G-31

SYNTHETIC FUELS FROM OCEAN FARMS

by

Howard A. Wilcox
Manager, Ocean Farm Project
Naval Undersea Center
San Diego, California 92132

13 January 1977

Encl (3)

ABSTRACT

The Ocean Food and Energy Farm Project aims to explore and develop the ability to raise giant California kelp (*Macrocystis pyrifera*) and/or other seaweeds, plants, and marine animals throughout the tropical and temperate oceans. Sponsored by agencies of the U. S. Government and private industry, the project is a three-phase, eleven- to fifteen-year effort to achieve a commercially viable farm system of 40,000 hectares (100,000 acres) in the Atlantic or Pacific by the 1990 time period. The system is projected to produce foods, liquid and gaseous fuels, lubricants, fertilizers, industrial chemicals, and plastics at a rate sufficient to supply all the related requirements of one average U. S. citizen per hectare (2.5 acres) of cultivated ocean. The productivity of the system is based on using wave-powered upwelling devices to bring the nutrients of the deep waters up into contact with the solar energy of the surface waters.

SYNTHETIC FUELS FROM OCEAN FARMS

INTRODUCTION

Ocean-grown biomass--seaweeds-- can become one of the world's major chemical feedstock and energy sources. These crops can become the largest fixed-carbon, fixed-nitrogen resource in the world--exceeding the total terrestrial production--and yet not compete with existing food, water, and shelter needs for civilization.

Solar energy is copious in supply (2.5×10^{21} Btu/yr) compared with man's present total energy use (about 2×10^{17} Btu/yr). Solar energy is "everlasting" for man's planning purposes, but most of it is absorbed by the oceans and not the land since the oceans cover 71 percent of the earth's surface and possess relatively low average reflectivities (1). Thus the oceans offer major potential for farming for both energy and food. Ocean plants can be highly efficient (2) as well as immune to drought or frost. Ocean areas offer five to ten times more "potentially arable" area than land and almost none of this has been brought under systematic cultivation. In fact, today's harvests represent only a small percent of the ocean's ultimate food production potential (3) and no significant contribution to the energy available. Potentially a square mile of Ocean Farm could produce enough energy and other products to support more than 300 persons at today's U.S. per capita consumption level, or more than 1,000 to 2,000 persons at today's world average per capita consumption level. Projections show that if marine farming grew from a base of 100,000 acres in the 1985-1990 period at a rate of 12 percent per year, more than 90 million square miles could be under cultivation by about 2100.

OCEAN FARM

The Ocean Farm (4) concept visualizes growing and harvesting suitable seaweed from submerged supporting lines and buoyancy-control structures in thousands of acres at depths of 40 to 100 feet below the ocean surface. Seaweeds convert carbon dioxide, water and other nutrients (mainly potassium, nitrogen and phosphorus) necessary for photosynthesis. All the other nutrients are provided by recycling process waste and bringing up cool, nutrient-rich water from 500 to 1,000 feet of depth. This process is an advantageous technique for harnessing solar energy since many desirable materials and forms of energy are produced and stored (unlike some other solar energy conversion methods).

Part of the seaweeds and associated animal communities are to be harvested periodically and converted to liquid and gaseous fuels, fertilizer, feed supplements, fibers, and human foods at coastal or sea site facilities. Mariculture operations are to be supported with feeds derived from the seaweed process streams.

Figure 1 is a sketch of one concept being studied. Other concepts based on tensioned structures or moored designs are also under consideration. Figure 2 shows the general flow of materials. Carbon and hydrogen leaving the Ocean Farm as fuel and products are replaced by atmospheric carbon dioxide and

CONCEPTUAL DESIGN
1000-ACRE OCEAN FOOD & ENERGY FARM UNIT

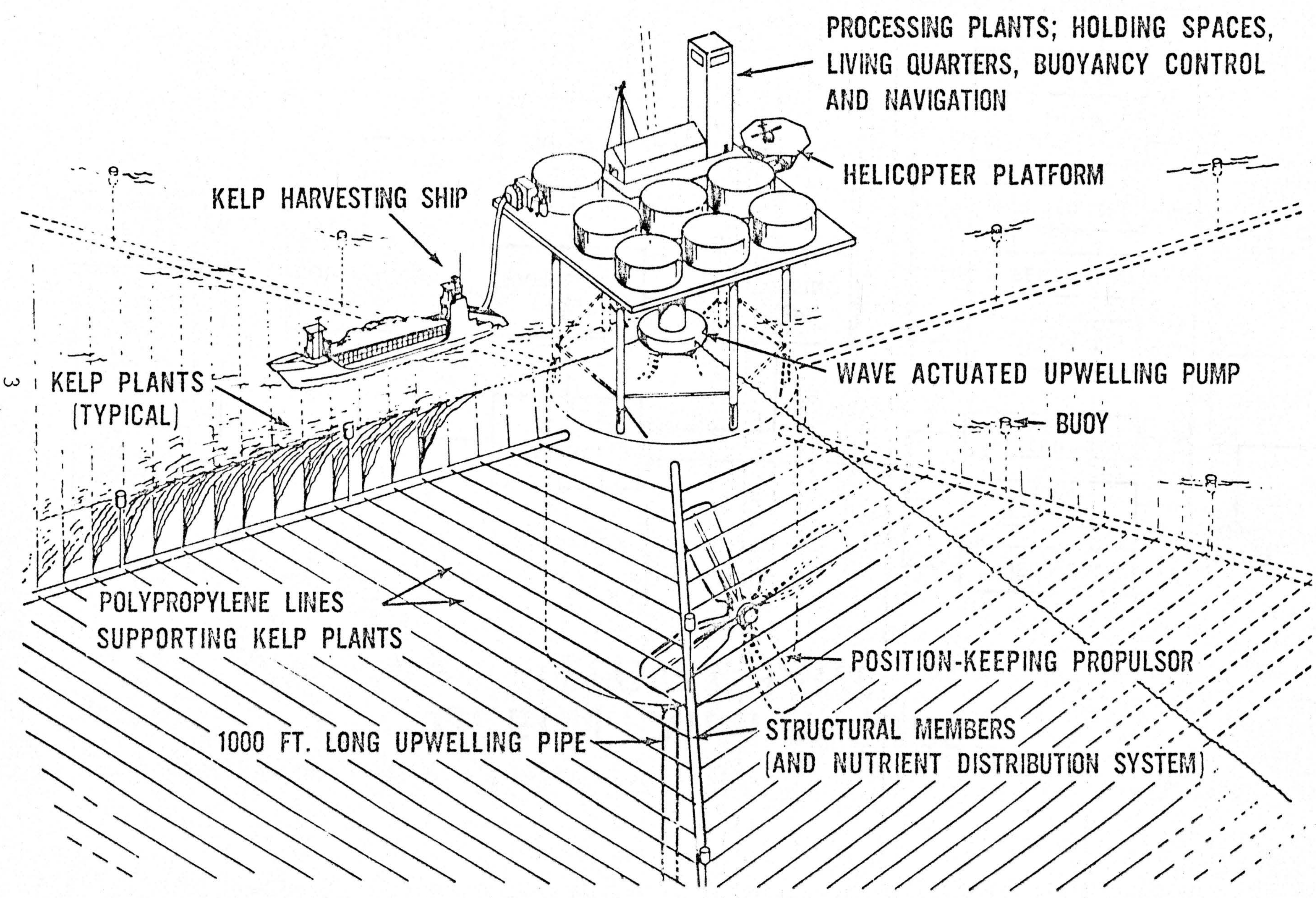

Figure 1

OCEAN FARM PROJECT
FLOW CHART

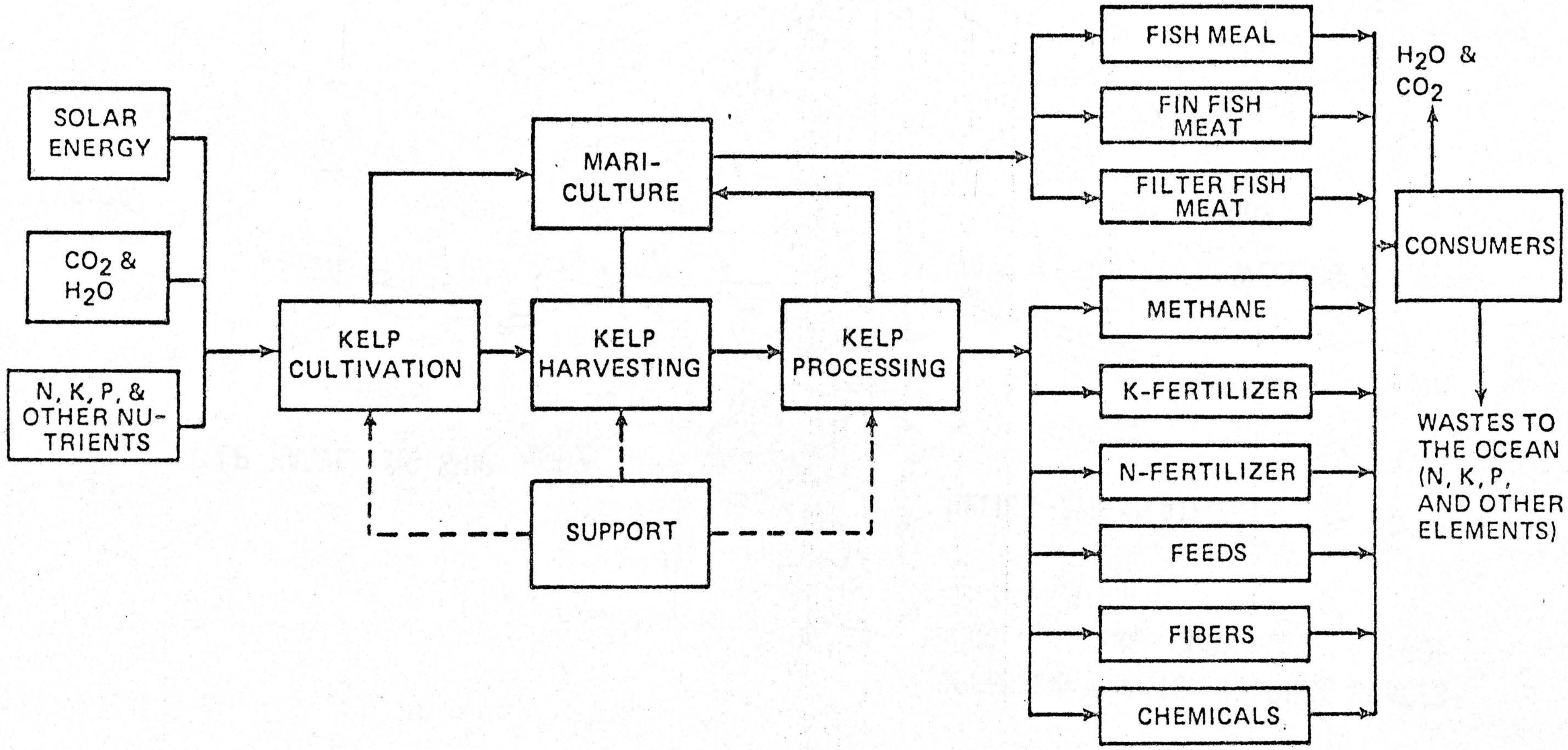

Figure 2

ocean water. Nitrogen, phosphorus and other trace minerals are replaced from upwelled deep nutrient-rich waters. A large portion of fermentation and process wastes are recycled as fertilizer, thus reducing requirements for upwelling.

The "giant California kelp" Macrocystis pyrifera (5), which grows along the coasts of California, Mexico, and New Zealand, has been selected for initial Ocean Farm feasibility studies. M. pyrifera is one of the world's fastest growing plants (fig. 3). Its reproductive cycle is well understood based on laboratory cultivation and harvesting in coastal areas over several years (6). Fronds produce numerous blades which lie along the surface of the ocean to absorb the sun's rays. Nutrients are absorbed from the water by all exposed surfaces of the plants.

The natural life expectancy of each frond is about six months, after which the old fronds die off to make way for the new fronds growing up from below. Therefore, the plant reproduces its own weight every six months or so (7). In the Ocean Farm situation, surface fronds will be harvested every three months. Replanting is not required after harvesting since over-all plants do not appear to exhibit natural aging. Plants only need to be replaced when torn away by storms, killed by disease or excessively damaged by encrustation or fish grazing (7).

Assuming a spacing of ten feet between plants, the Farm will support about 400 to 500 plants per acre. Each acre is expected to yield about 200 to 500 wet tons of harvested organic

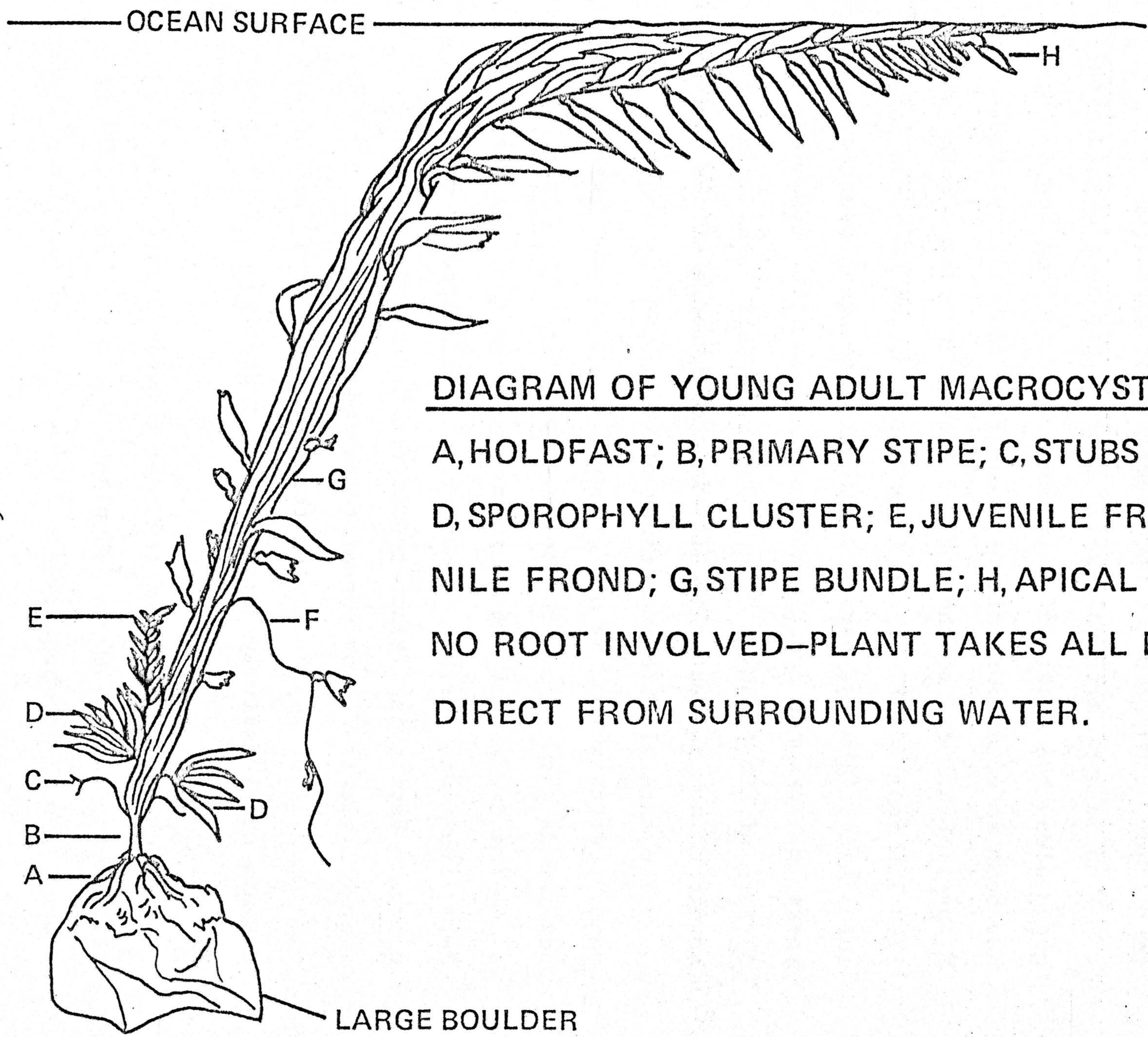

DIAGRAM OF YOUNG ADULT MACROCYSTIS PLANT.

A, HOLDFAST; B, PRIMARY STIPE; C, STUBS OF FROND; D, SPOROPHYLL CLUSTER; E, JUVENILE FROND; F, SENILE FROND; G, STIPE BUNDLE; H, APICAL MERISTEM. NO ROOT INVOLVED–PLANT TAKES ALL NUTRIENT DIRECT FROM SURROUNDING WATER.

Figure 3

material per year (approximately two percent conversion efficiency relative to the whole spectrum of the incident solar energy). This converts to roughly 300 to 400 million Btu of stored vegetational energy per acre per year.

The artificial upwelling system will require relatively little power, probably less than one horsepower per acre-foot of water per day. Needed power for upwelling and distribution of water will be provided primarily by harnessing wave (or wind) energy, although fuel product will be stored for occasional use for this purpose.

Kelp will be harvested with special vessels which will move over the Farm and cut off the upper portions of the fronds. These ships will take in the kelp and transport it to the processing plants. Some preprocessing, such as removal of water from the kelp, may be accomplished on the harvesting ships prior to transferring the kelp to the processing plants. Kelco Company of San Diego, California, currently employs special ships for their commercial harvesting of this type of kelp from the natural beds along the coast of California.

Process plant wastes providing nutrients in addition to nutrients from deep water by means of the upwelling system will also be carried and dispensed by the harvesting ships.

KELP COMPOSITION AND PRODUCTS

Efficient processing designs for the kelp must be worked out based on the chemical and physical characteristics of the freshly harvested feedstock. Figure 4 gives the best data

OCEAN FARM PROJECT
RAW KELP COMPOSITION

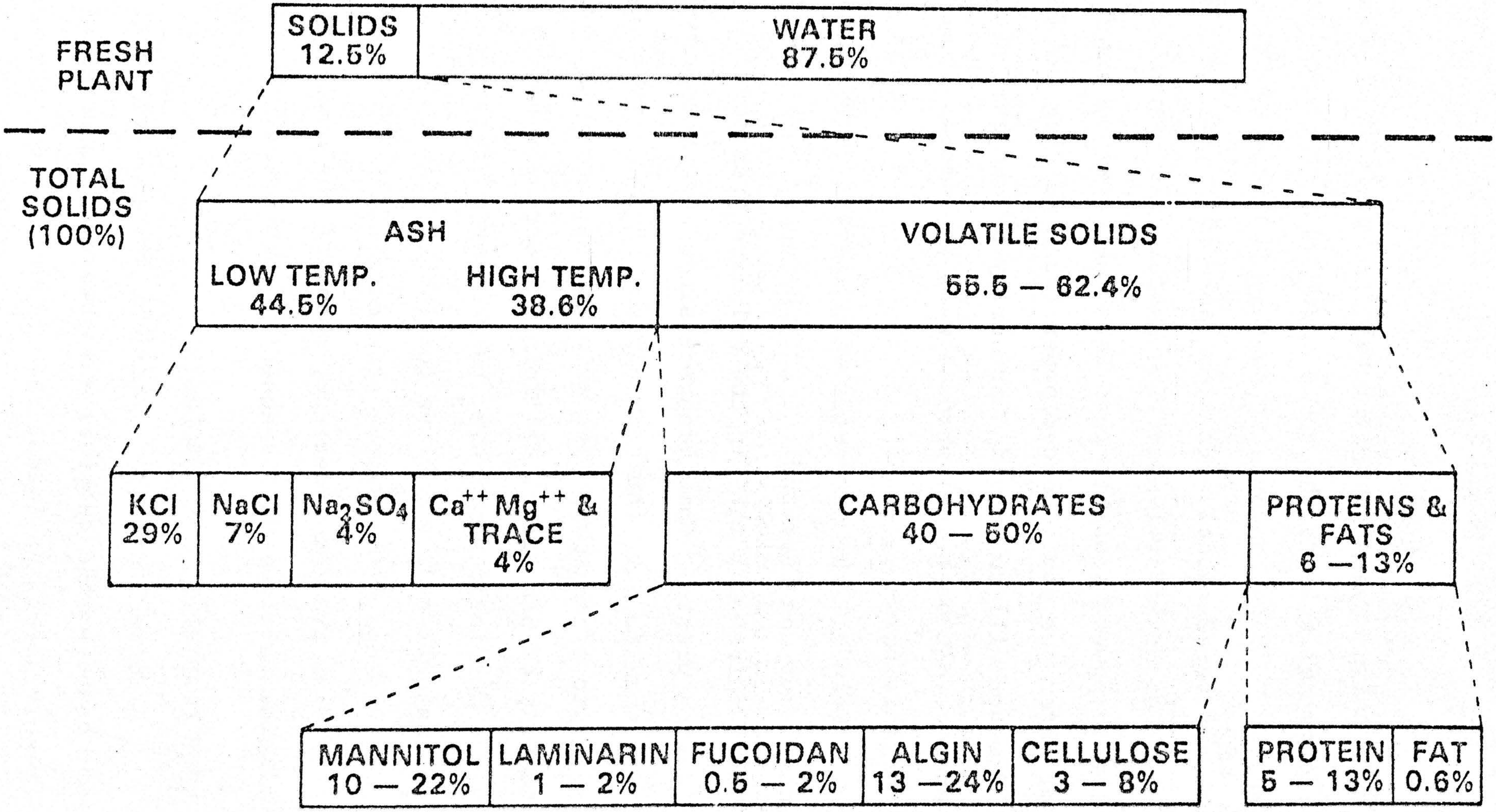

Figure 4

presently available concerning the chemical composition of M. pyrifera. A more complete analysis of seasonal variation characteristics of this seaweed will soon be forthcoming from the Naval Undersea Center. Figure 5 gives further data pertinent to the derivation of fuels and other products from the kelp.

Based on these data, Mr. Tom Leese of the U. S. Naval Weapons Center (NWC), China Lake, and his colleagues at the Western Regional Research Center (WRRC) of the U. S. Department of Agriculture, Berkeley, California, worked out the general, four-step processing approach depicted in figures 6 and 7. Then the WRRC scientists and engineers undertook to investigate the processes of chopping, chemical pretreatment, pressing, and separation of the carbohydrate and salt fractions from the press juice. Their results will be published soon, but here I can report that about three-fourths of the ash in the harvested kelp goes with the juice whereas roughly the same fraction of the volatile solids goes with the so-called press cake. Also, the energy required to carry out the pressing operation turned out to be only a few percent (less than 10%) of that contained in the feedstock.

The Institute of Gas Technology (IGT), Chicago, Illinois, was placed under contract to investigate the anaerobic digestion process for producing SNG ("synthetic" or "substitute" natural gas) from the harvested kelp. To enable their work to proceed, they received from WRRC three types of feedstock: raw kelp, press cake, and press juice. Figure 8 gives IGT's overall

KELP COMPOUNDS	SUGAR RESIDUE	FORMULA	ΔH_c (1) BTU/LB	ESTIMATED AVERAGE ELEMENTAL ANALYSIS LB/WET TON OF KELP			
				C	H	O	N
ALGIN	MANNURONIC ACID GULURONIC ACID	$C_6H_8O_6$	7794 (2)	16.67	1.86	22.21	
LAMINARIN	D-GLUCOSE	$C_6H_{10}O_5$	6642 (2)	17.73	2.48	19.69	
D-MANNITOL	D-FRUCTOSE	$C_6H_{14}O_6$	6246 (2)	6.92	1.36	9.22	
FUCOIDAN	FUCOSE	$C_6H_{10}O_5$	6732	5.57	0.77	6.18	
CELLULOSE	D-GLUCOSE	$C_6H_{10}O_5$	6732	5.56	0.78	6.18	
PROTEINS	–	$(CH_2)_n(NH_2)_mO$	–	5.66	2.01	0.001	7.334
MACROCYSTIS (OVERALL)	–	–	4410 (2)	58.11	9.26	63.48	7.334

(1) HEAT OF COMBUSTION

(2) NWC PARR BOMB CALORIMETER, DRY WEIGHT BASIS

Figure 5

GENERALIZED PROCESS, BASIC STEPS 1 AND 2

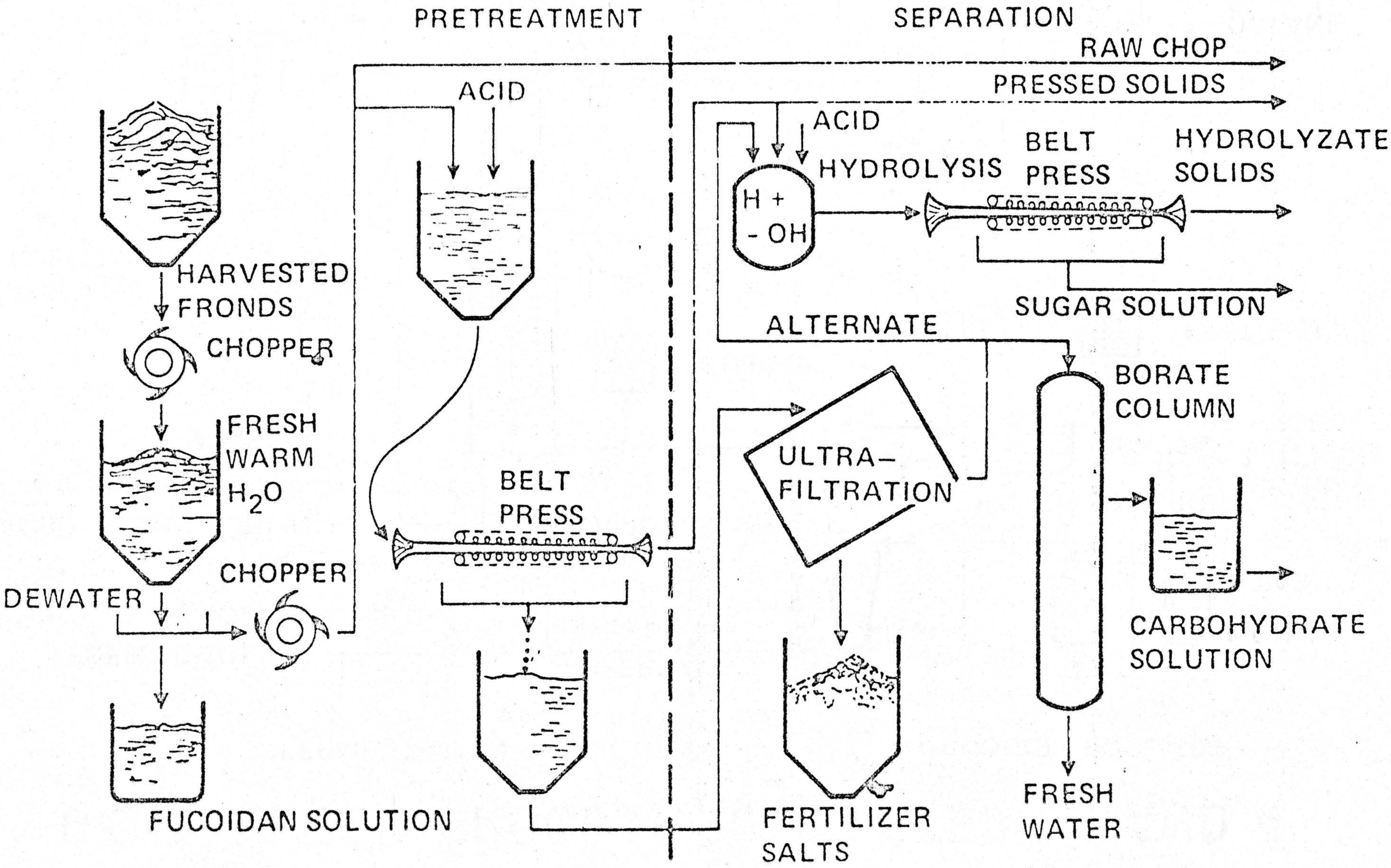

Figure 6

GENERALIZED PROCESS, BASIC STEPS 3 AND 4

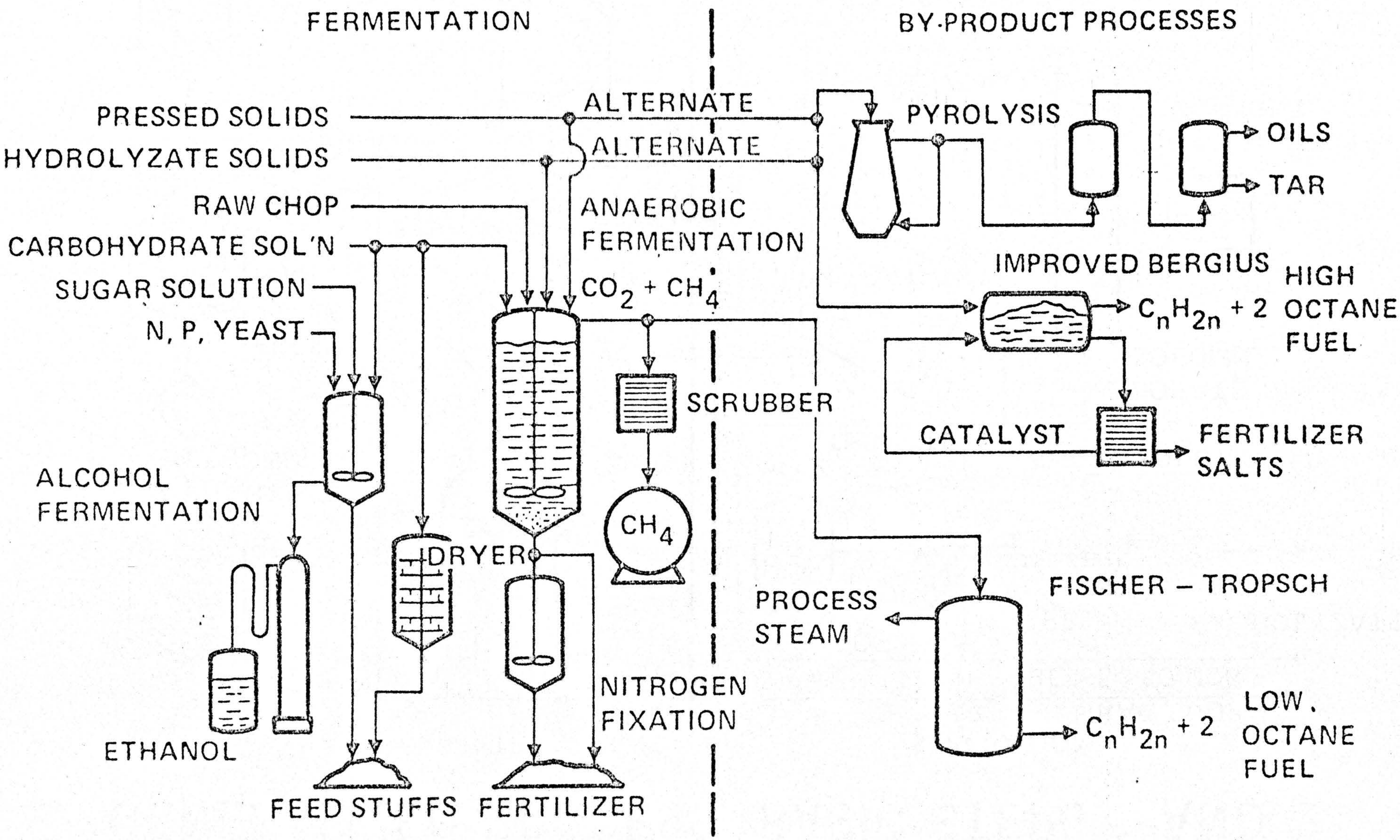

Figure 7

analysis of this material as received, and fig. 9 gives their elemental and energy analysis of the material.

A major question relates to the ability of the anaerobic organisms to grow adequately on each of these three feedstocks, and IGT's conclusion in this regard was favorable as stated in figure 10.

Figure 11 gives the digestion efficiencies achieved by IGT with each of the basic feedstocks they investigated. It should be emphasized that fig. 11 represents the first preliminary accomplishments and not the best results attainable; indeed, we believe that higher efficiencies and/or shorter detention times can readily be achieved with improved and better-acclimated cultures of anaerobic organisms. IGT's work in this area is continuing.

A further important question under study was that of the tolerance of the anaerobic digestion process to salt concentration buildup. Figure 12 states the promising conclusion which has thus far been obtained in that investigation.

No attempt has yet been made to produce liquid fuels from the kelp feedstocks, but such processes appear readily achievable.

OCEAN FARM PROJECT

SOME RESULTS ACHIEVED BY THE INSTITUTE OF GAS TECHNOLOGY

FEED TYPE	MOISTURE (% FRESH WT.)	VOL. SOLIDS (% TOT. SOL. WT.)	ASH (% TOT. SOL. WT.)
RAW KELP	89.7	54.2	45.7
PRESS CAKE	75.8	72.7	26.3
JUICE	93.6	26.7	74.5

Final report on Navy contract N00123-76-C-0271.

Figure 8

OCEAN FARM PROJECT

SOME RESULTS ACHIEVED BY THE INSTITUTE OF GAS TECHNOLOGY

	ELEMENTS (% TOTAL SOLIDS WEIGHT)								ENERGY
FEED TYPE	C	N	P	S	H	Ca	Na	K	(Btu/lb SOLIDS)
RAW KELP	26.1	2.56	0.49	1.09	3.69	1.05	4.3	14.4	4409
PRESS CAKE	36.1	3.34	0.46	0.88	4.64	3.20	1.8	6.4	6059
JUICE	10.2	1.12	0.34	1.16	1.90	2.00	6.8	24.5	1584

Final report on Navy contract N00123-76-C-0271.

Figure 9

OCEAN FARM PROJECT

SOME RESULTS ACHIEVED BY
THE INSTITUTE OF GAS TECHNOLOGY

"... THERE WAS NO MAJOR NUTRITIONAL DEFICIENCY IN ANY OF [THE KELP] FEEDS. SO, BARRING ANY TOXICITY PROBLEMS [NONE WAS ENCOUNTERED] THESE FEEDS WOULD BE EXPECTED TO PROMOTE ANAEROBIC DIGESTION WITHOUT THE ADDITION OF EXTERNAL NUTRIENTS."

Final report on Navy contract N00123-76-C-0271.

Figure 10

OCEAN FARM PROJECT

SOME RESULTS ACHIEVED BY THE INSTITUTE OF GAS TECHNOLOGY

ANAEROBIC DIGESTER FEED TYPE	FEED ENERGY (Btu/lb SOLIDS)	MOISTURE IN FEED	ENERGY OUT (CH_4) ÷ ENERGY IN FEED	DETENTION TIME(DAYS)
RAW KELP	4409	89.6%	52.7%	18
PRESS CAKE	6059	74.5%	42.6%	18
80/20 PC/JUICE			49.4%	18
60/40 PC/JUICE			47.1%	18

Final report on Navy contract N00123-76-C-0271.

Figure 11

OCEAN FARM PROJECT

SOME RESULTS ACHIEVED BY THE INSTITUTE OF GAS TECHNOLOGY

"IT IS POSSIBLE TO ACCLIMATE MESOPHILIC METHANE ORGANISMS TO [DIGESTER] SALT CONCENTRATIONS EQUIVALENT TO ABOUT 40,000 mg/l OF NaCl [SEAWATER ≐ 35,000 mg/l]. HOWEVER, . . . INHIBITION . . . MAY BEGIN AT . . . ABOUT 30,000 mg/l OF NaCl."

Final report on Navy contract N00123-76-C-0271.

Figure 12

REFERENCES

1. Sellers, W. D., Physical Climatology, University of Chicago Press, 1965, p. 23.
2. Govindjee, Encyclopedia of Science and Technology, McGraw-Hill, New York, Vol. 10, 1971, p. 203.
3. Bardach, J., Harvest of the Sea, Harper and Row, New York, 1968, pp. 178 ff.
4. Wilcox, H. A., "The Ocean Food and Energy Farm," paper presented to AAAS, New York, NY, Jan. 29, 1975.
5. Jackson, G. S., and North, W. J., "Concerning the Selection of Seaweeds for Marine Farms," Naval Weapons Center, China Lake, California, 1973.
6. North, W. J., Annual Progress Report, Kelp Habitat Improvement Project, 1972-1973, California Institute of Technology.
7. North, W. J., The Biology of Giant Kelp Beds (Macrocystis) in California, J. Cramer, Lehre, Germany, 1971.