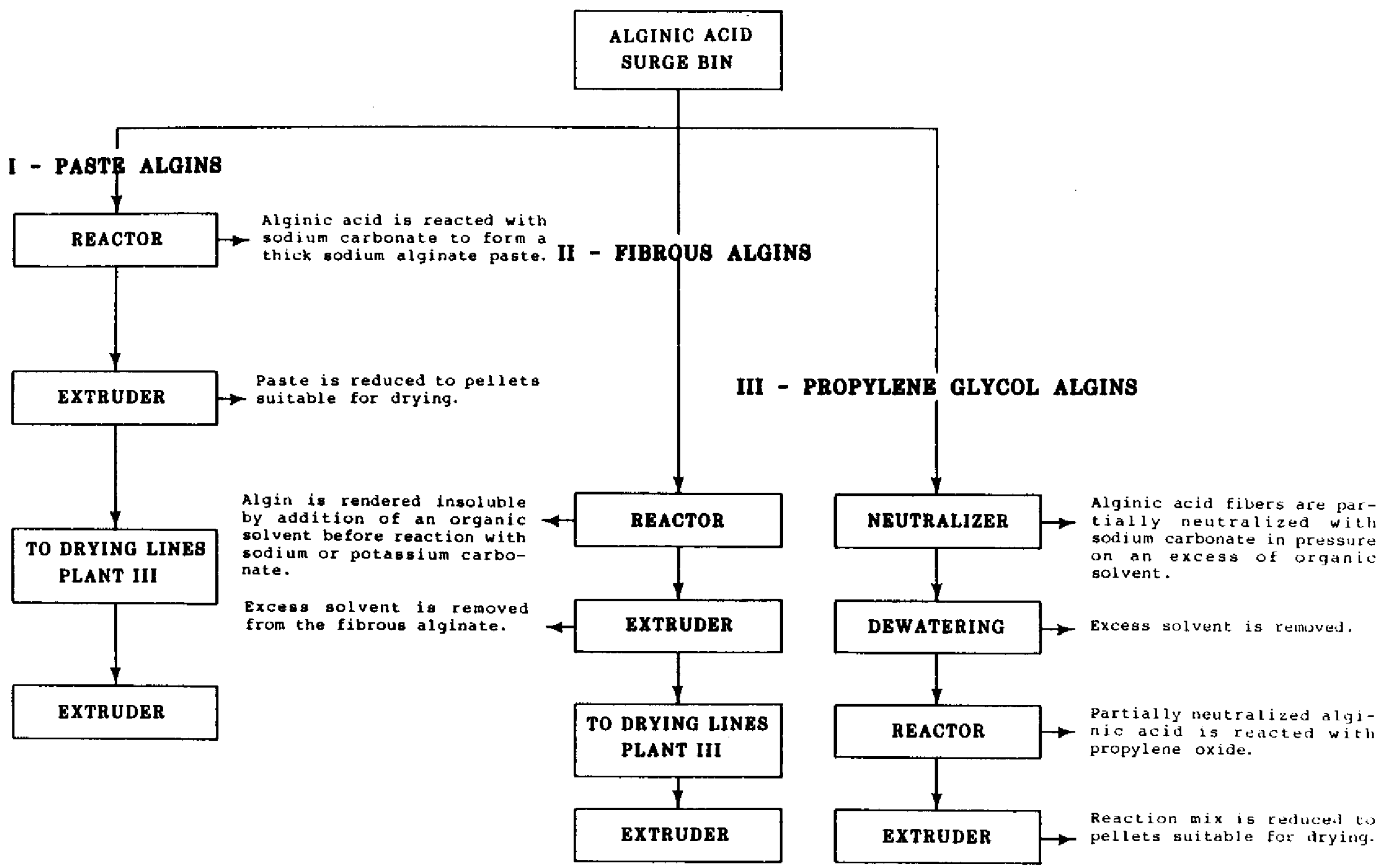
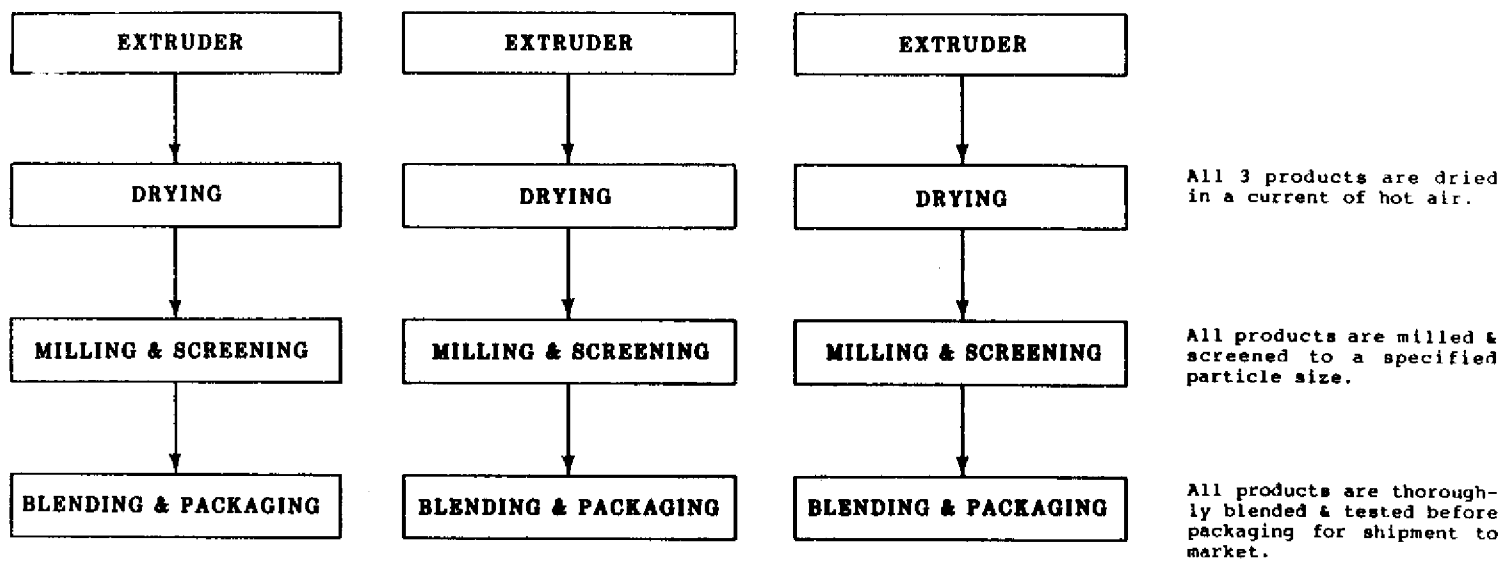


Figure 15. Steps in Algin Processing. Plant III: Drying, Milling and Standardization of Algin



The proportion of paste products sold, when compared with total algin sales, varies from country to country. In the North American market, we estimate that between 25 and 30% of all algin sales are of the paste type. The proportion is substantially higher in other countries, where a higher proportion of algin is used for industrial purposes. The alcohol-washed or acid-precipitated alginates are more highly refined than the paste products and usually sell for about $1.00 to $1.50 per pound more. By far the largest proportion of this type of product is used in food, totaling about 25 to 30% of all sales.

Algin can be modified, and the most popular modified product is propylene-glycol alginate, which normally sells for around $5.00 to $6.00 per pound. In the United States, roughly 40% of all algin sales are propylene-glycol alginate. Sales of propylene-glycol alginate are small and unimportant in other parts of the world except in Japan and Canada.

Propylene-glycol alginate can withstand lower acidities than other alginates, an attribute which gives it a wider profile of food uses. In the United States, Canada, and Japan, large volumes are consumed in salad dressing, fruit-pulp suspensions, flavor emulsions, beer-foam stabilizers, industrial suspensions, etc.

Sales Methods and Competition

As mentioned previously, there are neither published data pertaining to quantities and types of algin produced nor information on how much is used by any particular industry or major account within an industry. People skilled in the seaweed industries can make estimates which may approximate the current sales volumes. (See Table O.) Therefore, the following estimate is presented with this precautionary remark: although the estimate may not be accurate, it can contribute to an understanding of markets and uses of the product.

There are four principal producers of algin in the world: Kelco Company in San Diego, California; CECA, S. A. in France; A. S. Protan in Drammen, Norway; and Algin Industries, Ltd., England (owned by Kelco San Diego). Kelco (San Diego) and the English plant each produce between 6,000 and 7,000 tons of algin per year; CECA's volume is about 2,000 to 3,000 tons; and Protan makes between 3,000 and 4,000 tons annually. Nova Scotia has one plant making about 1,000 to 1,200 tons annually, and Japan has two plants making a total of 500 to 1,000 tons per year.

At this time we cannot estimate the impact the Chinese will have on the market. It appears that their government currently subsidizes the kelp farms, thus assuring delivery of cheap raw materials to the extraction plants. Obviously, the established major producers will have to cope with Chinese prices. It seems probable that the existing producers will not make a satisfactory profit for the next several years.

Considerable variation in prices exists among the manufacturers of alginates. The following illustrates current price competition: one major producer is charging $4.50 per pound for an alcohol-washed product used in battered food coatings; two other companies are offering products having approximately the same physical and chemical properties and designed for the same use at $2.85 per pound. Similar disparities in prices for products having approximately equal properties are occurring with increasing frequency. We expect that China's entry into the market will exacerbate the situation.

One competitive aspect of sales for both algin and carrageenan must be emphasized at this point. The four major algin producers obtain roughly 50% of their sales from about 10 to 20 of their large-volume products, which are sold to their 50 top customers. The remaining 50% of sales is derived from the sales of 200 to 300 small, specialized products. It is quite difficult for a manufacturer located in Europe to sell these small, specialized products in North America. Likewise, it is difficult for the American manufacturers to sell small-volume specialized products in Europe. For obvious reasons, maintaining an inventory of numerous small-volume products can be costly and difficult to manage, especially if the producer is distant from the market. A local manufacturer can produce this type of order upon receipt, eliminating the cost and need for maintaining an inventory. Although specialized, small-volume products sell for 25% to 200% more than large-volume "standard" products, a foreign supplier has difficulty meeting the competition of the domestic producer for small-volume specialized products.

In a prior section of this report, attention was called to the competition between algin and the synthetic gums and fermentation gums such as xanthan and gellan. There is also some competition between algin and one natural seed gum, guar gum. Guar gum is presently selling for around 80 cents per pound, and approximately 30 million pounds are used annually in the United States. Guar and alginate compete for some of the same uses in textile printing, paper sizing, and a variety of food uses. Usually 2 to 4 times as much guar is required to achieve the same effect as algin; this permits algin producers to compete with guar producers. Despite the fact that some accounts change back and forth between algin and guar, volume of production remains relatively constant.

Processing Steps and Costs

Table R shows the estimated capital needed for building and operating new 750-, 1,000-, or 1125-ton plants. In this estimate we assume that the prospective investor will purchase the land and erect building space. Raw materials and depreciation costs are by far the major factors.

Hawaii has no kelp in its surrounding waters, so it would have to be imported or grown here. Hawaiian Abalone Farms at Keahole Point of the Big Island is currently raising kelp in tanks to feed abalone, and plans to expand production. Supplies are available in Tasmania, but no carrier from Tasmania to Honolulu could be located. Chilean supplies appear to be the easiest to obtain, yet they must be trans-shipped from Los Angeles at $209 per ton. Added to the price of the kelp, the algin in the dry kelp before extraction costs $1.16 per pound.

Algin extraction also requires some chemicals. The present investigation shows that all of these chemicals imported from the United States mainland would cost slightly more (3% to 5% more) in Hawaii than on the U.S. mainland or in Europe.

It is questionable if seafarming around Oahu is politically acceptable. If pilot evaluations show that kelp seafarming can be conducted without adversely affecting the environment, and if such seafarming is economically competitive with wild and farmed foreign sources, an Oahu plant might be able to compete with the established plants. However, an Oahu plant would have higher costs of production than a plant located on the geothermal land near Pahoa.

Of the three major algal hydrocolloid processing businesses, algin processing has the least chance of becoming a successful business in Hawaii. On Hawaii Island, the geothermal situation does not offer sufficient advantages to overcome the competitive edge given to existing producers who use fresh kelp. Again, seafarming of kelp around the island of Hawaii might make the difference, and pilot evaluations in this regard are urged.

Table U. Estimated Production Costs of Algin (per pound)

Cost Item	U.S. Mainland Plant 1,000 Tons	U.S. Mainland Plant 6,000 Tons	Honolulu Plant 1,000 Tons	Geothermal Area 1,000 Tons
Raw Materials	$ .60	$ .36	$1.20	$1.33
Reagents	.31	.31	.31	.31
Utilities	.18	.18	.18	.09
Labor	.16	.16	.16	.13
Maintenance	.07	.07	.07	.06
Packaging	.08	.08	.08	.08
Sewer	.03	.03	.03	.01
Subtotal	$1.43	$1.19	$2.03	$2.01
Depreciation	.21	.21	.36	.36
Other Indirect Costs	.30	.30	.15	.15
Research and Quality Control	.15	.15	.15	.15
Sales	.22	.22	.25	.25
General Expenses and Administration	.20	.20	.24	.24
TOTAL COSTS	$2.51	$2.27	$3.33	$3.31
AVERAGE SALES PRICE	$3.25	$3.25	$3.25	$3.25
NET PROFIT PER POUND	.74	.98	(.08)	(.06)

CARRAGEENAN PROCESSING

Overview

Carrageenan products are water-soluble d-galactan colloids which can be used to modify water viscosity and flow properties. In appropriate concentrations, they form water-based gels. Both the viscosity and gel properties can be modified by a variety of manipulations.

Depending on the species, "carrageenan" seaweeds may contain one or more of three kinds of carrageenan. These are kappa, lambda, and iota. The tropical seaweeds producing kappa carrageenan are referred to in this text as "cottonii". "Spinosum" is used for those producing iota carrageenan. Both are groups of Eucheuma species. No lambda carrageenan is processed today from tropical seaweed, though its source species grows in Hawaii and could be farmed here.

The three kinds of carrageenan differ in their chemical and physical properties, giving the extractive manufacturer great flexibility in designing specific products for specific uses. Carrageenan can be modified with a variety of monovalent and divalent cations, still further increasing the range of properties. Additionally, molecular weights, which can be decreased to specific levels, further contribute to diversity. Carrageenans also react synergistically with some other hydrocolloids and with proteins in aqueous suspensions.

Markets

The growth and history of carrageenan production and sales can be seen in Figure 1. The 1982 volume was about 13,000 tons, with a value of about $101,000,000. Table O shows countries producing carrageenan products and the estimated amounts. This estimate does not include the so-called alkali-modified carrageenan (AMC) products, of which about 3,000 tons may have been produced in 1983 with a value of around $12,000,000 (Table V). Since 1983 the proportion of cottonii types of Eucheuma going into AMC has increased greatly.

About 70 to 75% of all carrageenan processing is done by three companies: Marine Colloids in Rockland, Maine; CECA, S. A., in France; and Copenhagen Pectin Company, Denmark. These three and another company in Denmark, Litex, supply 80 to 90% of the carrageenan market. It is estimated that each of these plants has between 25 and 30% surplus capacity, a result of expansion of production 3 to 4 years ago. Since then, sales have been either static or slightly lower, leaving this unused capacity available for growth. Like other products in this report, carrageenan now has probably stopped its trend toward lower volume of sales, and historic growth rates are expected to resume. Consequently, it is estimated that this surplus capacity will disappear within the next 3 to 4 years.

For a time during the past 3 to 5 years, the production and sale of carrageenan products slowed due to the combination of the recession and high prices. This was also true for other seaweed extractives. About 35 to 40% of all carrageenan produced is used in luxury-type foods. Although such use permits high prices during normal economic conditions, sales are sensitive to decline during recessions.

Uses of carrageenan are surprisingly diverse. They are used as additives to a wide range of foods, particularly those that contain both proteins and water, such as milk. Carrageenan is also used in a number of cosmetics and pharmaceuticals. Only minor amounts are used for industrial purposes. Since carrageenans are complex, the sales staff for these products must understand food/pharmaceutical/cosmetic formulations and chemistry.

Table V. Estimated Production of Alkali-Modified Eucheuma in Tons

Company Name	Location in the Philippines	Estimated Annual Capacity Chips	Estimated Annual Capacity Powder	Estimated Annual Production 1982	Estimated Annual Production 1983
Shemberg	Cebu	1,400	720	1,196	1,200
MCPI	Cebu	1,600	1,200	882	1,080
Marcel	Zamboanga	600	600	340	400
KPF	Cebu	240	0(?)	28	120(?)
Antonio-agro (Ms. Lua)	Cebu	360	360	0	120
Goodwill Foods	Pampanga	360	0	100	120
Arch-agro (Gen. Santos)	Cotabato	360	0	0	0
UNISEAPRO (Chua)	Manila	360	0	0	0
Enrich	Manila	360	0	0	0
TOTALS				2,546	3,040

Note: Goodwill Foods is a subsidiary of Hispanagar, a Galatos company.)

During the mid-1960's, carrageenan products sold for $1.60 to $1.85 per pound. By the late 1970's, prices had increased to $4.00 to $5.00 per pound. This increase was primarily due to the high cost of energy (oil) and the cost of the seaweeds from which carrageenan is extracted. The currently abundant and cheaper seaweed supplies, reduced oil costs, and excess extraction capacities have created an intensely competitive market. Prices have declined from their high point of several years ago to $2.50 to $4.00 per pound, or by roughly 30 to 40 percent. Assuming that oil prices will remain at current levels, the present investigation indicates that this situation of intense competition will continue for at least 3 to 4 years and may be permanent for this industry.

In the late 1970's, costs and prices of carrageenan reached record high levels, inducing major users to search for lower-priced alternate colloids, even though such changes lowered the quality of their products. Industry leaders estimate that this type of loss amounted to about 10% of the 1978-to-79 volume. The high cost of carrageenan also resulted in another development that inhibited growth during this period. Manufacturers of retail foods, etc., constantly develop new products. When the use of a water-soluble colloid is indicated, they evaluate those products having the approximate desired properties and costs. When carrageenan prices became disproportionately high, carrageenan was excluded from new evaluations and thus from new products. Now carrageenans are priced more in proportion to the values they contribute to products, and producers and buyers of carrageenan are currently working their way through this problem. It takes 2 to 4 years to research a new formula, market-test it, and place it on the market. Consequently, it is anticipated that carrageenan production will increase slightly in 1984, followed by substantial growth (8% to 12% or more) in 1985.

The major reason for this changing picture is the rather recent ability of the carrageenan industry to control the costs, quality, and quantity of its raw material sources. As explained earlier, this is due to the sea farming of the Eucheuma seaweeds. The resulting cheaper raw materials (compared with those of the mid- to late 1970's) have reduced extractive prices. There has been a concurrent improvement in cost effectiveness and competitiveness.

Roughly 30 to 35% of all carrageenan is used as a stabilizer or gelling agent in milk-based products. For example, it is the suspending agent for all commercially bottled chocolate milk, and it is one of the stabilizing colloids used to retard ice crystal growth in about 85 to 90% of all ice cream.

Another 30 to 35% is used to increase the viscosity of the water portion of various foods or to make water-based gels. To illustrate, it is used in various table syrups to give viscosity, body, and mouth feel, and as the suspending agent for fruit pulp in various fruit drinks, etc. It is also used in higher concentrations to form various dessert-type or other food gels. Carrageenan has a potential use in any food containing water if there is a need to modify the food in some way, e.g. to hold it in a stable condition or to achieve a specific effect.

Another 25 to 30% of carrageenan sales go into a miscellaneous group of pharmaceuticals, cosmetics, and industrial uses. It is used as a thickener and stabilizer in toothpaste, hand lotions, face creams, etc. For years the major industrial use was in air-freshener products, where it was used as a gelling agent. This group of uses was recently taken over by the alkalin-modified Eucheuma, AMC, which is described next. Approximately 13,000 to 13,500 tons of carrageenan were sold world-wide in 1982. Their major uses are listed in Table W.

Alkali-Modified Cottonii

In the mid-1970's, a new commercial product, alkali-modified cottonii (AMC), appeared. It is the result of using a high-pH potassium hydroxide, in cooking, rinsing, and drying the cottonii type of Eucheuma. In the normal extraction of carrageenan, the carrageenan is dissolved out of the seaweed. However, in this newer process the non-carrageenan materials are dissolved away, leaving the carrageenan and a little cellulose. The product is chopped, dried, and ground.

It is then ready for sale. This simple processing lowers the price to about $1.00 per pound less than the lowest-priced extracted carrageenan.

The alkali-modified product contains between 85 and 95% carrageenan, and it can often be used to replace extracted kappa carrageenan. It is especially useful in products that are opaque or colored, for its gels are slightly turbid. It is blended with other extracted gels to cut costs. It can be used for stabilizing ice cream, as a gelling agent for milk puddings, and as a stabilizer for cakes. It is now widely used in pet foods and in air-freshener gels.

Table W. World Uses of Carrageenans in Thousands of Pounds.

Product types	United States	Europe	Japan	Others
Ice Cream	3,000-3,500	1,500-2,000	500	500
Chocolate Milk	1,500-1,700	700-900	100	200
Milk Dessert Gels	600-800	1,500-1,800	---	200
Milk-based Foods[a/]	1,500-1,700	1,000-1,200	?	?
Protein-based Foods[b/] (other than milk)	1,100-1,500	1,000-1,200	200	400
Water-based Dessert Gels	600-700	1,000-1,100	800-900	400
Water-based Liquids (i.e. fruit juices)	700-900	400-500	?	?
Pharmaceutical Items & Cosmetics	500-550	500-550	100	---
Other[c/]	---	3,500-7,500	---	---
Totals	9,000-11,350	11,100-16,750	1,700+	1,700+

a/ Instant breakfast drinks, artificial milks for babies, evaporated milk stabilizer, coffee cream stabilizer, etc.
b/ Extruded artificial meats, sausage stabilizers, meat sauces, gravies, etc.
c/ Cake mixes, biscuit mix, icings, candies, vegetable toppings,etc.

We estimate that this type of product has some growth potential, and that it will eventually compete with 25% or less of the current extracted carrageenan. AMC is expected to develop new sales volume based on its own merits. It may grow to an annual volume of over 4,000 to 5,000 tons soon. Table U lists the current producers and their volumes.

Promoters of the AMC product have characterized and sold it as carrageenan. The FDA is now seriously considering whether it can be properly represented as carrageenan. Industry leaders are predicting the FDA will require it be sold under a more descriptive name, e.g. crude carrageenan, or will subject it to extensive animal feeding studies, etc. Anyone evaluating the potential of this product should carefully examine its FDA status.

We do not believe the alkali-modified non-extracted carrageenan products are candidates for Hawaiian processing unless *Eucheuma* is farmed in the area.

Raw Materials

From the beginning of the carrageenan industry until the mid-1960's, almost all carrageenan seaweeds came from the Canadian Maritimes, the British Isles, France, and Spain. In the mid-1960's, substantial quantities were harvested in Chile, the Philippines, and Indonesia. All of these sources were from "wild" beds, with production dependent on the weather, economic and political conditions, competition, etc. By the late 1960's, carrageenan seaweeds were in short supply, and all available sources were being used. By the early to mid-1970's, increasing amounts of "farmed" cottonii began to appear, relieving the shortage and permitting continued growth of the industry.

By 1960 Marine, Colloids could see that all available supplies would eventually be used, and under the technical guidance of the Department of Botany, University of Hawaii, they developed the capability of farming Eucheuma species for their carrageenans in a ten-year program. The seaweeds judged to have the best chance of success were the cottonii varieties, from which kappa carrageenan is obtained, and Eucheuma denticulatum (the "spinosum" of commerce), which contains iota carrageenan.

Two other seaweeds which are sources of carrageenans are Iridaea and Chondrus. Iridaea is harvested in Chile and is exported as Gigartina radula. Between 5,000 and 6,000 tons of this seaweed are used annually. Iridaea yields a weak mixture of kappa and lambda carrageenan, and its properties are significantly different from cottonii carrageenan. The current price of Iridaea is about $400 to $450 per metric ton, FOB Chile. This seaweed normally yields about 35 to 37% carrageenan, compared with 30 to 32% for normal-quality Eucheuma.

The development of the carrageenan industry was originally based on the availability of Chondrus crispus (commonly known as Irish moss), found in the Maritime Provinces of eastern Canada. This area has produced as much as 12,000 tons annually. However, the increased cost of labor in that area compared with that of the western Pacific has resulted in significant competition from the lower-cost farmed Eucheuma from the Pacific. Prices of Chondrus crispus from the northeast Atlantic presently range from $600 to $1,100 per ton. Chondrus crispus and other members of the closely-allied order of red seaweeds, the Gigartinaceae, are also harvested along the coasts south of the Cherbourg Peninsula of France and along the northwestern coasts of Africa. These seaweeds cost about $450 to $500 per ton delivered.

About 28 to 32% of the current carrageenan sales volume probably consists of the kappa extractive of cottonii and the iota extractive of spinosum. An extractor needs several different species to provide a range of fractions and properties in order to offer a full range of competitive products. Hence, there is a need to supplement the Eucheuma supplies with other seaweeds such as Iridaea and Chondrus crispus.

Production

Each fraction of carrageenan (kappa, lambda, and iota) has the capability of combining with a number of cations, particularly sodium, potassium, and calcium. Sulfate radicals can be removed and other modifications made. Molecular weight can also be modified. Consequently, the manufacturing procedures required for carrageenan are more complex and capital-intensive than for either algin or agar. Table R shows the estimated capital requirements.

The flow chart, Figure 13, briefly describes the essential steps in the carrageenan extraction process.

The extraction of carrageenan is costly (Table X), largely because it requires great quantities of heat. The heat, the need for extensive analytical and other control procedures, and the larger capital requirements make the cost of extracting carrageenan higher than that of algin or agar. Costs of producing the various carrageenan products depend in part on the number of processing steps required, the cost of the original seaweed, and the degree of standardization desired. Adminstrative and sales costs are relatively standard for this type of product.

Comparative Carrageenan Processing Costs

It is revealing to compare the costs of producing carrageenan in established plants at three sites: 1. In New England or Europe, 2. Near Honolulu, 3. At Pahoa, Hawaii Island, Hawaii geothermal area. It is assumed that the same steps, those of figure 13, would be taken at all three sites.

Freight costs from Cebu City and Manila to LeHavre, Boston, and Honolulu were identical: $106 per ton. Marine Colloids and CECA must pick up the seaweed at port and haul it another 130± miles at an estimated cost of $25/ton. Total cost of delivered carrageenan seaweed = $325 FOB Philippines plus $106 plus $25 for freight plus about $10 for port charges and incidentals, with a total cost of $456 per ton.

The above freight cost calculations are based only on Philippine Eucheuma, which offers the best quality and lowest costs.

We turn now to a consideration of Iridaea. Chilean Iridaea costs about $450 per ton FOB Chile. Freight to Boston or LeHavre is $156 per ton. Thus the cost to Marine Colloids is about $650± per ton. At about 36% yield for Iridaea, the cost of delivered extractive in the weed is 80 cents per pound. Our only freight quote to Honolulu for Iridaea was $156 to Los Angeles plus an estimated $50 to transship it to Honolulu. This will increase the delivered cost of a pound of extractive in the seaweed to about 6 cents above that of Marine Colloids. If the $50 extra needed to transship to Hilo is added, the difference becomes 11 cents per pound. However, only minor amounts of Iridaea are normally blended with the Eucheuma extractive, so this cost difference would have only small significance. Other savings at the geothermal plant are great enough to absorb this cost disadvantage.

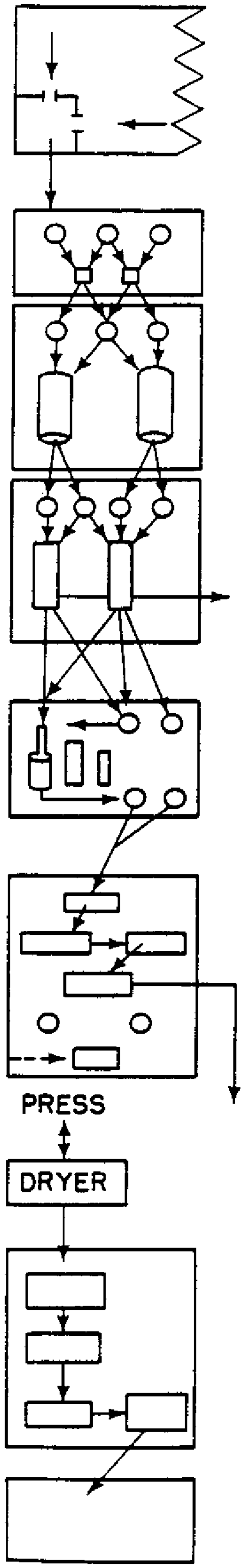
Transshipment of the seaweed from Honolulu to Hilo adds $50.00 per ton or about 5 to 6 cents per pound. Thus in Table M, the total cost of raw materials per pound is shown as 71 cents.

It is estimated that one geothermal well will handle the energy requirements of a 600-ton carrageenan plant. To drill the well, connect it and equip it will cost $1,500,000. Distributed over the 10-year life of the well, this would be $150,000 per year, plus an additional $75,000 per year for fees and operational costs. Total energy costs of $225,000 per year or 17 cents per pound for production of 1,320,000 lbs per year may be anticipated (Table X).

Wages on Hawaii Island are estimated to be more than 20% below those of Honolulu or Maine, hence 17 cents per pound is given for labor.

The four bottom lines of Table X compare the total of all costs with the average prevailing price of carrageenan. However, the prices of individual products vary widely. For example, large-volume buyers of carrageenan used for

Figure 16. Steps in Carrageenan Processing



1. Raw materials warehouse
2. Bale breaking, grinding
3. Soaking tanks - hydrate dry seaweed
4. Reitz grinders - to fine paste
5. Cooking tanks - to 165°-190°F
6. Holding tanks - at 160°F - 180°F for a number of hours
7. Heat to 200°F - 212°F - add filteraide
8. Automatic filters - high pressure at 200°F

8A. Filterade discharge line

9. Filtrate holding tanks
10. Double effect evaporators - remove 1 - 2 volumes H_2O
11. Condensed filtrate holding tanks
12. Filtrate - alcohol blender - carrageenan dewatered into fibrous strings
13. Wet fibers separate from water/alcohol mix
14. Fiber is pressed
15. Dryer - water and alcohol removed from fiber using vacuum and heat
16. Alcohol distillation units - capacity - 1 part filtrate with 1 part alcohol - 80%
17. Compressor - for condensing alcohol vapor

17A. Watercooling tower or pond

18. Grinders and dust collectors
19. Sifters
20. Blenders
21. Packaging
22. Finished product storage

Table X. Estimated Production Costs of Carrageenan in Cents per Pound

Items affecting cost and profit	Established plant in the U.S. or Europe	New plant in Honolulu or vicinity		New plant at Pahoa geothermal area	
	2500 tons or more	600 tons	1200 tons	600 tons	1200 tons
Variables:					
Raw Materials	66	65	65	71	71
Chemicals and Packaging	29	31	31	31	31
Waste Disposal	5	6	6	2	2
Variable Energy	68	68	68	17	17
Wages & Fringe Benefits	21	23	21	17	17
Maintenance	10	10	10	10	10
Total Variables	199	203	201	148	148
Indirect Costs	8	8	7	7	7
Depreciation	14	42	39	40	39
Research & Quality Control	14	14	14	14	14
Sales	19	21	18	21	18
General & Administrative Costs	19	20	17	20	17
Total Cost per Pound	273	308	296	250	243
Federal Taxes	28	12	18	39	42
After-Tax Profit	34	15	21	46	50
Average Selling Price	335	335	335	335	335

ice cream stabilizing can buy it for $2.25 per pound. This type of product is less refined and has a much higher throughput rate than the average carrageenan. Therefore, an ice-cream blend costs less. Other specialized products produced in 5,000- to 10,000-pound lots may have prices as high as $6.00 to $8.00 per pound.

When we made this analysis, we found that the shipping costs of Eucheuma seaweeds from the Philippines and Indonesia to Hawaii were not much different from the shipping costs to competitive plants elsewhere. NYK Lines will deliver bulk seaweeds to Honolulu in container lots from either Cebu City or Manila for $106 per ton. Shipments from Indonesia cost $106 plus $15 for extra handling. Costs from Micronesia to Honolulu have not been established.

As can be seen from the estimated production costs, a thorough feasibility study may confirm that a carrageenan plant located in the geothermal area near Pahoa would be economically viable, even though it must import its raw materials at extra cost through Honolulu and Hilo. Hilo is about 20 miles north of Pahoa, and the road between them is good.

An even greater advantage could result from locally-farmed Eucheuma, which grows readily in Hawaii and nearby waters. Based on knowledge of these seaweeds, we believe that farming areas can be selected that will not adversely affect Hawaii's environment. Pilot evaluations have proved this point. One or two square miles of Eucheuma farm would provide a substantial number of jobs and enough seaweed to support an extraction industry with a scale economically competitive with similar operations elsewhere.

Based on the above estimates, it appears that a new plant at the Pahoa geothermal site could easily and effectively compete with established producers elsewhere.

CONCLUSIONS AND RECOMMENDATIONS

Markets for Edible Seaweeds

Discussion

Substantial markets ranging into the hundreds of millions of dollars have been established for edible seaweeds. Significant growth of this market is taking place, and that growth should continue. It has resulted in the development of farming and merchandising methods for the seaweeds involved, and this development has further stimulated the market. The major markets are in Japan, Korea, and China, but the western world is now also becoming a growing, significant market.

It is doubtful that the major markets for table-use seaweeds in areas other than North America can be penetrated by seaweeds grown in Hawaii.

However, the growing North American market could be penetrated by Hawaiian seaweeds. There has been some penetration already by _Gracilaria_, _Caulerpa_, _Monostroma_, and _Eucheuma_; others should be able to penetrate the North American market also. The seaweeds mentioned above are excellent and readily-acceptable salad vegetables. If seaweed production is to become an attractive and stable industry, farm production and improved post-harvest handling would be needed. Both of these are technically feasible and economic.

Further development of such industries in Hawaii is dependent on the availability of subtidal land on lease from the state for farming. Grants of this nature have not been made to date and the government's attitude in this matter is not clear.

Recommendations

The state should obtain funding for the projects proposed, to discover and recommend methods of production and marketing of table-use seaweeds.

The legal basis should be laid for granting the exclusive use of small plots of subtidal land for pilot production of table-use seaweeds. These temporary occupation licenses should be of finite duration and restricted purpose, and they should be renewable.

The evaluation of these pilot plots should include a description of the environmental effects of the subtidal land farming, though nothing detrimental is anticipated.

The state should give immediate encouragement to production of _Gracilaria_ on the outer islands and its export to Oahu and North America as a table vegetable.

Appropriate research and development studies should be funded so that the projects at Keahole and the University of Hawaii at Manoa will be able to provide information, assistance, and demonstrations of technique.

Processing for Extractives

Discussion

There are no seaweed resources in Hawaii now that can support a local extraction industry. Nevertheless, an extraction plant could operate at a profit in Hawaii by importing all the seaweed it processes. Hawaii would have a distinct competitive advantage if the seaweeds could be farmed locally, since freight charges would be greatly reduced.

If a processing plant were in operation in Hawaii today, its production of algin, carrageenan, or agar would require the importation of dried seaweed from other producing areas around the Pacific basin. Such dried raw materials are available for each of these gel types at competitive prices. However, algin-processing plants thrive largely on local fresh seaweed.

Nowhere in the world is there an opportunity such as is found in Hawaii for developing the economic production of commercial seaweeds for drugs or other new uses. This would most appropriately involve the Keahole Point Natural Energy Laboratory of Hawaii support facility for aquaculture development and the 547-acre commercial crop production area associated with the adjacent Hawaii Ocean Science and Technology Park.

In addition to academic research to find new seaweed products and to learn to produce the seaweeds from which they would be extracted, the state's Keahole facilities could foster the development of methods of producing the pilot amounts needed to obtain federal clearances for drug and food usage and, when cleared, provide the large areas essential for production of the commercial crops. Adjacent private property could also be utilized for commercial production.

The geothermal low-cost energy opportunities on the island of Hawaii couple very nicely with the introduction of a seaweed extraction industry using imported seaweeds or those grown on supratidal lands by new techniques, e.g. on the lava flats in South Kona or near Keahole Point.

The cost studies of this report show that the competitive advantage of Hawaii is largely due to low-cost geothermal energy for producing algin, agar, or carrageenan. However, there are other constraints in respect to these three industrial opportunities as follows:

*The Algin Opportunity. For this to be economic, at least some of the seaweed used would have to be locally farmed fresh weed. There may not be enough farming area available. Furthermore, the temperatures in Hawaii are largely too high for growing the currently used seaweed strains, and certainly they are too high for the essential sexual stages of the kelps.

*The Agar Opportunity. Profitability is indicated for extracting agar in Hawaii if the cheap energy of the geothermal wells is available, even despite a possible requirement for importing all the seaweed raw materials for the industry. It would be possible to produce very desirable Gracilaria in Hawaii in significant amounts for an agar industry if subtidal land were made available for leasing. The economic feasibility of producing agar from seaweed in Hawaii has not been determined, though it is likely to be a success if low-cost energy can be used. However, dependable raw material resources must be found or developed before anyone invests in a full-scale in-depth feasibility study.

*The Carrageenan Opportunity. In view of the substantial requirements of the carrageenan industry for heat and other energy, the availability of cheap geothermal energy would provide outstanding cost advantages to a plant established in Hawaii. The industry could be profitable even if special geothermal wells have to be drilled and amortized for the purpose and all the seaweed raw materials imported. New raw material resources are now being developed in Kiribati and Micronesia, which would serve the latter purposes well. The reef flats of Hawaii, if made legally available by appropriate subtidal leasing conditions, would significantly improve the already-attractive apparent profitability of such an industry in Hawaii.

Recommendations

The opportunity to utilize the Hawaii Ocean Science and Technology Park for developing aquacultural production of already-commercial seaweeds on supra-tidal land should be seized, and development of the possible sources of algin, agar, and carrageenan evaluated through pilot studies at Keahole Point.

Gracilaria should be included among the agar sources, and the production of it should be encouraged in Hawaii, with attention given to the highly priced ones such as sugar-reactive agars.

At the same time, development of methods of growing small amounts of species known to have as yet non-federally-cleared pharmaceutical products or otherwise industrially desirable products should be encouraged by state-supported projects at both the academic and the industry level. Specific methods should be developed for each species with emphasis on methods that can be scaled to commercial size. These methods should involve adaptation of field machinery that would make possible eventual large-scale economic production of the species economic in Hawaii.

Special support might well be given to studies of strains of kelp whose sporophytes produce adequate and desirable algin in the Hawaiian marine environment. Growing kelp through its life cycle may be possible, though the temperatures required dictate producing the gametophytic stages elsewhere than at the field sites where the crops would be grown.

Instituting a simple legal system allowing temporary occupation licenses for farmers to farm seaweed on the suitable subtidal lands of Hawaii is highly important. Such licenses should be for non-destructive farming using methods that would allow reef flats to return to natural conditions if the farming ceases.

An academic approach should be supported to change the rather well-known plant designs for algin, agar, and carrageenan so they can be powered by geothermal energy. This energy is available from the waste water from electrical generation systems in Hawaii. This information should be published expeditiously.

It is recommended that the attention of the appropriate processing companies be drawn to the attractive cost advantages of siting seaweed production and processing in Hawaii, especially for agar and carrageenan.