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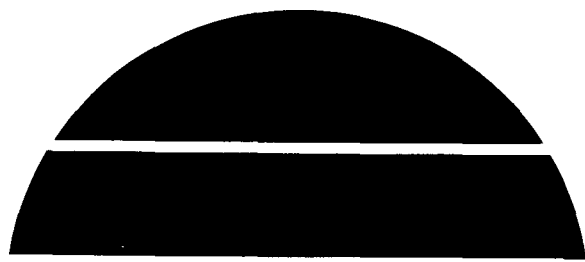
OCEAN THERMAL ENERGY CONVERSION MISSION ANALYSIS STUDY
PHASE I

Volume 2. Appendices to Final Report

June 1977

Work Performed Under Contract No. EX-76-C-01-2421

General Electric Company—Tempo
Center for Advanced Studies
Washington, D. C.



MASTER

U.S. Department of Energy

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Solar Energy

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MISSION ANALYSIS STUDY
PHASE I
VOLUME II
APPENDICES TO FINAL REPORT

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PREPARED FOR:
U.S. ENERGY R&D ADMINISTRATION
DIVISION OF SOLAR ENERGY

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TABLE OF CONTENTS

	<u>Page</u>
APPENDIX A - MISSION SELECTION CRITERIA	A-1
APPENDIX B - MARKET AND PROCESS DATA ON POTENTIAL OTEC PRODUCTS	B-1
APPENDIX C - EFFECT OF PARAMETER ASSUMPTIONS ON OTEC DELIVERED POWER COSTS	C-1
APPENDIX D - BACKGROUND ON OCEAN FARMING	D-1
APPENDIX E - COST REDUCTION TREND PROJECTION METHODOLOGY	E-1
APPENDIX F - BACKGROUND ON POLITICAL AND INSTITUTIONAL FACTORS	F-1
APPENDIX G - OTEC FINANCING WITH MARITIME SUBSIDY	G-1
REFERENCES	

APPENDIX A

MISSION SELECTION CRITERIA

Underlying selection to the list of candidate process applications is a set of criteria representing varied and often conflicting objectives of new energy technology programs. While acceptance of potential economic competitiveness is the prerequisite for commercialization of a concept, it is also apparent that the uncertainty involved in predicting this characteristic offers the opportunity for injecting other criteria which, though valid, are difficult to put in economic terms. Among these (See Table A-1) are: electrical energy intensiveness, conservation of scarce materials for use in applications where they are more critically needed, the consequent implications for strategic self-sufficiency in critical raw materials, criteria associated with environmental compatibility, and the virtually unquantifiable concepts of conducting industrial activities in a politically, institutionally, and environmentally acceptable way.

In seeking the central elements of clusters of related criteria, the three with which this investigation was begun remain appropriate: economics, energy, and the ocean environment.

Many of the energy and ocean criteria expand upon the first cluster: economic viability. In the economic cluster, emphasis is properly put on differences between conventional and OTEC supported processes, since it is this comparison which to a great extent determines whether the OTEC process can "go". The main differential elements, especially when different processes are considered, are the costs of energy, labor, process plant equipment, real estate or ocean platform, logistics, and methods of financing. These are the criteria used in the evaluation of the mission candidates as explained in the text.

Under the heading of energy are measures of gross as well as electrical energy intensiveness of the process (in both its conventional and OTEC

TABLE A-1
Initial Screening Criteria
for Product/Process Applicability
in OTEC Context

ECONOMIC CRITERIA

- POTENTIALLY COMPETITIVE
- EFFICIENT TRANSMISSION OR TRANSPORT
- EFFICIENT SITING RE: MARKETS, MATERIALS

ENERGY CRITERIA

- ENERGY INTENSIVE - ESPECIALLY ELECTRICAL ENERGY
- LARGE DEMAND
- CONSERVES SCARCE FEEDSTOCKS
- ENHANCES NATIONAL SELF-SUFFICIENCY
- NOT LABOR INTENSIVE

OCEAN CRITERIA

- COMPATIBLE WITH OCEAN ENVIRONMENT
- EXPLOITS OCEAN RESOURCES

supported forms), the absolute magnitude of its energy demand and the projected growth rate of that magnitude, and the degree to which the OTEC candidate contributes to a net energy reduction or fuel and feedstock conservation per unit of product.

In the area of ocean-related criteria are found two clusters: aspects of environmental compatibility (platform stability, physical isolation, salt spray environment, etc.) and the engineering oriented issues of efficient utilization of ocean resources.

These criteria were used in the screening and selection of missions as described in Section I.

APPENDIX B
MARKET AND PROCESS DATA
ON POTENTIAL OTEC PRODUCTS

Because information was needed on the demand and the energy requirements of production of many of the potential products proposed for OTEC systems, a survey of the processes that are presently in use in industry and the projections for future demand for these products was made. The information appears to be generally useful in the overall evaluation of OTEC missions; and as a result, is included here. Table B-1 lists the products considered and presents the estimates of demand for these products in ten-year increments from 1990 through the year 2020.

The pages following Table B-1 contain brief descriptions of the specific products listed in B-1. These descriptions are listed alphabetically. The format for this descriptive material is as follows:

- The first page contains a brief summary of the energy use in production by present (non-OTEC) processes, identifies substitutes, and gives a summary of the demand through the year 2020 with low and high estimates for the year 2000.
- The following page or pages contain a description of the market and its behavior.

Incremental Demand
(1000 short tons)

	1990-1999	2000-2009		2010-2020	
	Increment	Increment	Cumulative	Increment	Cumulative
SEA CHEMICALS					
Chlorine	14,223	23,394	37,617	43,483	81,100
Magnesium	831	1,173	2,004	1,856	3,860
Sodium Sulfate	3,001	4,034	7,035	6,058	13,093
Bromine	181	268	449	453	902
Potash	2,909	3,872	6,781	5,755	12,536
Nitrogen (Fixed)	7,228	9,713	16,941	14,586	31,527
Phosphate	17,040	22,855	39,895	34,244	74,139
INDUSTRIAL CHEMICALS AND PLASTICS					
Hydrogen	17,972	34,048	52,020	73,516	125,536
Oxygen	25,112	41,287	66,399	76,707	143,106
Nitrogen (elemental)	4,631	6,224	10,855	9,344	20,199
Methanol	3,857	8,330	12,187	20,668	32,855
Ethylene	31,612	62,189	93,801	139,761	233,562
Vinyl Chloride	14,382	34,053	48,435	93,187	141,622
Acetylene	0	0		0	
METALS					
Aluminum	7,488	12,051	19,539	21,862	41,401
Iron and Steel	22,260	25,164	47,424	31,427	78,851
Titanium	491	662	1,153	998	2,151
Manganese	230	268	498	349	847

Table B-1.
Summary of Demand for
Potential OTEC Products.

ALUMINUM

Energy Use:

The energy required to produce 1 short ton of primary aluminum metal in the United States from imported bauxite is within the 202-278 million BTU range as shown below.

Bauxite, Caribbean or South America, 4-5 short tons	million BTU 3 - 8
Alumina, from Caribbean or South American Bauxite, 1.9-1.95 short tons	29 - 44
Primary Metal, prebaked or Soderberg anodes, 1 short ton	65 - 86
Total energy	97-138
Total energy if electricity for reduction of alumina is thermally generated at 30 percent efficiency	202 - 278

About 6 million to 25 million BTU is required to recover 1 ton of aluminum from aluminum base scrap.

Substitutes:

Copper, steel, wood, zinc, magnesium, titanium, and plastics are a few of the materials that could be substituted for aluminum in some of its applications.

Substitution almost invariably requires new types of manufacturing equipment or major modifications of existing equipment; and over the long term, the substitute material must offer rather decisive advantages in costs and performance to justify the cost of adopting a manufacturing process.

Demand Outlook:

Summary of Forecasts of Annual Demand

(1000 short tons)

	1973	1985	2000			2020	
			LOW	BASE	HIGH		GROWTH %
United States	5,783	10,500	15,000	20,800	27,000	55,197	4.8
Rest of World	10,607	22,000	27,500	45,300	53,000	137,385	5.5
Total	16,390	32,500	42,500	66,100	80,000	192,582	5.4

Consumption:

Measured either in quantity or value, aluminum use exceeds that of any other metal except iron. It is used to some extent in virtually all segments of the world economy, but principal markets have been developed in six major industries:

construction	27%
transportation	21%
containers and packaging	15%
electrical	14%
consumer durables	10%
mechanical equipment	7%

The United States has long been the leading world consumer of aluminum, but its share of world demand has decreased from 40 percent in 1964 to 36 percent in 1974. In 1974, in decreasing order of consumption, the USSR, Japan, West Germany, the United Kingdom, France, and Italy were the next largest consumers.

Domestic demand for primary aluminum from 1964 to 1974 increased at an average annual rate of 7.4 percent. The largest growth rate was in demand for aluminum cans and containers and for refractories.

Recent developments in aluminum technology and increase in energy costs foreshadow increased use of aluminum in transportation and machinery. Moreover, the price differential between aluminum and copper for electrical applications is expected to continue to favor the use of aluminum as an electrical conductor.

Notwithstanding, aluminum growth is expected to decline. The annual average growth rate of 5.1 percent from 1973 compared with the 11-year trend of growth of about 8.1 percent per year during 1964-74.

After 1985, the growth rate is expected to slow further to about 4.5 percent per year for the remainder of the century, averaging 4.8 percent per year for 1973 to 2000.

The growth rate in less developed countries in Africa, Asia, and South America is expected to be considerably higher than that in industrialized countries.

Production:

Of the major primary aluminum-producing countries, only France and the USSR produce a major portion of their ore requirements. The other principal aluminum producers, including the United States, rely mostly on imported bauxite or alumina.

About 40% of the world's bauxite is mined in Jamaica, Surinam, and Guyana. Australia (the world's largest producer), Guinea, and the USSR accounted for an additional 40 percent. Greece, France, Hungary, and Yugoslavia also produced significant quantities.

Bauxite reserves in the United States are equivalent to only 2 or 3 years consumption. Most of these reserves have been apportioned for use in two alumina plants in Arkansas and cannot be used efficiently in other existing alumina plants.

In 1974, the United States was the leading producer of primary aluminum metal, accounting for 34 percent of the world total. Other producing countries include the USSR (11%), Japan (8%), Canada (8%), West Germany (5%), and Norway (5%).

The aluminum industry is highly concentrated. Over 40 percent of the world productive capacity for bauxite plus over half of the world alumina and aluminum capacity is operated by six corporate groups:

Alcan Aluminum Ltd.
Aluminum Company of America (Alcoa)
Reynolds Metal Company
Kaiser Aluminum and Chemical Corporation
Pechiney Ugine Kuhlmann Group
Swiss Aluminum Ltd.

Of the 12 domestic firms producing primary aluminum metal in the United States in 1975, 3 accounted for 67 percent of production capacity. Alcoa and Reynolds were integrated from domestic mines through the primary metal stage.

Price:

	<u>Average Annual Price</u>	
	(dollars/pound)	
	current dollars	constant 1973 dollars
1973	.25	.25
1974	.34	.31
1975	.40	.33

These prices are the annual average of major producers' prices for unalloyed primary aluminum ingot quoted by the American Metal Market.

In April 1976, some domestic producers announced a 3 cent per pound increase in the price of unalloyed ingot and a range of \$.41 to \$.44 per pound was quoted.

Imports/Exports:

Almost 90 percent of the domestic supply of aluminum raw materials is imported. Domestic reserves of bauxite are small relative to aluminum demand and are more difficult to process than foreign bauxite.

Although domestic bauxite mines could be expanded moderately, only 2 domestic alumina plants are designed to process the high-silica domestic bauxites efficiently. Hence, both the short-term and long-range strategic positions of the United States with respect to aluminum is vulnerable to political and economic actions in other countries.

During 1964-74 the United States produced 93 percent of the primary aluminum metal it consumed. However, an increasing proportion of domestic demand for primary aluminum metal probably will be met by imports of metal from countries with low-cost electric energy.

Environmental Considerations:

High flourine concentrations in the aluminum reduction plants or in the area immediately surrounding the plants can be a potential hazard to foliage and animal life, and most areas require that flourine emissions be kept below certain levels.

Sources: Bureau of Mines, Mineral Facts and Problems, 1975 Edition.

_____, Mineral Industry Surveys

Stanford Research Institute, World Mineral Availability, 1975-2000.

Merner, Peter, "Aluminum: Focus on Overseas Transaction Prices and on the Likely Supply and Demand Balance in the Free World Through 1978". April, 1976.

BROMINE

Energy Use:

Energy in all forms required to produce one pound of bromine (excluding the energy in raw materials, such as chlorine) was found to be about 5.08 KWHR, or 17,300 BTU.

Process Feedstock: Cl_2 , Air

Process Co-Product: Sodium sulfate

Substitutes: The chemical properties of Chlorine and Iodine are similar to those of Bromine, and these elements are sometimes substituted for Bromine, particularly as sanitizing and disinfecting agents.

Ethylene dichloride is used along with ethylene dibromide as a lead scavenger in gasoline.

Demand Outlook:

Summary of Forecasts of Annual Demand (1000 Short Tons)

	1973	1985	2000			2020	
			LOW	BASE	HIGH		GROWTH %
United States	186	303	340	555	775	1,239	4.1
Rest of World	120	243	350	583	650	1,871	6.0
Total	307	546	690	1,138	1,425	3,111	5.0

Consumption:

Bromine is consumed in the manufacture of:

Ethylene dibromide	71%
Fire retardants	15%
Sanitation preparations	10%

Production:

The United States produced two-thirds of world Bromine output. The top three U.S. manufacturers accounted for over 82% of this U.S. total. Among these three, Dow Chemical was the leader. Other major U.S. producers include:

Arkansas Chemicals (Arkansas)
Ethyl Corp. (Arkansas)
Dow Chemical (Arkansas, Michigan)
Great Lakes Chemical Corp. (Arkansas)
Michigan Chemical Corp. (Arkansas, Michigan)
Morton Chemical Co. (Michigan)
Kerr-McGee Chemical Corp. (California)

All new U.S. installations for Bromine production are expected to be located in the Arkansas area to take advantage of the high Bromine concentrations there.

Other major Bromine-producing nations in the order of production are: the United Kingdom, Israel, France, the U.S.S.R., and Japan.

Price:

Average Annual Price (Cents/Pound)

	<u>Actual Prices</u>	<u>Constant 1973 Dollars</u>
1973	16.05	16.05
1974	27.24	24.70

The price of bromine declined steadily over the past 20 years (on a constant dollar basis) because of improved raw materials and improved extraction efficiency, but increased sharply in 1974. While future trends are uncertain, the price of bromine is expected to remain steady or decline slightly until the end of the Century.

Imports-Exports:

Imports of bromine compounds into the U.S. are trivial, whereas exports are large and are increasing year by year. The export tonnage for 1974 was estimated at 16 percent of U.S. production.

Sources:

U.S. Department of Interior, Bureau of Mines, Mineral Facts and Problems, 1975 Edition.

"Mineral Industry Surveys"

Chemical Marketing Reporter

CHLORINE

Energy Use:

Chlorine production represents the largest single industrial consumption of electricity amounting to approximately 2% of the total domestic consumption. In 1973, the total energy requirement exceeded 398.6 trillion BTU. With conventional electrolytic cells, about 2,700 kilowatt hours of electric power are required for each ton of chlorine produced.

Process Feedstock: Brine, NaCl

Process Co-Product: Sodim Sulfate

Substitutes: Bromine or iodine may sometimes be substituted for chlorine as a sanitizing agent.

Demand Outlook:

Summary of Forecasts of Annual Demand
(1000 Short Tons)

	1973	1985	2000			2020	
			LOW	BASE	HIGH		GROWTH %
United States	10,340	18,900	27,300	39,500	46,000	106,819	5.1
Rest of World	18,266	33,900	55,000	73,700	80,000	203,110	5.2
Total	28,606	52,800	82,300	113,200	126,000	309,929	5.2

Consumption:

Percentage of chlorine output used in the manufacture of:

Chemicals	33%
Plastics (Vinyl Chloride)	22%
Pulp and Paper	18%
Chlorination of Drinking Water and Sewage	6%
Pesticides - Germicides	5%
Other	16%

Production:

In 1975, 35 companies operated 67 plants in 23 states of the U.S. Fifty-eight percent of these plants were located east of the Mississippi River while Texas and Louisiana accounted for 28%. The leading producers are listed below.

<u>Producer</u>	<u>Capacity</u> (Tons/day)	<u>Producer</u>	<u>Capacity</u> (Tons/day)
Alcoa	470	Monsanto	250
Allied	1,650	Olin	1,625
Diamond Shamrock	2,000	Pennualt	950
Dow	10,000	PPG	3,330
du Pont	940	Shell	375
Ethyl	640	Sobin	310
FMC	790	Stauffer	980
Goodrich	300	Vulcan	375
Hooker	1,780	Syandott	1,550
Kaiser	535	Paper Co.	690
Linden Chlorine	460	Other	1,180
Mobay	200	Total	31,480

Price:

Average Annual Price

(\$/short ton)

	<u>Actual Prices</u>	<u>Constant 1973 Dollars</u>
1973	75	75
1974	100	90.66
1975	129	108.14

Prices are quoted on a freight-equalized basis. The F.O.B. prices should be about 60 percent of the published prices. Higher costs of electricity, caused by diminishing supply of fuels for power generation contributed to higher prices of chlorine in 1974 and 1975, and will probably continue to do so in the future.

Imports/Exports: International trade is minimal.

Environmental:

EPA has affected chlorine production directly in its regulations regarding chlorine plants and indirectly in regulations pertaining to finished products that contain chlorine. Production of chlorinated solvents has slackened considerably because of strict environmental regulations.

Sources: U.S. Department of Interior, Bureau of Mines,
Mineral Facts and Problems, 1975 Edition.

Chemical Marketing Reporter.

ETHYLENE

Energy Use:

The energy requirement when naphtha is used as feed is 40.38 MM BTU per ton ethylene of which less than 2% is electrical. In 1973, total energy consumption amounted to 1460.3 trillion BTU.

Sixty-one percent of 1973 energy usage in the production of ethylene occurred in Texas and 23% of the ethylene energy usage was in Louisiana.

Process Feedstock:

Ethylene producers have their choice of three types of feedstocks: ethane, propane, and the heavier hydrocarbons such as butane, naphtha, and gas oil. The primary determinant of feedstock use is availability. The heavier feedstocks produce substantial amounts of byproducts such as butadiene, propylene, and aromatics.

Demand Outlook:

Summary of Forecasts of Annual Demand (1000 short tons)

	1973	1985	2000			2020	
			LOW	BASE	HIGH		GROWTH %
United States	12,678	24,939	42,932	68,795	109,323	266,214	7.0
Rest of World	11,135	21,904	37,707	60,440	96,018	233,884	7.0
Total	23,813	46,843	80,639	129,235	205,341	500,098	7.0

Consumption:

Ethylene oxide is consumed in the manufacture of:

ethylene glycol	60%
nonionic surface agents	11%
diethylene glycol	7%
glycol etheis	7%
ethanolamines	6%
triethylene glycol	2%
polyethylene glycol	1%
other	6%

Production:

For 1973, ethylene value of shipments amounted to \$183.2 million.

Major ethylene oxide producers in the United States are listed.

<u>Producer</u>	<u>Capacity</u> <u>(thousand tons/years)</u>
Union Carbide	895
Jefferson Chemical	250
Dow Chemical	250
Others	1,032
Total	<u>2,377</u>

Ethylene plants are large, with an average capacity of 560 million pounds per year. The new plants being built are even larger, with the usual capacity being 1 billion pounds per year. The size of the ethylene plants varies greatly from a 75 million pound annual capacity to 1.5 billion pound annual capacity.

Sources: Chemical Marketing Reporter

International Research and Technology Corporation, Energy Study of the Industrial Chemicals Group.

Horburg, Lindal, El-Ramly, Preliminary Research on Ocean Energy Industrial Complexes: Phase I.

HYDROGEN

Energy Use:

Hydrogen is produced mainly as a byproduct of other products, such as chlorine, ethylene, acetylene, and refinery operations. In addition to these byproduct sources, there are two important processes for making hydrogen. The partial oxidation process, widely used in refineries, appears to be less significant in producing hydrogen than steam hydration. The steam hydration process requires a significant amount of energy on a unit basis, about 180 million BTU per ton.

Process Feedstock: Water

Process Co-Product: Oxygen

Substitutes:

There is no substitute for hydrogen in the production of synthetic anhydrous ammonia, and methanol.

Demand Outlook:

Summary of Forecasts of Annual Demand (1000 short tons)

	1973	1985	2000			2020	
			LOW	BASE	HIGH		GROWTH %
United States	7,233	12,206	24,721	40,593	78,659	145,747	6.6
Rest of World	13,484	24,440	37,644	59,275	119,393	175,809	5.6
Total	20,717	36,646	62,365	99,868	198,052	321,556	6.0

Consumption and Production:

Ninety-nine percent of hydrogen production is captive.

The principal end uses of hydrogen in 2000 are expected to be in synthetic fuel processing, chemicals, and petroleum refining:

synthetic anhydrous ammonia	41%
oil refining industry	41%
methanol manufacturers	10%
food processing	3%

Between 70,000 and 80,000 cubic feet of hydrogen are required to produce one short tone of synthetic anhydrous ammonia, including the amount that does not react to form ammonia.

Selling prices of hydrogen decrease rapidly up to capacities of about 20 million cubic feet per day.

Transportation and storage costs are significant in the merchant hydrogen industry but are of less importance with respect to captively produced hydrogen.

Arab and some Latin American countries will probably develop or expand iron and steel industries based on hydrogen and natural gas far more quickly than developed countries with investments in older techniques.

Price:

Average Annual Price (cents/1000 standard cubic feet)

	captive		merchant	
	actual price	constant 1973 cents	high purity	low purity
1973	30	30	492	80
1974	40	36.27	760	98
1975	60	49.96	N/A	N/A

A reversal of the declining historical price trend is occurring due to the abrupt increases in the price of natural gas, the prime raw material for producing hydrogen. Moreover, the impact of sharp rises in the price of crude oil is already noticeable in the prices of naphtha and residual fuel oil, prime hydrogen feedstocks.

IRON AND STEEL

Energy Use:

836 KWH of electricity are consumed in the manufacture of a ton of steel. In addition, 25,760,000 BTU of thermal energy are also required.

Substitutes:

There are satisfactory substitutes for steel in most of its applications, but few do the job as well as steel. Among the nonferrous metals, aluminum, copper, titanium, zirconium, and beryllium often can be used in place of steel. Among non metallic materials, wood, plastics, fiberboard, glass and graphite are steel substitutes.

Demand Outlook:

Summary of Forecasts of Annual Demand

(1000 short tons)

	1973	1985	2000			2020	
			LOW	BASE	HIGH		GROWTH %
United States	142,500	165,000	182,000	198,000	246,000	271,981	1.6
Rest of World	543,800	775,000	1,100,000	1,210,000	1,500,000	2,185,530	3.0
Total	686,300	940,000	1,282,000	1,408,000	1,746,000	2,457,511	2.8

Consumption:

The uses of iron and steel can be divided into three categories—structural members, coverings, and mechanical elements. Considering as structural members, the supporting parts of automobiles, rail in railroads, and the frames of aircraft, ships, and commercial and electrical equipment, the principal use of steel is for its strength in structural frames. Its use in machine elements probably ranks second, closely followed by its use as a covering or in containers in which the strength is inherent in the skin or shell.

Production:

More than 75% of the world's iron and steel is produced in the United States, Japan, the Soviet Union, and the European Coal and Steel Community.

The steel industry of the United States is composed of approximately 175 companies which produce a wide range of steel mill products. Most of the steel industry of the United States is in the industrial complex surrounding the lower Great Lakes ports in Illinois, Indiana, Michigan, Ohio and western Pennsylvania.

The high capital cost of integrated steel plants has made the smaller scrap melting electric furnace plants more economic. The minimum economic size is 50,000 tons per year.

For large volume, economies of scale favor the fully integrated, blast furnace-basic oxygen furnace combination.

Most of the changes foreseen in the world supply-demand relationship concern broadening of the supply base by producers in Brazil, Venezuela, Canada, and Australia.

The oil-rich countries in the Middle East may become large producers of steel, and some of the monetary resources they are accumulating may be used to build steel plants in other countries. A worldwide increase in the demand for iron and steel products is anticipated; the market is expected to be both broader and larger.

Price:

	<u>Average Annual Price</u>	
	(cents/pound)	
	actual price	constant 1973 cents
1973	9.380	9.380
1974	11.217	10.170

Steel prices were raised approximately 10% during 1975 based on the Iron Age finished steel composite price which is a rated index of prices

quoted for bars, shapes, pipes, wire, rails, black pipe, hot- and cold-rolled sheets, and strip. The composite price at the beginning of the year was 12.5 cents per pound. It increased erratically until June when it was 12.891 cents per pound, and in the last quarter reached 13.7 cents per pound.

Imports/Exports:

In 1974-75, U.S. exports of steel mill products ranged from a low of 1,685,000 tons in 1967 to a high of 7,057,000 tons in 1970. Exports in 1974 totalled 5.8 million tons. In 1969-73, exports trended sharply downward until 1972 and then reversed sharply as the U.S. dollar was devalued and the domestic steel industry again became price competitive.

U.S. exports of steel mill products in 2000 are forecast to range between 2 and 10 million tons with a probable figure of 6 million tons.

Environmental Considerations:

Steel mills and foundries inherently present a wide variety of environmental problems. In operation, they produce solid waste, excess liquids, gases, and noise all of which must be controlled to prevent pollution. Slags from the iron and steel making furnaces, flue dust and mill scale are the principal solid wastes.

Among the liquids, water, sulfuric acid, hydrochloric acid, pickle liquids, and oils and greases all present environmental problems if not properly handled.

Effluents from steel mills may contain zinc, manganese, lead, and nitrates, and may be acidic or caustic.

Sources: Bureau of Mines, Mineral Facts and Problems, 1975 Edition.

_____, Mineral Industry Surveys.

U.S. House of Representatives, Committee on Science and Astronautics, Subcommittee on Energy, Energy Facts, 1973.

MAGNESIUM

Energy Use:

Approximately 20,000 kilowatt hours are required to produce a ton of magnesium from ore. Magnesium produced from seawater is considerably more energy intensive requiring, roughly 90,000 kilowatt hours per ton of product.

Process Feedstock: Seawater

Process Co-Products: sodium sulfate, sodium chloride, magnesium chloride, potash,

Substitutes:

Aluminum and zinc can be substituted for magnesium in many die casting applications. Sodium as well as magnesium are used to reduce titanium tetrachloride to produce titanium metal. Depending upon requirements, some of the following materials may be used in magnesia refractories: Alumina, Zirconia, Chromite and Kyanite.

Demand Outlook:

Summary of Forecasts of Annual Demand (1000 short tons)

	1973	1985	2000		2020		
			LOW	BASE	HIGH		GROWTH %
United States	1,159	1,750	1,740	2,945	3,540	5,860	3.5
Rest of World	4,475	5,950	5,730	8,505	9,450	13,670	2.4
Total	5,634	7,700	7,470	11,450	12,990	19,530	2.7

Consumption:

About 90% of the magnesium consumed in the U.S. is in non-metallic applications, with the remainder consumed as metal. Magnesium minerals are the lowest cost, high temperature refractories available to the metallurgical industry and their use should increase in proportion to the growth in production of iron and steel.

Production:

Magnesium compounds are produced by eight companies from seawater in California, Delaware, Florida, Mississippi, New Jersey, and Texas; by four companies from well brines in Michigan, and by two companies from brines of the Great Salt Lake in Utah.

The leading producers are:

magnesium compounds from seawater

Basic Magnesia, Inc.
Barcroft Co.
Dow Chemical Co.
Corhart Refractories Co.
F.M.C. Corporation
Harbison-Walker Refractories
Kaiser Aluminum and Chemical Corp.
Merck Co.

magnesium compounds from lake and well brines

Dow Chemical Co.
Great Salt Lake Minerals and Chemicals Corp.
Kaiser Aluminum and Chemical Corp.
Morton Chemical Co.

primary magnesium metal

American Magnesium Co. (Texas)
Dow Chemical (Texas)
N.L. Industries (Utah)
Northwest Alloys (Washington)

Price:

Average Annual Price

	metal (cents/pound)		non-metal (\$/ short ton)	
	actual	1973 constant cents	actual	1973 constant \$
1973	38.25	38.25	85.40	85.40
1974	41.25-75	37.40-68	99.90	90.57

Imports/Exports:

U.S. imports of magnesium in compounds of 115,000 tons in 1973, as in previous years, were primarily from Greece. The U.S. exported 40,000 tons of metal and continued to be a net exporter of metal.

Sources: Bureau of Mines, Mineral Facts and Problems, 1975 Edition.

_____, Mineral Industry Survey.

MANGANESE

Energy Use:

Approximately 13,000 kilowatt hours of energy are consumed per ton of manganese product.

Substitutes:

Manganese is essential for the production of virtually all steels. There are no satisfactory substitutes for this purpose. Manganese also is important in the production of aluminum and cast iron.

Demand Outlook:

Summary of Forecasts of Annual Demand (1000 short tons)

	1973	1985	2000			2020	
			LOW	BASE	HIGH		GROWTH %
United States	1,554	1,680	1,960	2,130	2,700	2,925	1.6
Rest of World	9,184	13,100	18,500	20,400	25,400	36,846	3.0
Total	10,738	14,780	20,460	22,530	28,100	39,771	2.8

Consumption:

The principal use of manganese is for the production of iron and steel, and its demand for this purpose far exceeds all other demands.

The three principal domestic consumers of manganese ore have consisted of the country's two largest steel companies and its largest producer of ferroalloys and dry cell batteries.

Other industries which consume manganese products include: construction, transportation, machinery, cans and containers, appliances and equipment, oil and gas, chemicals, and batteries.

Production:

World production of 10.7 million tons (contained manganese) came from many countries, but the USSR, the Republic of South Africa, Brazil, Gabon, Australia, India, and the People's Republic of China were the largest producers.

There is currently no domestic manganese ore producing industry and the few domestic producers of manganiferous ores are usually considered a part of the iron ore industry.

The domestic manganese ferroalloy plants are located east of the Mississippi River except for one plant in Houston, Texas, and one in Portland, Oregon; the spiegeleisen plant is in Pennsylvania, and metal plants are in Mississippi, Ohio and Tennessee.

Environmental considerations at manganese ferroalloy plants have entailed numerous adjustments and large capital expenditures for pollution control measures. Energy costs and availability have become problems also.

Price:

	<u>Average Annual Price</u> (dollars/ton)	
	<u>actual prices</u>	<u>constant 1973 dollars</u>
1973	.65	.65
1974	.90	.82

Published quotations only reflect the general condition of the market.

All manganese ore prices are negotiated, dependent on such variable factors as chemical analysis, physical character, delivery terms, freight rates, insurance, inclusion or exclusion of export and/or import duties, and the general availability of the ores of the desired quality.

Imports/Exports:

Brazil and Gabon supplied 2/3 of total U.S. ore imports with the remainder originating in six other countries.

In addition, imports of manganese contained in alloys and metal were supplied by the Republic of South Africa, France, Norway, India, and Japan.

Sources: Bureau of Mines, Mineral Facts and Problems, 1975 Edition.

House Subcommittee on Energy, Energy Facts, 1973.

METHANOL

Energy Use:

In 1973, total energy input for methanol production amounted to 126.07 trillion BTU's. Of this, 63 percent was used for methanol production in Texas, while production of methanol in Louisiana accounted for another 33 percent.

Process Feedstock: naphtha or natural gas

Demand Outlook:

Summary of Forecasts of Annual Demand (million gallons)

	1973	1985	2000			2020	
			LOW	BASE	HIGH		GROWTH %
United States	1,134	2,448	4,866	7,755	12,286	36,145	8.0
Rest of World	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Consumption:

Methanol is consumed in the manufacture of:

formaldehyde	45%
solvents	10%
DMT	7%
other	38%

Production:

Methanol may be produced by two methods — a high pressure process which uses naphtha as feedstock and a low pressure process which requires no naphtha.

Due to shortages of naphtha and natural gas, ninety six percent of the plants built since 1971 have been designed to use the low pressure system.

Major methanol suppliers and production capacity are listed below.

<u>Producer</u>	<u>Capacity</u> <u>(million gallons/year)</u>
du Pont	300
Celanese	280
Borden	160
Monsanto	100
Georgia Pacific	100
Hercules	100
Tenneco	80
CSC	50
Air Products	50
Rohm and Haas	22
Total	<u>1,242</u>

Sources: Chemical Marketing Reporter

International Research and Technology Corporation,
Energy Study of the Industrial Chemicals Group.

Hornburg, Lindal, El-Ramly, Preliminary Research on
Ocean Energy Industrial Complexes: Phase 1.

NITROGEN (ELEMENTAL)

Energy Use:

The manufacture of gaseous nitrogen required 8.5 trillion BTU's in 1971.

Process Feedstock: Air, negligible quantity of caustic soda.

Process Co-Product: Oxygen

Substitutes: Other classes of inert gases could serve almost as well as elemental nitrogen. Some of these are more expensive, such as argon for blanketing metals and chemicals, others are less effective, such as carbon dioxide for refrigeration. But since nitrogen is so abundantly available everywhere, it should continue to be used in growing quantities for the jobs it does so well.

Demand Outlook:

Summary of Forecasts of Annual Demand (1000 short tons)

	1973	1985	2000			2020	
			LOW	BASE	HIGH		GROWTH %
United States	8,171	12,000	14,000	18,000	24,000	32,510	3.0
Rest of World	38,400	58,000	66,000	97,000	110,000	193,064	3.5
Total	46,571	70,000	80,000	115,000	134,000	225,574	3.4

Consumption:

Elemental nitrogen consumption is distributed roughly as follows:

chemicals	56%
food products	17%
electronic components	7%
nonferrous metal	2%

Thirteen percent of nitrogen production was consumed captively.

Demand for elemental nitrogen is expected to grow more rapidly in electronics uses and refrigeration of food than in chemicals, which are already the major consumer. Low temperature scrap processing should require increasing quantities of liquid nitrogen. Markets in metal processing, glass and rubber are expected to continue to develop.

Production:

Elemental Nitrogen is a co-product of oxygen; no large plants are operated for nitrogen alone.

The largest producers of elemental nitrogen are those industrial gas companies that are the major producers of oxygen, namely, Union Carbide, Airco, Air Products, Chemetron, Liquid Air, Big Three, Liquid Carbonic and Burdiox.

In 1974, domestic plants numbered 231. The following regions accounted for the greatest concentration of output.

Great Lakes Area (Ohio and Illinois)	44	production plants
Pennsylvania	21	" "
California	13	" "

Price:

Average Annual Price (\$/short ton)

<u>Actual Prices</u>		<u>Constant 1973 Dollars</u>	
<u>Pipeline Gas</u>	<u>Bulk Liquid</u>	<u>Pipeline Gas</u>	<u>Bulk Liquid</u>
1973	7.20	43.07	7.20
1974	9.05	48.24	8.20

The cost of producing elemental nitrogen consists to a large extent of the cost of energy.

Imports/Exports:

Elemental nitrogen production and consumption are confined to the major industrial countries, where the demand exists. These patterns are not expected to change significantly in the foreseeable future.

Sources: Bureau of Mines,
Mineral Facts and Problems, 1975 Edition

FIXED NITROGEN (AMMONIA)

Energy Use:

For one ton of ammonia, about 38,000 cubic feet of natural gas, or the equivalent in other fuels is required. This can be translated into approximately 46,000 cubic feet per ton of nitrogen. In addition, one ton of ammonia also consumes 15 KWH of electrical energy.

In 1973, this total energy requirement amounted to 617.3 trillion BTU.

Process Feedstock: Seawater, hydrogen

Substitutes:

Fixed Nitrogen is one of three major plant nutrients that must be supplied to the soils to maintain fertility.

Demand Outlook:

Summary of Forecasts of Annual Demand

(1000 short tons)

	1973	1985	2000			2020	
			LOW	BASE	HIGH		GROWTH %
United States	13,100	19,000	22,000	29,000	38,000	52,300	3.0
Rest of World	38,400	58,000	66,000	97,000	110,000	193,000	3.5
Total	51,500	77,000	88,000	126,000	148,000	245,400	3.4

Consumption:

Approximately 74% of U.S. production of fixed nitrogen goes into fertilizers. Ammonia, the basic product of the fixed-nitrogen industry, is used in that form by the consumer. However, a large number of secondary products are also manufactured from ammonia. The 13 million tons of fixed nitrogen produced and consumed in the United States in 1974 included, in addition to nitrogen in ammonia, the following estimated quantities in nitrogen-bearing compounds, in thousand short tons.

	gross weight	nitrogen content
acrylonitrile	700	200
ammonium nitrate	7551	2500
ammonium sulfate	2065	400
ammonium phosphate	6829	1200
nitric acid	8186	1700
urea	3687	1600
Total		<u>7600</u>

Production:

Production, distribution, and consumption of fixed nitrogen are phases of a large international business with production at cheap energy sources and consumption at point of need.

Capacity at the beginning of 1975 was over 14.6 million tons of contained nitrogen, or 17.7 million tons of ammonia.

The leading ammonia producers are:

<u>Producer</u>	<u>Capacity (1000 short tons)</u>
C.F. Industries, LA	720
Amoco, Texas	700
Standard, Ohio	500
Union, Alaska	500
Olin, Louisiana	485
Agrico, Oklahoma	425
Monsanto, Louisiana	420
Cominco, Texas	400

By the end of this century, natural gas is expected to be very scarce and ammonia production will have to be based on coal.

Price:

	<u>Average Annual Price</u> (\$/short ton)	
	actual price (quoted)	constant 1973 dollars
1973	65	65
1974	143	130

Imports/Exports:

Fertilizer compounds, including anhydrous and aqua ammonia, ammonium phosphates, and urea, have been the largest items in this trade. The U.S. had a net export surplus of nitrogen from 1966 to 1973, but in 1974 the balance was unfavorable; exports of 994,000 tons of fixed nitrogen were exceeded by the 1.154 million tons of imports.

The future supply of nitrogen in elemental or fixed form is not endangered, but the U.S. may be entering an era of growing dependence for fixed nitrogen on foreign sources that have access to cheap natural gas.

U.S. dependency on foreign fixed nitrogen is likely to increase because of growth in ammonia producing facilities around the world where natural gas is still abundant.

Sources: Bureau of Mines, Mineral Facts and Problems,
1975 Edition

_____, "Mineral Industry Survey"

Stanford Research Institute, Chemical Economics Handbook

OXYGEN

Energy Use:

Average consumption of electrical energy in a plant where gaseous oxygen is the sole product (although nitrogen is also available) is about 1.4 kilowatt hours per 100 cubic feet of product, or about 340 KWH per ton.

Compressing the oxygen to a delivery pressure of 450 psi takes another 1.8 KWH per 100 cubic feet (430 KWH per ton).

Process Co-Product: Nitrogen

Substitutes: There is no substitute for oxygen in any of its uses, and it is not recycled or reclaimed.

Demand Outlook:

Summary of Forecasts of Annual Demand (1000 Short Tons)

	1973	1985	2000			2020	
			LOW	BASE	HIGH		GROWTH %
United States	16,200	32,000	50,000	62,000	230,000	167,666	5.1
Rest of World	38,500	55,000	66,000	86,000	111,000	155,344	3.0
Total	54,700	87,000	116,000	148,000	341,000	323,010	3.9

Consumption:

Tonnage oxygen is consumed by the following industries in the proportions indicated:

Iron and Steel	70%
Chemicals	12%
(acetylene, ethylene oxide, coal gasification)	
Non-ferrous Metals	6%
Metal Fabrication	6%

More than 90% of the steel plants purchase their oxygen from industrial gas companies, and there is a trend toward industrial gas company ownership and operation.

In the future, large increases in the demand for tonnage oxygen may come from waste treatment and coal conversion plants. Gasification of coal to produce medium or high BTU gas, and possibly liquefaction of coal, will demand quantities greater than those presently used by the steel industry. A typical first-generation coal gasification plant using Lurgi or similar technology will need about 6,000 tons of oxygen to produce 250 million cubic feet per day of substitute natural gas (SNG) from about 16,000 tons of coal; this will probably be a typical gasification-plant size.

Production:

Annual growth in the production and consumption of oxygen has been vigorous for the past two decades. For 1954-73, it averaged 16.6 percent. The industry is still in the initial rapid growth stage, and many oxygen applications are on the frontiers of technology. The market is the major factor in the decision of where to locate an air separation plant because of high distribution costs, but energy costs also play a part.

In 1974, 168 establishments in 37 states reported the production of oxygen. Thirty-six plants were located in the East North Central area centered on Chicago, 30 in the Middle Atlantic area, and 31 in the West South Central area around Texas and Oklahoma. Only 5 plants were located in New England, and much merchant oxygen moves into the area.

The eight largest U.S. producers of industrial gases, including oxygen, nitrogen, argon, and other more specialized gases, shipped 79.3 percent of the total in 1974. These industrial gas firms, ranked in approximate order of size are:

Linde Division of Union Carbide Corp.
Airco, Inc.
Air Products and Chemicals, Inc.
Chemetron Corp.
Liquid Air, Inc.
Big Three Industries, Inc.
Liquid Carbonic Corp.
Burdock

Price:

	<u>Average Annual Price</u> (Dollars/Short Ton)	
	<u>Actual Prices</u>	<u>Constant 1973 Dollars</u>
1973	11.22	11.22
1974	15.18	13.76

In current dollars, the price of pipeline oxygen declined from over \$21 per ton to \$11 per ton in the 13 years from 1960 to 1973. In 1974, energy costs contributed to the increased price.

Imports-Exports:

Oxygen cannot be economically transported for great distances, either as a gas or as a liquid; consequently, there are no significant exports or imports.

Sources:

U.S. Department of Interior, Bureau of Mines, Mineral Facts and Problems, 1975 Edition.

PHOSPHATE

Energy Use:

Not much energy needs to be purchased for phosphoric acid manufacture, just electricity for motive power. 0.3 million BTU's are needed in the form of electricity per ton of P_2O_5 in wet process acid. 1.57 trillion BTU's in net electricity were consumed in operations in 1973.

If the energy used in mining the sulfur by the common Frasch process is included, 10.4 million BTU's are required per ton of P_2O_5 in wet process acid.

When higher purity is needed, phosphate rock is converted to elemental phosphorus in an electric furnace before it is made into acid. Although less than 20% of the acid is made by this route, the dry process consumes 14 times as much energy per year as the wet process. This energy is about equally divided between net electricity and coke.

Process Feedstock: phosphate rock, coke, silica, carbon dioxide

Substitutes:

Phosphorus is not recovered by recycling processes, does not have a secondary recovery source, and does not have a substitute in agricultural application. However, efforts have been made to reduce the level of sodium tripolyphosphate in detergents to reduce the eutrophication of receiving streams by substituting other compounds.

Demand Outlook:

Summary of Forecasts of Annual Demand
(1000 short tons)

	1973	1985	2000			2020	
			LOW	BASE	HIGH		GROWTH %
United States	31,233	45,000	53,000	69,000	90,000	124,600	3.0
Rest of World	80,304	162,000	232,000	387,000	499,000	1,241,300	6.0
Total	111,537	207,000	285,000	456,000	589,000	1,365,900	5.5

Consumption:

The agriculture segment dominates the consumption of phosphate rock. With over 84 percent used in agriculture, principally for phosphatic fertilizer production, the remaining 16 percent of the phosphate rock was used to produce elemental phosphorus, electric furnace phosphoric acid, and anhydrous derivatives. These include phosphorus pentoxide, phosphorus pentasulfide, phosphorus trichloride, and phosphorus oxychloride. Principal end uses for furnace phosphoric acid were sodium tripolyphosphate and dicalcium phosphate.

Most of the phosphate rock was used to produce wet-process phosphoric acid, from which the two major phosphatic fertilizers, diammonium phosphate and triple superphosphate, were produced. Animal feed supplements, normal superphosphate, and numerous nitrogen, phosphorus and potassium mixed fertilizers completed the distribution pattern.

The world consumption pattern for phosphate rock was estimated to be similar to the pattern established in the United States. It is probable that the world distribution pattern may have as much as 90 percent of the total allocated for agricultural purposes.

Production:

The United States (39%), the USSR (22%), and Morocco (17%), dominated the world supply of phosphate rock in 1973 and 1974, furnishing 78 percent of the world supply.

In the United States, there are three major phosphate rock producing areas: Florida and North Carolina (80.9%), the Western states of Idaho, Montana, Utah, and Wyoming (13.8%), and Tennessee (5.3%). The leading high purity phosphorus producers in the United States are:

<u>Producer</u>	<u>Capacity (1000 short tons)</u>
Monsanto	230
F.M.C.	137
Stauffer	110
Occidental	60
T.V.A.	34
Electro-Phos.	22
Mobil	5
Total	598

The depletion of U.S. reserves of phosphate rock, particularly from Florida and Tennessee, is projected to occur before or shortly after the end of this century.

Reserves of phosphate rock identified in North Africa and Australia are the largest reserves available for increased exploration, and it is probable that this will occur as reserves in the United States and the USSR are depleted.

Imports/Exports:

The United States does not import significant quantities of marketable phosphate rock. The Netherland Antilles and Mexico have supplied small tonnages of low-flourine phosphate rock that is used as animal feed supplements.

For the short term, the United States has adequate supplies of phosphate rock to meet both domestic and international commitments and will continue to be a net exporter of phosphate rock and fertilizer derivatives. The industry's production capability far exceeds U.S. consumption; and a surplus is available to export. It is estimated that about 45 percent of the phosphate rock produced in the United States is exported either as rock, a higher value fertilizer, or as an industrial chemical.

During the last decade of this century, with depletion of reserves and other restrictions reducing available supplies of phosphate rock, adequate fertilizer supplies to meet future demands of agriculture will become a serious strategic consideration.

Sources: Bureau of Mines, Mineral Facts and Problems,
1975 Edition

International Research and Technology Corporation,
Energy Study of the Industrial Chemical Group

Imports/Exports:

Domestic consumption of hydrogen is essentially equal to production. There are no imports, and exports are a small part of total output.

Source: Bureau of Mines, Mineral Facts and Problems, 1975 Edition.

POTASH

Energy Use:

Conventional domestic potash production requires 1,492 KWH of electricity per ton.

A Bureau of the Mines canvas of energy consumed in the production of 2,168 million short tons of potash in New Mexico in 1973 revealed the following pattern of energy use:

purchased electricity	344.28×10^6	KWH
diesel fuel	1.293×10^6	gal
gasoline	422,000.	gal
other petroleum	767,000.	gal
natural	9.232	billion cubic ft.
Total	$3,234 \times 10^6$	KWH

Process Feedstock: Seawater, MgCO_3

Process Co-Products: Sodium sulfate, bromine, magnesium chloride

Substitutes: About 95% of U.S. potash consumption is for fertilizer. It is an essential plant nutrient for which no alternative exists.

Demand Outlook:

Summary of Forecasts of Annual Demand (1000 short tons)

	1973	1985	2000			2020	
			LOW	BASE	HIGH		GROWTH %
United States	5,550	9,000	10,000	12,000	15,000	21,256	2.9
Rest of World	18,450	31,000	40,000	48,000	55,000	113,553	4.4
Total	24,000	40,000	50,000	60,000	70,000	134,809	3.7

Consumption:

Potash is sold in the following forms:

KCL or potassium muriate
 $K_2SO_4 \cdot 2MgSO_4$ langbeinite
 K_2SO_4

About 95% of potash is used for fertilizer in the states of Illinois, Iowa, Indiana, Minnesota, Ohio and Wisconsin.

Production:

Potash extraction is centered in three states:

New Mexico 83%
Utah
Calif. 17%

Leading firms in the industry include:

<u>Name</u>	<u>Annual Capacity</u> (short tons)	<u>State</u>
Potash Co. of America	550,000	New Mexico
International Minerals and Chemical Corp.	380,000	"
Duval Corp.	260,000	"
Amax Chemical Corp.	550,000	"
National Potash Co.	350,000	"
Kerr-McGee Corp.	350,000	"
Mississippi Chemical Corp.	270,000	"
Texas Gulf	180,000	Utah
Great Salt Lake Minerals and Chemicals	120,000	"
Kaiser Aluminum and Chemicals Corporation	60,000	"
Kerr McGee Chemical Corp.	200,000	California
Total Estimated Capacity	3,000,000	

Price:

Standard grade potassium muriate, bulk, carload lots, freight equalized, f.o.b. Carlsbad, New Mexico, was quoted at 65-70 cents per short ton unit of K_2O on December 29, 1975, compared with 65¢ a year earlier.

	<u>Average Annual Price</u> (\$/short ton)	
	<u>Actual Prices</u>	<u>Constant 1973 Dollars</u>
1973	43.26	43.26
1974	63.29	57.38

Future price trends, save for short run disturbances, are expected to be steady until the end of this century.

Imports-Exports:

About 42% of the U.S. demand is currently met from domestic sources. Since 1962, imports from Canada have increased greatly and now meet most of the remainder of the U.S. demand.

Sources:

United States Department of the Interior, Bureau of Mines, Mineral Facts and Problems, 1975 Edition.

"Mineral Industry Surveys."

SODIUM SULFATE

Energy Use:

1,320 kilowatt-hours (4,500,000 BTU) are required to produce one ton of natural sodium sulfate.

Process Feedstock: Seawater

Process Co-Product: Brine (for use in magnesium production)

Substitutes: Sodium sulfate is also produced as a by-product in the manufacture of rayon, phenol, boric acid, hydrochloric acid, lithium carbonate, and sodium dichromate.

Demand Outlook:

Summary of Forecast of Annual Demand

(1000's short tons)

	1973	1985	2000			2020	GROWTH %
			LOW	BASE	HIGH		
United States	7,113	10,180	14,100	15,630	19,150	28,229	3.0
Rest of World	16,185	25,950	42,100	46,720	57,200	102,335	4.0
Total	23,298	36,130	56,200	62,350	76,350	130,564	3.7

Consumption: Sodium Sulfate is used in the manufacture of:

Pulp and paper	70%
Detergents	20%
Glass	7%
Other	3%

Production:

Sodium sulfate is extracted from brines of California, Texas, and Utah. Naturally, derived sodium sulfate produced by three companies operating five plants in three states supplied about half of the total sodium sulfate market in 1975. About three quarters of the by-product sodium sulfate plants are located east of the Mississippi River. Major U.S. sodium sulfate producers include:

	<u>1000's tons/yr</u>
FMC	240
Kerr-McGee	450
Ozark Mahoning Co.	155
Morton-Norwich Products	120

Price:

Average Annual Price
(\$/ton)

	<u>Actual Prices</u>	<u>Constant 1973 dollar</u>
1973	17.26	17.26
1974	23.99	23.76
1975	41.48	34.54

Imports-Exports:

The U.S. imports a net average of 16% of the apparent domestic consumption. Major world exporters include: Canada, the U.S.S.R., West Germany and France.

In addition to the United States, major world importers include: The United Kingdom, Italy, Sweden, New Zealand, and Finland.

Sources:

United States Department of the Interior, Bureau of Mines, Mineral Facts and Problems, 1975 Edition.

U.S. Department of Interior, Bureau of Mines, "Mineral Industry Survey."

Chemical Marketing Reporter

TITANIUM

Energy Use:

Energy requirements for alluvial mine production are about 500 KWH per ton of product. Production of pigment requires energy in the range of 4,000 to 15,000 KWH per ton of product, depending on the process used, the inclusion or exclusion of energy costs for chlorine production, and the titania content of the final product. Sponge production uses from 7 to 22 KWH per pound of metal, depending on the choice of leaching or vacuum distillation in the final purification step, and on the inclusion or exclusion of energy costs involved in regenerating chlorine.

Substitutes:

Selection of titanium metal over other materials of construction in aerospace applications normally is made on a performance versus cost basis. High strength, low-alloy steels, aluminum, or other metals may be substituted for titanium in many structural applications, but such substitution usually results in redesign and may result in lower performance.

Titanium carbide is used extensively as a cutting surface in machine tools; here its principal competitor is tungsten carbide. A number of materials such as zinc oxide, talc, clay, silica, and alumina serve the same function as, and can be used in place of, titanium dioxide pigment.

Demand Outlook:

Summary of Forecasts of Annual Demand

(1000 short tons)

	1973	1985	2000			2020	
			LOW	BASE	HIGH		GROWTH %
United States	645	921	1,065	1,450	1,975	2,618	3.0
Rest of World	1,055	2,255	2,190	4,185	5,020	11,532	5.2
Total	1,700	3,176	3,255	5,635	6,995	14,150	4.6

Consumption:

Titanium is manufactured in two forms: titanium oxide (90%) and titanium metal (10%).

The prime consumers of titanium oxide are: paint (60%), paper (14%), plastics (12%), and inks (3%), with the remaining 11% used in miscellaneous applications.

Demand for titanium metal was divided between military hardware (mostly aircraft), commercial aircraft, and industrial uses in about a 2:2:1 ratio in 1973.

Demand for titanium for commercial aircraft has weakened, however, and remains light. Increased industrial use of titanium, principally in condensers and heat exchangers, may eventually take up the slack.

Production:

Rutile and ilmenite are the mineral sources of titanium products.

About 96% of the world's rutile production is from eight mines along Australia's east coast.

About 70 percent of the ilmenite produced in the United States comes from three mines, two in Florida and one in New York. The remainder is produced at two mines in New Jersey and two other mines in Florida.

The United States accounts for 35% of the world's pigment capacity, followed by West Germany (11%), the United Kingdom (10%), Japan (9%), France (6%), and Italy (5%).

The titanium industry is characterized by a moderately high degree of integration from raw materials to semifinished products. Several companies mine and utilize the ore minerals in producing titanium pigments, but Titanium Metals Corp. of America, owned jointly by NL Industries, Inc. and Allegheny Ludlum Steel Corp. is the only producer of titanium metal that is fully integrated from rutile concentrate to semifinished titanium products.

NL Industries, Inc., and E.I. Du Pont de Nemours and Co., Inc. own or control about 35% of the world productive capacity for titanium pigment.

Price:

<u>Year-End Price</u> (\$/lb.)				
	rutile pigment		sponge metal	
	actual	constant 1973 dollars	actual	constant 1973 dollars
1973	.50	.50	1.42	1.42
1974	.72	.65	2.25	2.04
1975	.73	.60	2.70	2.25

Imports/Exports:

In 1974 the major titanium consuming countries, including the United States, but excluding the USSR, continued to rely on foreign sources for a substantial part of their supply.

Domestic mines produced all of U.S. requirements for ilmenite, imports of major quantities of slag from Canada continued, and rutile requirements were met almost entirely by imports from Australia.

Source: Bureau of Mines, Mineral Facts and Problems,
1975 Edition

VINYL CHLORIDE

Energy Use:

Approximately 2,900 KWH are required per ton of product.

Process Feedstock: Using a balanced ethylene/acetylene process with an estimated optimal annual production rate of 150,000 tons; 112,052 tons/year of naphtha and 101,599 tons/year of chlorine are required as input.

Process Co-Product: Polyvinyl chloride

Substitutes:

Should requirements for worker safety or environmental controls drive the price of VC or PVC resin upward, it seems likely that some VC/PVC products would be displaced by products using other plastics or other materials.

The more prominent substitutes for VC/PVC include:

polyethylene
polypropylene
crylics
cellulosics
styrene
polyurethanes

Demand Outlook:

Summary of Forecasts of Annual Demand (1000 short tons)

	1973	1985	2000	2020	
	LOW			BASE	HIGH
					GROWTH %
United States	2,650	7,453	12,779	27,149	56,510
Rest of World	9,761	21,983	28,144	60,653	127,966
Total	12,411	29,436	40,923	87,802	184,476
					387,881
					8.0

Consumption:

PVC has become a very important polymer as evidenced by the broad dependence of nearly every branch of industrial and commercial activity upon products and components fabricated from this plastic.

Major consumption sectors of VC/PVC include:

building and consumption	42%
home	13%
electrical	9%
recreation	8%
packaging	7%
apparel	5%
transportation	5%
other	11%

Production:

U.S.-based manufacturers currently produce about one-third of the western world's supply of resins, with the U.S. market also consuming about one-third of the total.

During 1973, VC production was at the 5.3 billion pound level with PVC and its copolymers at the 4.6 billion-pound level.

The U.S. VC/PVC industry has shown an average annual growth rate of 14% over the past five years. This rate of growth is expected to taper off only moderately in the near term.

The VC monomer is synthesized in 15 U.S. plants, while 43 facilities are engaged in polymerization of PVC.

The largest VC producers include:

	Annual Capacity (1000 short tons)
Allied Chemical Corp., LA	150
Continental Oil Company, LA	325
Dow Chemical, USA (TX, LA)	645
Ethyl Corp., TX, LA	225
B.F. Goodrich Co., KY	500
Monochern, Inc., LA	150
PPG Industries, Inc., LA, PR	450
Shell Chemical Co., TX	770
American Chemical Corp.	87.5
Tenneco, Inc.	112.5
Total	3,415.0

Imports/Exports:

In 1973, 3.7% of PVC and 7.8% of VC manufactured in the U.S. were exported.

There is presently an import duty on PVC resin from countries with status as most favored nations of 11/4 cents per pound plus six percent ad valorem and from other nations of four cents per pound plus 30 percent ad valorem. Given the current U.S. market price of 18 to 24 cents per pound for the general purpose uncompounded resin, there has been little incentive to import PVC resin. Also, because of short U.S. supply and unattractive foreign prices. However, higher prices as a result of more stringent worker or environmental controls in PVC resin plants in the U.S. than abroad might well stimulate significantly increased imports.

Source: EPA, "Preliminary Assessment of the Environmental Problems Associated with Vinyl Chloride and Polyvinyl Chloride", September 1974.

Makhijani and Lichentberg, "Energy and Well Being", Environment, Vol. 14, No. 5, June 1972.

APPENDIX C
EFFECT OF PARAMETER ASSUMPTIONS ON
OTEC DELIVERED POWER COSTS

There is a tendency for advocates of alternatives to choose favorable assumptions for their choice and unfavorable assumptions for competing choices. By considering the ranges of assumptions and the factors which go into them, an approach to evenhandedness is attempted.

Capacity Factor

The capacity factor at which conventional plants and OTEC plants can be operated is an important determinant of economic competitiveness of OTEC. Many of the same factors that limit the capacity factor of conventional plants will similarly limit the capacity factor of OTEC plants, so one must avoid assuming differences that may not be real.

First, a brief excursion into terminology and definitions. A plant has a nameplate rating that essentially represents its maximum output. Almost all components are tailored to be as required to meet this rating with adequate reliability, neither bigger nor smaller. Exceeding rated load by more than a few percent for a small fraction of the time may reduce reliability or cause damage, and is frowned upon by the manufacturer: warrantor of this product. Operating at less than rated load all the time means that less output, in this case megawatt hours per year, is produced; there is an economic penalty because the fixed costs must be allocated over the smaller base of output. The ratio of actual megawatt hours produced to the rated output times 8,760 hours per year is called the capacity factor.

A number of causes can prevent achieving a capacity factor of 1.00 or (100 percent). The plant may not be available for operation or it may have to operate at less than rated output.

Availability is defined as the time percentage in the month (or year) that the unit was available to generate electricity. It may be unavailable because of a planned outage or a forced outage. The former is controllable and will cause minimum economic penalty if scheduled for months when the demand is low. Major maintenance tasks, refurbishment, nuclear plant refueling are planned outages; there are also maintenance outages for minor leaks, inspections, and adjustments which may be done during daily or weekly low-load hours.

Forced outages are those not scheduled, where shutdown must be immediate or within days because of damage or the possibility of damage. For each unit the forced outage rate (FOR) and the FPC is the ratio of the hours in a period (month, year, or cumulative) that the unit is unavailable because of forced or unplanned outage, divided by the hours of forced outage plus hours of actual operating time during the period. This definition gives no credit for time when the unit was available but not operated because of low demand or other discretionary reasons; a gas turbine that is only operated 500 hours in a year and has a part fail that required 2,000 hours to order and replace would have a FOR of 0.80.

There are also alternative reasons why a unit may operate at less than its rated capacity. Foremost is the variable demand pattern of the utility or power pool. Rather than either operating all units at full rated capacity or shut down, the utility may choose to operate some at partial load to permit following load changes expeditiously. However, technical and legal limitations may compel operation at less than full load. Nuclear power plants may be allowed to supply only authorized power levels in several steps during the power ascension phase of commercial operation. Where trouble is located or suspected, they may be required to reduce ratings. All steam plants operating condensing may be unable to put out rated power in the seasons when the cooling water, or cooling air for wet or dry towers, is warmer than the design temperature.

While the term availability is generally defined in the on-off sense, regardless of limitations on capacity, the term "capacity availability" is sometimes used considering partial as well as total unavailability of capacity. This will differ from capacity factor in only the unused capacity available but not needed to meet the load demands.

Evaluation of the record of nuclear plants to date is sometimes obscured by failing to make the distinction between availability and capacity factor. From the Nuclear Regulatory Commission's (NRC) Operating Status Reports for two months, in October 1974, 41 nuclear plants had an availability of 0.763 and a capacity factor of 0.57. In April 1976, 53 plants had an availability of 0.56 and a capacity factor of 0.46. The cumulative capacity factor of 50 reactors to April 1976 was 0.578. The cumulative capacity factor of 50 reactors to April 1976 was 0.578. The cumulative availability to 1963 was 0.789. A part at least of the deterioration in availability and capacity factors in the past several years is attributable to the new requirements placed on them by the NRC and local agencies.

Typically, the unavailability of nuclear plants comprise 0.10 for planned outage including refueling, 0.05 for smaller maintenance outages, and 0.16 to 0.18 for forced outages. In October 1974 and in April 1976 the FOR was 0.168 and 0.179. For the best 20 nuclear plants the cumulative average FOR is 0.07, and for all nuclear plants to 1973, according to Edison Electric Institute (EEI) data (FPC, 1975), the FOR was under 0.082, so trouble is not universal. Similarly, for the best 20 nuclear plants the capacity factor to date is 0.695.

* As reported in Nuclear Industry: The Monthly Magazine of the Atomic Industrial Forum, for June 1976 and December 1974.

The above indicates that it is wise to look at a range of nuclear plant capacity factors as low as the recent past 0.45 to 0.60 but also to consider the long-term expectations of AEC, FEA, and industry for a capacity factor of 0.75 and availability of over 0.80.

Fossil-steam plants have planned outages of 0.06 to 0.09, maintenance outage of 0.03 to 0.045, and forced outage rates of 0.04 to 0.165 (FPC, 1975). This source summarizes EEI data for several periods including 1960-1969 and 1961-1973. The point is made of the correlation of FOR with unit size. Small steam plants (200 MW to 389 MW) had a FOR average under 0.05, intermediate sizes (390 MW - 599 MW) had 0.085, large plants (600 MW and up) had a FOR of 0.125 in 1960-1969 and 0.165 in 1964-1973. There are several possible causes of this size correlation.

- Outages take longer to repair on large units.
- Reliability inherently decreases with increasing size (approaching the limits of technology).
- The larger plants are generally newer and suffer from "infant mortality" failure types. That is, they are still in the process of being debugged as the maximum size limit continues to move upward.
- The largest, newest plants are more likely to be coal-fired, and coal-fired boilers give more trouble than oil or gas fuels.

The same data base estimates the range of unit availabilities for large coal-fired plants as 0.56 to 0.79. Since the capacity factor cannot be greater than the availability, coal plants should also be considered at CF = 0.60 and less as well as 0.75.

Fuel Costs

The costs of fuels assumed in the report are the estimates from the sources named. The GE reports assume considerable net escalation (above inflation) for nuclear and coal fuel costs between 1974 and 1980 and then

assume the escalation is the same as general inflation to the end of the century. The Nuclear Energy Project Independence Task Force Report assumes a value in 1977 that is much smaller than GE's 1974 values, and has it escalate to approximately the GE value by 1990 under the "Accelerated Scenario." There is no indication whether the net escalation is expected to continue at the same rate after 1990 or reduce to the general inflation rate. Few, if any, commodities have had a sustained net escalation above general inflation for periods of 20 years or more.

The future course of nuclear fuel costs are uncertain and controversial. The uncertainties include the rate at which richer deposits will be depleted and new reserves will be found, the cost of enrichment if new separation plants use newer technologies such as centrifuges or lasers, and/or are privately operated. The Project Independence Task Force Report is based on significant increases -- from \$8 per pound of U_3O_8 to \$50, from \$42 to \$75 per unit of separative work.

Properly using the methodology described by Doane (1976) requires converting future annual fuel costs into a "discounted average" by finding the present value of fuel costs over the 30-year life and then reconverting to uniform annual costs over the same period using the discount rate appropriate for the general inflation assumed. This does not change the annual cost of a component assumed to have no net escalation. If there is, as an upper extreme, a continuation of the 0 percent *net* escalation assumed from 1980-1990, the levelized fuel costs for plants starting operation in 1980, 1985, and 1990 would be roughly doubled, and every five years thereafter the fuel cost would rise by a factor of 1.34. This would suggest 10.8 \$/MWH in 1990 and 19.3 \$/MWH in the year 2000. As a lower extreme, the nuclear fuel cost could decline if rich new reserves are found and enrichment costs decrease. Decline of more than 2 \$/MWH is unlikely and this has little effect on the requirements OTEC must meet.

Fixed Charge Rate

A fixed charge rate of 0.15 is used as compatible with Doane (1976), Project Independence (1974), and the GE studies mentioned. In the past several years, when inflation was 8 percent or more, utilities have sometimes used 0.18 as FCR, but this is not compatible with the financial assumptions, including inflation. Different types of financial structure will require different fixed charge rates. Principally it is affected by the debt to equity ratio; the cost of money for bonds; the required return on equity capital, considering corporate income taxes and the risk level associated with the enterprise property and other taxes; and financial incentives that are applicable such as investment credits, fast depreciation, etc. A municipality, with no income tax or property tax to pay, bonded indebtedness which may be as tax-free bonds, no equity, and a financial practice to not include risk as a cost, may use a FCR as low as 0.08. An industry that is not regulated may require a "payback" of investment within three to four years, corresponding to a FCR of up to 0.30.

Reference to equation III-1 indicates that the term that includes FCR is directly proportional to the capital cost per KW and the $\overline{FCR}$, and inversely proportional to capacity factor. One can get the same effect as raising the FCR by 20 percent by raising the capital cost or lowering the capacity factor by 20 percent.

Implications on OTEC Cost Requirements

The examples given in the discussion used optimistic values of capacity factor for both conventional systems and for OTEC. If less favorable assumptions on nuclear plant capacity factor, fuel costs, $\overline{FCR}$, or capital costs are made; the break-even costs that an OTEC need achieve for competitiveness will be greater. Some examples:

<u>Assumption Changes</u>	<u>OTEC \$/KW</u>
None	784
CF = 0.60	955
CF = 0.45	1240
$\overline{FL}$ = 10.8	1067
CIpv = 700	940
CF = 0.6; $\overline{FL}$ = 10.8	1240

However, in fairness, many of the same considerations that restrict the achievable capacity factor in a nuclear or coal-fired plant may also be applicable to OTEC. The proponents have almost universally assumed 0.9, sometimes for conservatism also listing the effect of an 0.8 capacity factor. There is no body of experience available on what the planned outage, maintenance outage, and forced outage rates of an OTEC plant will be. Nor is there experience on what factors will derate the OTEC, limiting its output. Some of these can be anticipated and likely values, or a range, assigned to them.

Planned outage and maintenance outage have their OTEC counterpart in the recognized need for periodic overhaul whether in place or by towing modules to shore as Lockheed proposes. Unavailability of a module must be counted as reduced capacity availability as previously defined. As with conventional plants, planned outages will be distributed over the months other than the July to October summer peak demand period. Cleaning heat exchanger tubes of biofouling may be continuous, with minimum loss of capacity or may be a form of maintenance outage, performable during off-peak hours of the day or on weekends. It is difficult to justify assuming that the maintenance outage rate will be significantly less or greater than for small steam plants, ie, about 0.03. Planned outage will depend upon the severity of corrosion, biofouling, and leakage found in efficient heat exchangers, and in the logistics of either performing major maintenance off-shore or moving modules to shore for overhaul. Again, one can reasonably expect that planned outage will be no better than that for small mature steam plants, about 0.07, and may be considerably poorer (> 0.12) during the early years of commercial operation.

OTECs initially planned will be more comparable to small steam plants than to large ones in output but comparable to the intermediate or large (> 600 MW) range in physical size because of the low pressure, low efficiency, working cycle. The forced outage rate may be comparable to that of small steam plants, 0.044, on the basis of output, or a number of the factors causing the higher forced outage of large

steam plants may be applicable. These were listed on page C-5. The large components may take longer to repair or replace than their small steam plant analogs; as new devices, much debugging and "infant mortality" may occur during the early years of operation; or they may have inherent sources of unreliability (e.g., corrosion). A range for the forced outage rate, FOR, should be assumed: 0.14 for the first three to five years of operation and perhaps 0.05 during mature operation.

Another form of forced outage that OTEC must consider is the derating or cessation of operation that may be necessary if protective measures are needed during tropical storms or hurricanes to assure survival of the plant and the safety of personnel. No measure of this is assigned; it is assumed included in the FOR.

Thus, the maintenance related outage rate covers the range from 0.15 to 0.29. The capacity availability can hardly be greater than 0.85 and may be as low as 0.70 during the introductory years, comparable to nuclear power's current teenage traumas. This availability range is not the capacity factor, as it does not as yet include any derating or part load operation that is not maintenance related.

SEASONAL DERATING

The surface temperature of the oceans has a seasonal variation. In northern latitudes it is greatest in late summer, July-September, and in the southern hemisphere in January-March. Near the equator the variation is usually less but not zero. Deep water temperatures have less seasonal variation, so the ΔT available to an OTEC will vary seasonally for any length of cold water pipe. Ocean sounding data is presented by Paul Wolff (1976a) for a number of areas. That for the Gulf Stream in the Florida Straits (27°N, 079°W) is reproduced as Figure C-1. While the intermediate depths; e.g., 300 meters, usually have a small seasonal variation in phase with the surface variation, note that in this location the 300m depth is colder in the summer than the winter so that mean ΔT varies from 7.5°C to 15.0°C. The standard deviation and the max/min limits depict variation within 2° rectangles, different days of

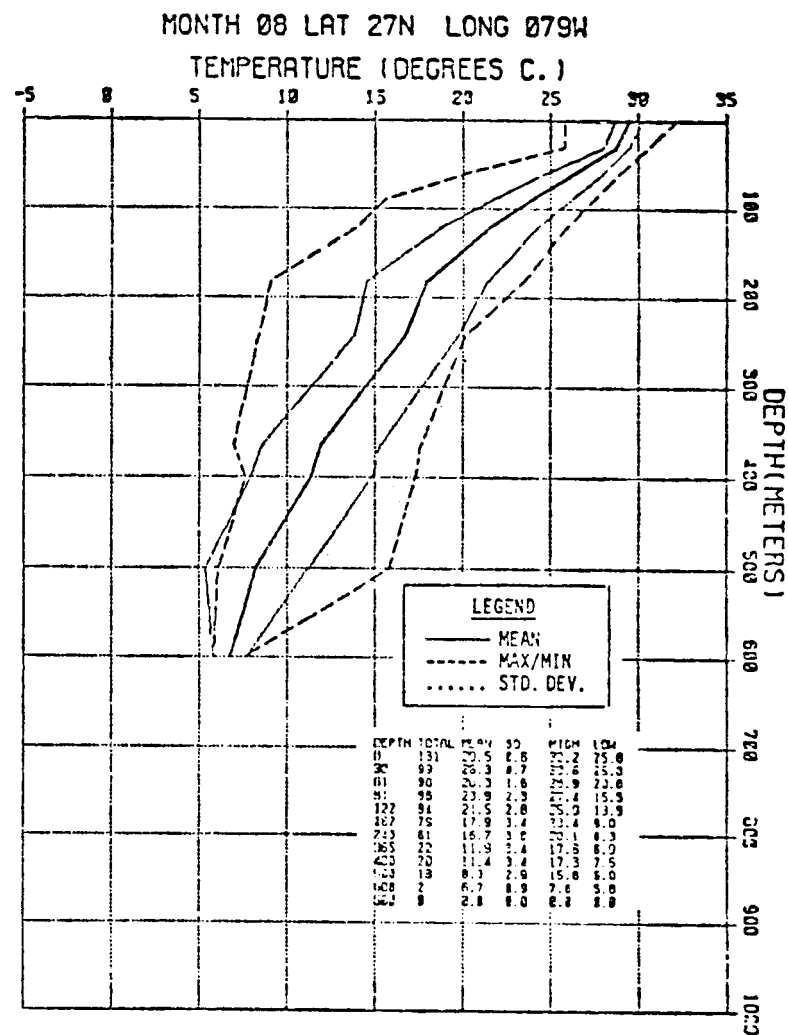
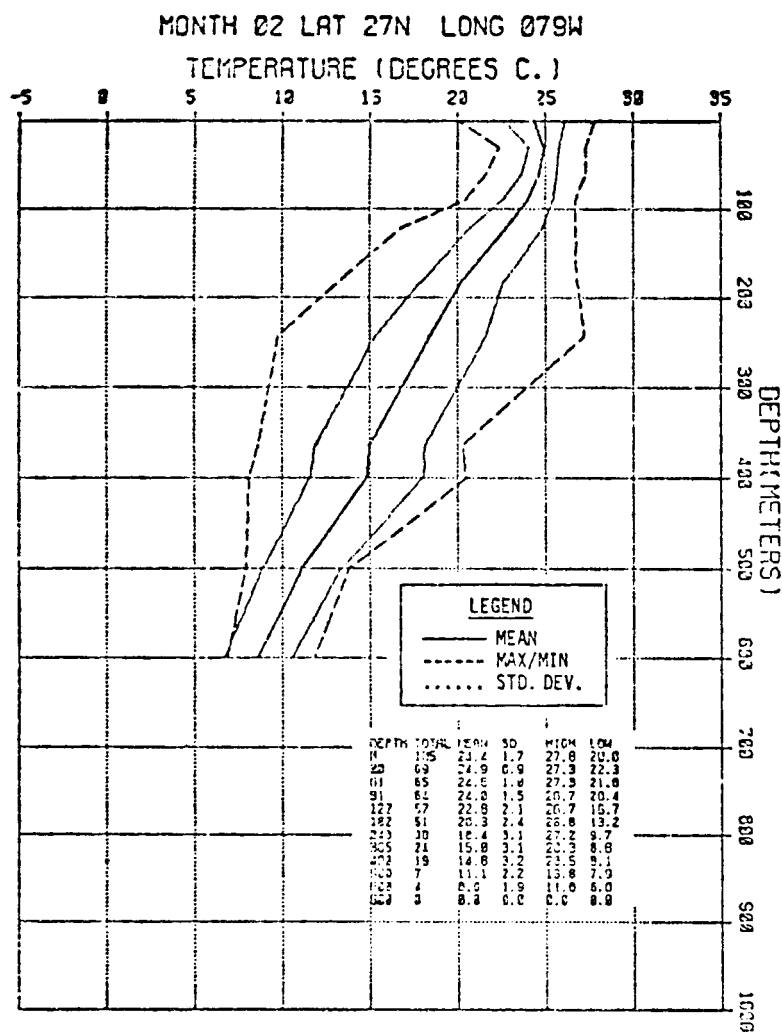


Figure C-1. Thermal profile envelopes for Florida Straits Rectangle Number 10, February and August.

the month, and different years. From this chart there is no measure of the relative magnitude of these sources of variation or of the correlation between surface and depth temperatures.

By subcontract to GE-TEMPO, Paul Wolff (1976b) prepared some temperature cross-sections across specified traverses of latitude and longitude. Figures C-2 through C-5 are examples. The traverse is at 26°N (including available data from 25°N to 27°N) and east and west of the Florida Coast, which extends from 80.5° to 81.5°W. In Figure C-2, all soundings available in the data base on this east-west strip for summer (July-August) were searched by the computer, the difference between surface temperature and the temperature at various depths was found and coded:

X - $\Delta T > 14^{\circ}\text{C}$ and $< 18^{\circ}\text{C}$
O - $\Delta T > 18^{\circ}\text{C}$ and $< 20^{\circ}\text{C}$
T - $\Delta T > 20^{\circ}\text{C}$

and the resulting symbols plotted at the longitude of the sounding. Contours were drawn subjectively by an experienced oceanographer, and rudimentary error checking for consistency was used. Figure C-2 gives summer data; Figures C-3, C-4, and C-5 give fall, winter, and spring data. Figure C-6 presents the water depth contour at the three latitudes 25°, 26°, and 27°N bounding the traverse.

The seasonal variation of ΔT between the surface and 400m (1,300 ft) was taken from this set of charts, and others in Wolff (1976b), for various latitudes and longitudes as shown in Table C-2. While many more could be taken from these charts, or others for various parts of the world could be derived by Wolff, the four selected seem representative enough for preliminary analysis of the cost requirements on OTEC as a function of capacity factor.

The variance in the data, the subjective contour drawing, and the interpolation step can be mitigated in part by use of a physical model. As a first approximation, one would expect the surface temperature and the temperature difference to 400m to vary sinusoidally over the year. The hypothesis of a sinusoidal variation in surface temperature is

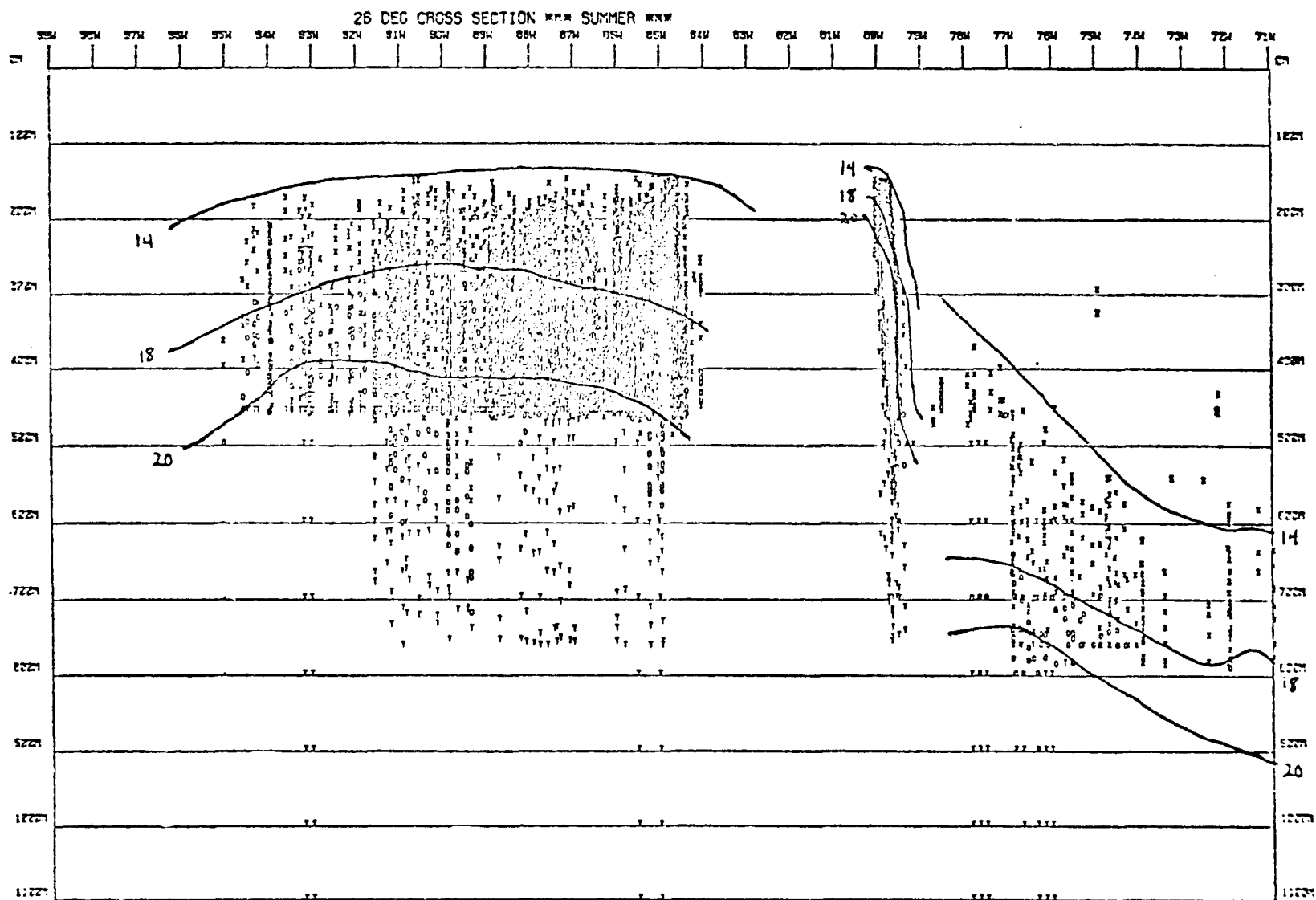


Figure C-2. 25° - 27°N lat., 71° - 99°W long., Summer, analyzed.

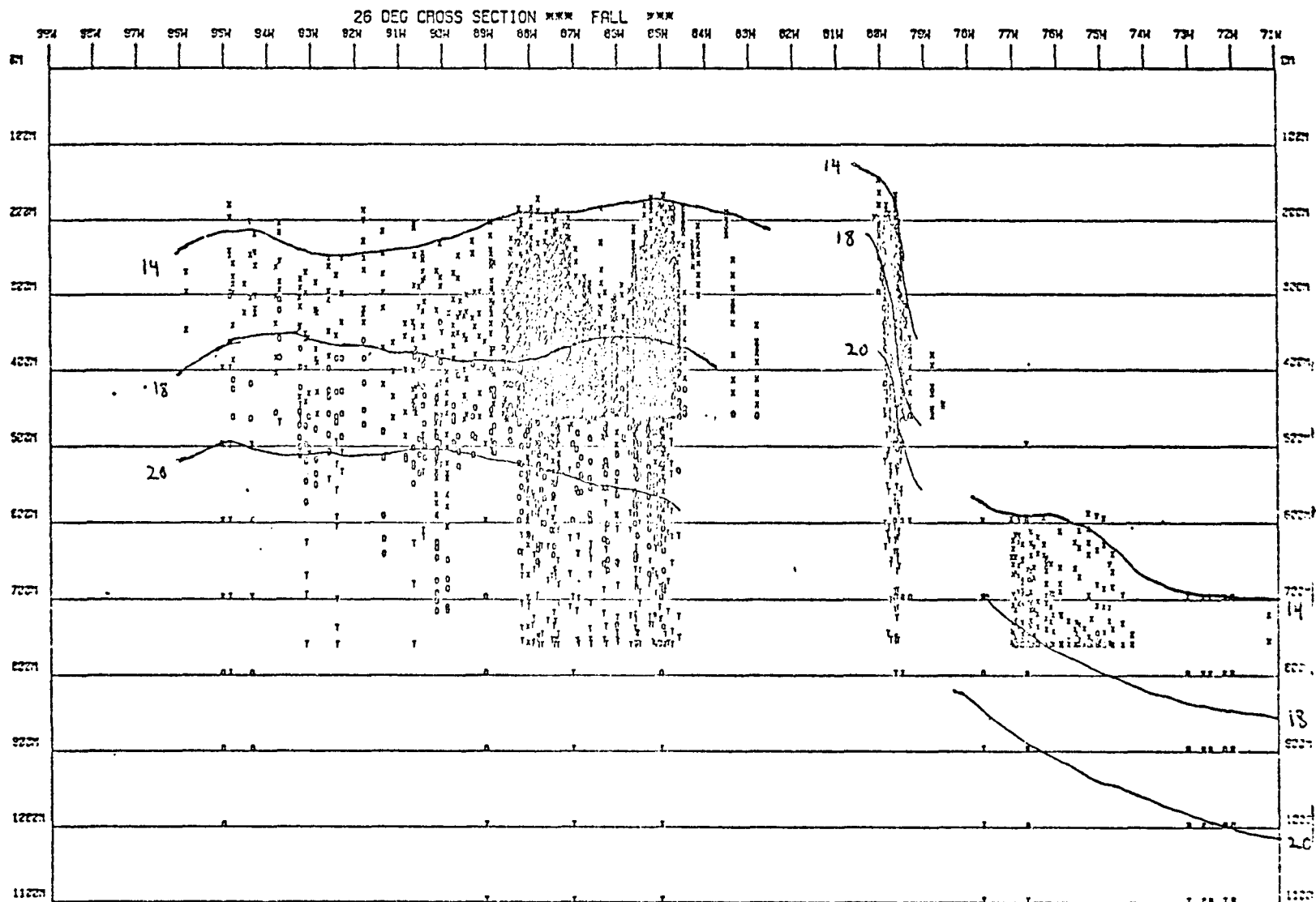


Figure C-3. 25° - 27°N lat., 71° - 99°W long., Fall, analyzed.

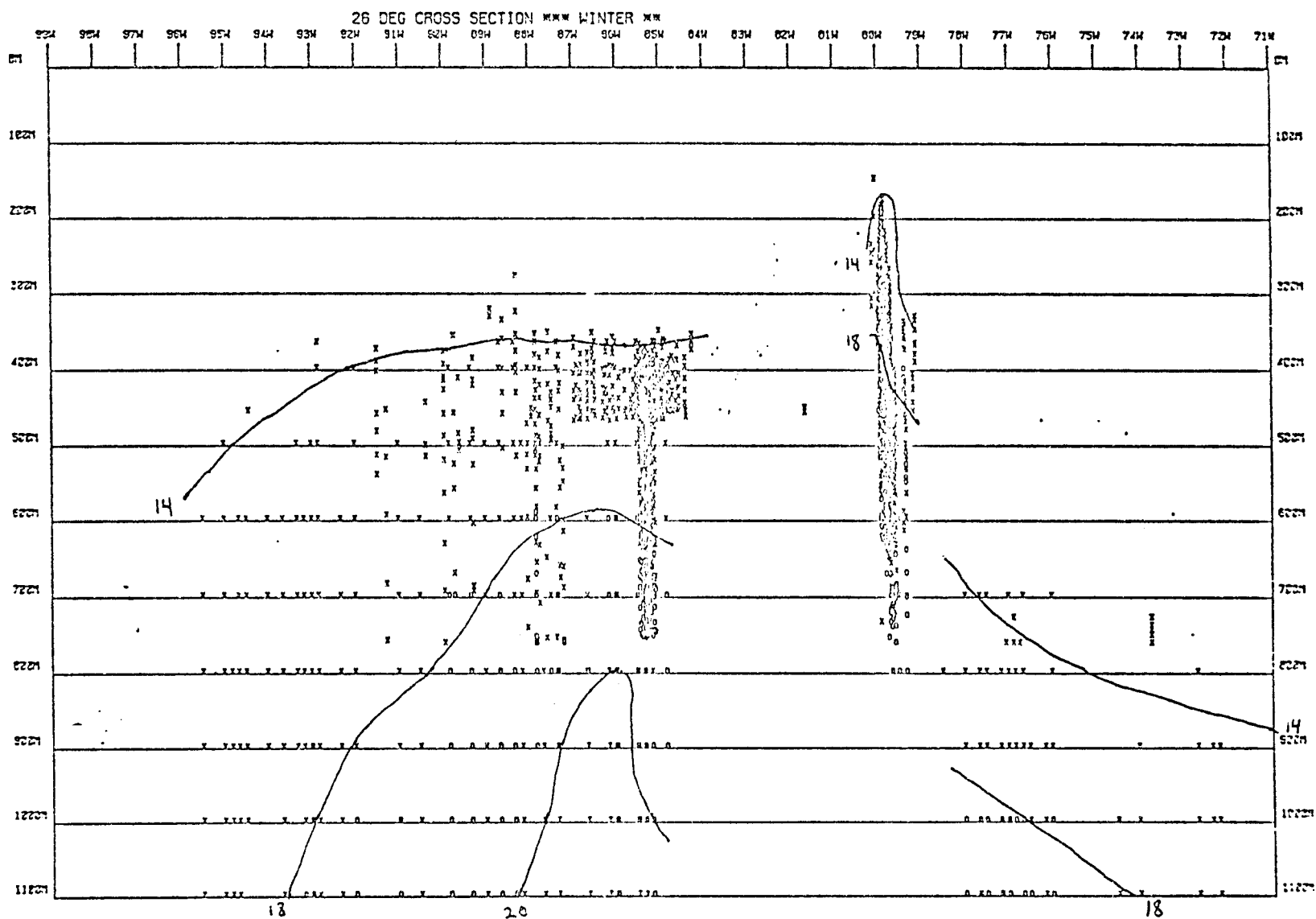


Figure C-4. 25° - 27°N lat., 71° - 99°W long., Winter, analyzed.

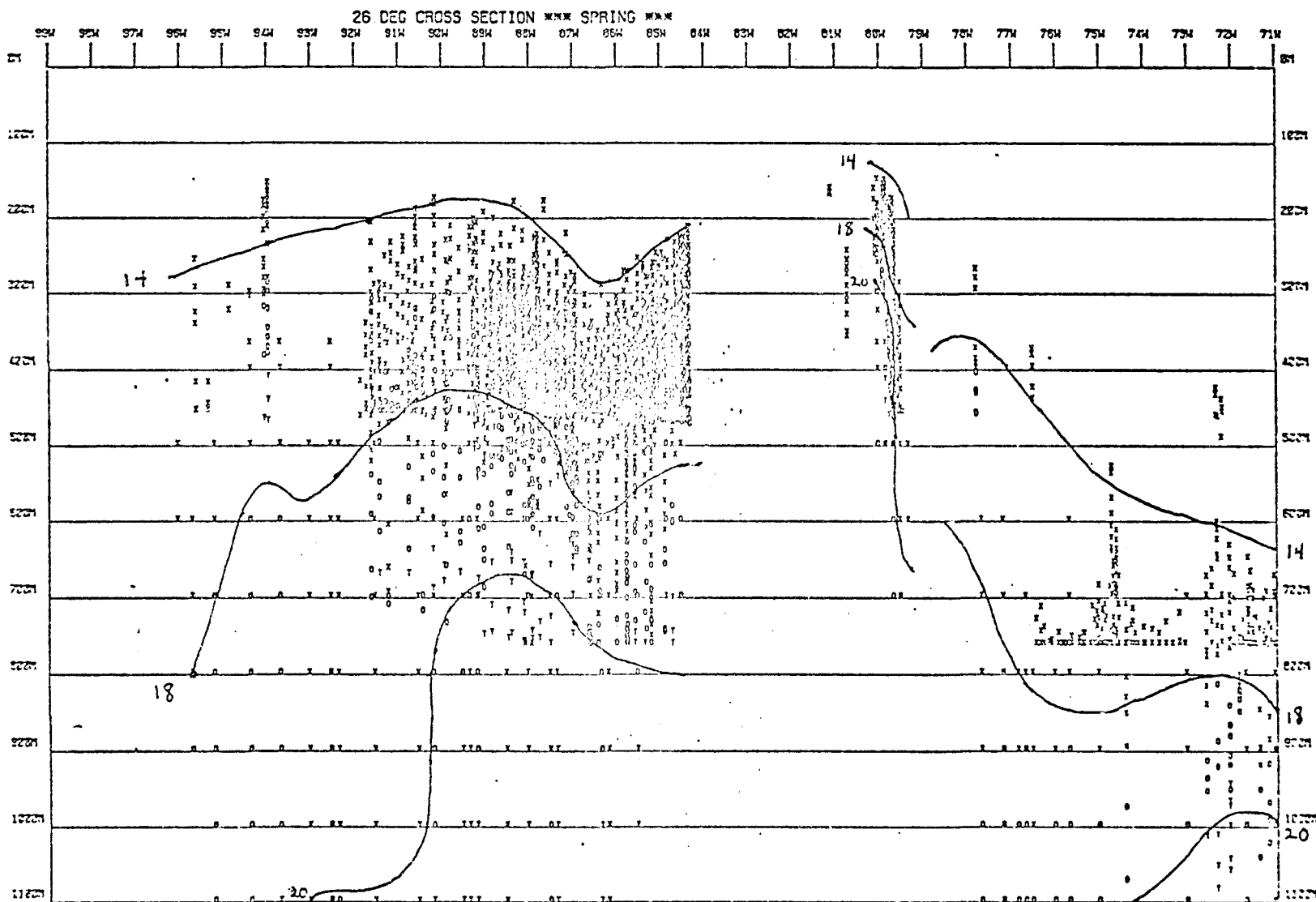


Figure C-5. 25° - 27°N lat., 71° - 99°W long., Spring, analyzed.

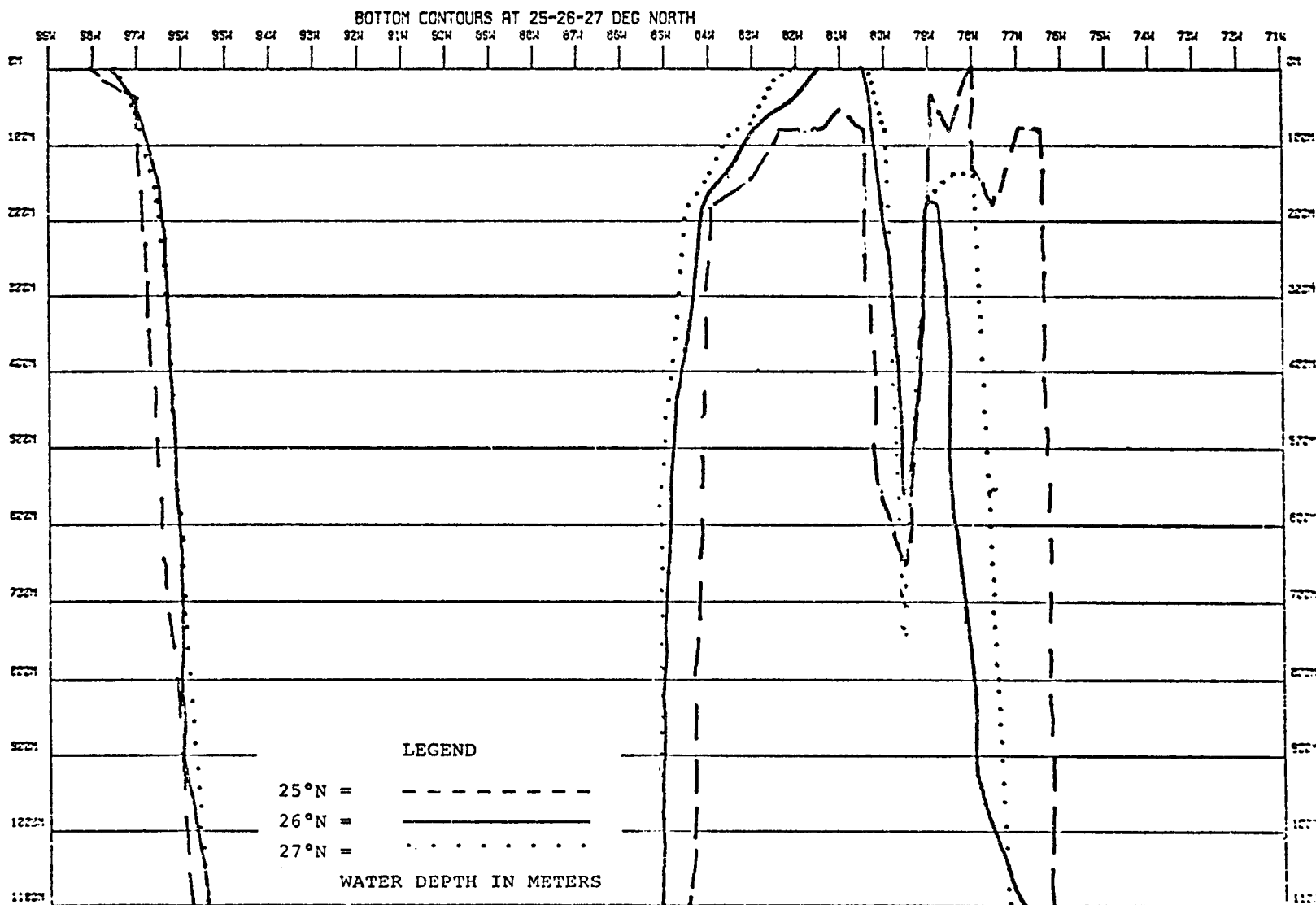


Figure C-6. 25° - 27°N lat., 71° - 99°W long., Bottom Depth Chart E-W Section I.

Table C-1 Seasonal ΔT variations.

	<u>Lat.</u>	<u>Long.</u>	<u>ΔT ($^{\circ}C$)</u>				<u>Comment</u>
			<u>Sum.</u>	<u>Fall</u>	<u>Win.</u>	<u>Spr.</u>	
1.	26N	80W	22.0	20.5	18.5	21.0	Gulf Stream, off Miami
2.	26N	90W	20.1	18.2	13.7	17.6	Gulf Coast, off New Orleans
3.	30N	80W	21.0	20.5	18.5	19.0	Gulf Stream, off Jacksonville
4.	36N	74W	18.3	17.6	15.4	15.5	Gulf Stream, off Cape Hatteras

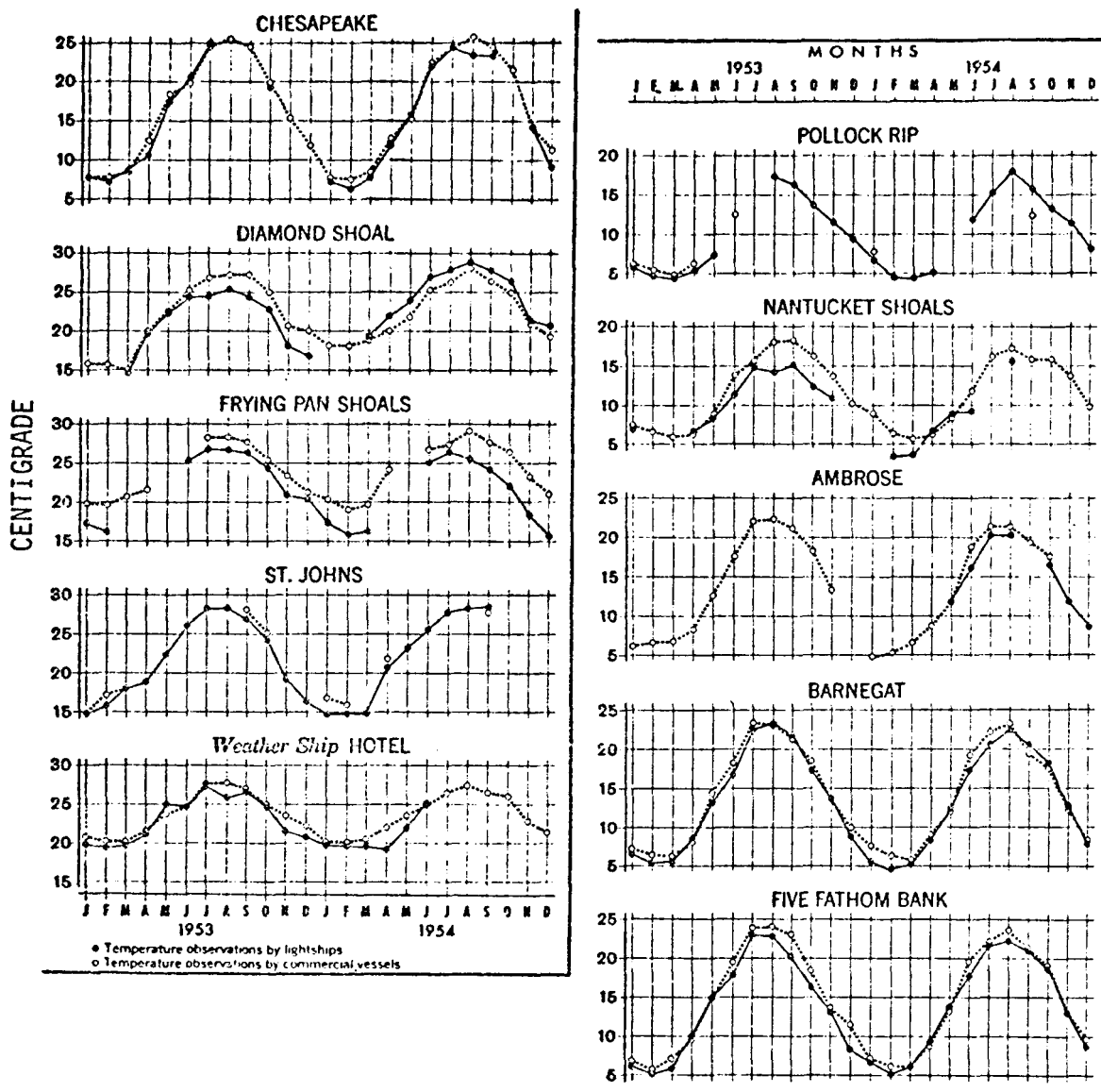
supported by Figure C-7 (Robert Pyle, 1962) which shows monthly temperatures (1953-1954) at various lightships, supported by data from commercial vessels. Unfortunately all of the lightships are in shallower water than the Gulf Stream. Weather Ship HOTEL is in the Gulf Stream but at $37^{\circ}N$, $70^{\circ}W$, well beyond the zone of interest for direct-cable OTEC.

It may be expected that the peak will not occur at the summer solstice but will lag. The first estimate would be that the peak occurs in July-August; these are the months used by Wolff (1976b). Figure C-7 indicates an August peak in most places. If this assumption were true, the values for spring and fall would be roughly equal. Inspection reveals that the time lag to peak is somewhat greater than expected. A phase angle as well as an amplitude for a sine wave model is a better approximation. The summer peak may be shorter or longer than the winter minimum. This is tested by comparing the average of summer and winter with the average of spring and fall; the Gulf Stream cases have a small difference between these averages; that of the Gulf Coast is over $1.2^{\circ}C$. The sets of four temperatures T_1 , T_2 , T_3 , T_4 for the seasons starting with summer can be matched by a model:

$$T = A \cos (\theta - \alpha) + B \cos 2(\theta - \alpha) + C \quad (C-7)$$

where

- θ is 0, $\pi/2$, π , and $3\pi/2$ for the four seasons
- α is the phase angle of time lag
- A,B,C have dimensions of temperature.



Source: American Geophysical Society (1962).

Figure C-7 Monthly average temperature reported by lightships compared with corresponding observations from commercial vessels in the surrounding 30-minute squares. Gaps in the lightship records indicate no observations available. Gaps in the commercial vessel records indicate insufficient reports to provide a representative monthly average temperature.

The values of these parameters are

$$C = (T_1 + T_2 + T_3 + T_4)/4 \quad (C-2)$$

$$\alpha = \tan^{-1} ((T_2 - T_4)/(T_1 - T_3)) \quad (C-3)$$

$$A = (T_1 + T_2 - T_3 - T_4)/2(\cos \alpha - \sin \alpha) \quad (C-4)$$

$$B = (T_1 + T_3 - T_2 - T_4)/4 \cos 2\alpha \quad (C-5)$$

Applying these equations to the four exemplar cases of Figure C-2 gives the data in Table C-1.

Table C-2. Model parameters for seasonal derating.

	C	α°	A	B	T_{max}	T_{min}
1.	20.5	- 8.13	1.768	-0.269	22.0	18.47
2.	17.4	+ 5.36	3.455	-0.509	20.35	13.436
3.	19.75	+30.96	1.458	0	21.2	18.29
4.	16.7	+35.91	1.790	0.481	18.97	15.39

There are few surprises in these data. There is a greater seasonal variation off the Gulf Coast than there is in the Gulf Stream. The values of the second harmonic are small, but probably large enough to have statistical significance. The time lag in the peak temperature increases as the Gulf Stream goes northward; within the limits of the data base it would appear to be in late July off Miami, in late August off Jacksonville, and in early September off Cape Hatteras. Correction for the phase angle gives a lesser spread in the maximum temperature shown in Table C-2 than in Table C-1.

Temperature Dependence of Output Power

The variation of output power with temperature is not linear. In Solar Sea Plant Power Plants, Cost and Economics, Abraham Lavi (1975) of CMU indicates that costs of the heat exchangers and water flux dependent components vary with the temperature difference as $1/T^{2.5}$. TRW (1975) gives sample data from their system optimization program for the total cost of systems designed

for values of ΔT : 32, 36, 40, and 44°F (17.8, 20, 22.2, 24.4°C). They discuss several curve fitting approaches; if ΔT^{-k} is used, k varies from 2.03 to 1.50, with 1.79 being the best fit. J.H. Anderson has suggested that $(\Delta T - T_0)^{-1}$ is a better fit for temperature variation.

In a private communication from C. Zener of CMU, the reasons for the differences between their choice of exponent and TRW's data were discussed. For heat exchangers, two limiting cases give exponents of 2 and 3: when the heat transfer on the working fluid side (ammonia evaporator and condenser) is limiting, the exponent is 2; when the film thickness on the water side is limiting, the exponent is 3. The heat exchanger costs are major and some other parts of the system are virtually independent of ΔT .

For reasonable interpolation by curve fitting, short of computer optimization, a case can be made for all the parameters in the following equation

$$\text{Cost} = C (\Delta T - T_0)^{-k} + C_1$$

C_1 represents the parts of the system that are insensitive to ΔT .

T_0 as a parameter fits the intuitive concepts that: (a) there is a temperature difference at which pumping requirements use all the output so there is zero net energy, and (b) a portion of the available ΔT is lost in the temperature drops between inlet and outlet and through the heat exchange films.

The exponent k measures the expected non-linearity of temperature dependence.

For analysis in this study, the data and the goal do not warrant great complexity. It was found that the TRW cost points for a 100 MW optimized plant were fitted well by the parameters

$$\text{Cost (\$M)} = 6.47 \cdot 10^6 (\Delta T)^{-3} + 80.6 \quad (\Delta T \text{ in } ^\circ\text{F}) \quad (\text{C-6})$$

$$\text{or } 1.11 \cdot 10^6 (\Delta T)^{-3} + 80.6 \quad (\Delta T \text{ in } ^\circ\text{C}) \quad (\text{C-7})$$

This represents the variation in the cost of OTEC's optimally designed for different values of ΔT and the same power output (100 MW).

If the design (and cost) is kept constant and the ΔT is reduced, the variation in power output with ΔT will be more severe than that in equation C-7 for two reasons: (a) the system is off the design ΔT for which it was designed, so is by definition worse than optimum, and (b) for a lesser power output even a design that is optimum for the lesser ΔT would be more costly per kilowatt if there is any economy-of-scale effect in OTEC designs. Many components and whole plants, chemical and electrical, have a cost relationship (a between 0.6 and 0.8):

$$\frac{C_1}{C_0} = \left(\frac{P_1}{P_0} \right)^a \quad (C-8)$$

Thus, to find the variation of power output with temperature we have the relationship

$$\frac{P_1}{P_0} = \left(\frac{1.11 \cdot 10^6 (\Delta T_0)^{-3} + 80.6}{1.11 \cdot 10^6 (\Delta T_1)^{-3} + 80.6} \right)^{\frac{1}{a}} < \frac{(\Delta T_0)^{-3} + 7.26 \cdot 10^{-5}}{(\Delta T_1)^{-3} + 7.26 \cdot 10^{-5}} \quad (C-9)$$

For the four cases in Table (C-3) a system designed for 100 MW at the summer ΔT would be derated at its winter ΔT to less than P_1 :

Table C-3. Seasonal derating of capacity factor.

Case	1	2	3	4
	26N 80W	27N 90W	30N 80W	36N 74W
Power P_1 (MW)	72.0	39.5	75.2	63.1
Maximum CF	0.881	0.723	0.876	0.766
Estimated CF	0.764	0.640	0.757	0.664

By integrating the power output over the seasons of the year using a 9-point quadrature formula (Abramowitz and Stegun, 1964; 25.4.18) and normalizing to the rated power output (summer peak), the maximum capacity factor possible, operating without interruption all year is found as shown in the second line of Table C-2.

Planned outages for maintenance can be assumed to be in the season of lowest output, but the maintenance outages and forced outages occur through the year and must be deducted from the annual output at the average power rate. Using the low estimates of OTEC outage, 0.07 for planned outage and 0.08 for maintenance and forced outage, give the estimated capacity factor on the third line of Table C-2. As an immature product during its early years, the OTEC performance may be 0.10-0.15 lower than these figures. If the exponent a (Equations C-8 and C-9) is found to be near 0.6, indicating considerable penalty for being off optimum design for the lower values of T , a further decrease of 0.05 to 0.10 in capacity factor may be found.

For these locations, a reasonable upper limit on OTEC capacity factor may be 0.75 and under unfavorable assumptions and for the less favorable sites (2 and 4) may be under 0.60.

ENERGY AND CAPACITY DISPLACEMENT

Another approach to comparison of OTEC with other baseload capacity is in terms of fuel energy displaced and the capacity of other types displaced by addition of OTEC's to a utility system. OTEC, as well as other solar energy systems, get full credit for the annual cost of the fuel energy that would be required by another type of generating capacity with the same annual electric output. An important concern in utility planning is reliability; the capacity displacement credit for an OTEC depends on the probability of its availability, particularly during the days and hours of peak demand.

OTEC is unique among solar energy forms in that it does not suffer from the hour-by-hour variability of the source, as is characteristic of solar thermal, photovoltaic, and wind energy. These latter may have an availability of 0.25 more or less, or capacity unavailability as likely to occur during peak demand as in low demand hours. OTEC not only has no rapid source fluctuations, but also has its peak output in the late summer months when the peak demand occurs for the South Atlantic and Gulf Coast areas of interest. If an OTEC has the same maintenance and forced outage rate as a coal or nuclear plant of the same

capacity it will get the same capacity displacement credit as they do. If there are differences in the outage rates or the capacity there will be a difference in the "effective capability" of contributing to the reliability of the system. In some cases this can be a significant asset to OTEC economic comparison.

There is extensive literature on capacity displacement; two papers by L.L. Garver (1966 and 1970) describe the concepts and methods of use. A utility must maintain enough reserve capacity to keep the probability of failing to meet the varying demands extremely low. Loss of Load Probability (LOLP) of 0.1 days per year is a common goal. Since planned and maintenance outages can be scheduled away from peak seasons and hours, the determinant of LOLP is the probability of enough simultaneous forced outage of capacity to exceed the margin between peak demands and total capacity. With many generating units of different sizes, forced outage rates, and other characteristics such as time to start or shut down a unit, accurate assessments require computer simulation. Garver proposed an approximation in terms of a parameter m , the slope of the plot of LOLP versus reserve margin in megawatts, which includes the effects of all existing units and their outage rates. His equation is:

$$c^* = c - m \ln [(1 - r) + re^{c/m}] \quad (C-10)$$

where

c is rated capacity in MW of unit to be added

m is the system slope characteristic

r is the unit's forced outage rate

c^* is the effective load carrying capability of unit of rating c .

For zero FOR, $c^* = c$. For c much less than m , $c^* = c(1 - r)$. When c is much larger than m , the value of c^* is much less than c . Take as examples a nuclear plant rated at 1000 MW and an OTEC rated at 100 MW, with each having an FOR of 0.10. Let $m = 200$ MW

$$c^*(\text{nuclear}) = 1000 - 200 \ln (0.9 + 0.1e^{5.0}) = 449.0 \text{ MW}$$

$$c^*(\text{OTEC}) = 100 - 200 \ln (0.9 + 0.1e^{0.5}) = 87.4 \text{ MW}$$

Roughly, ten OTEC's would add 880 MW effective capability or 425 MW more than one nuclear plant. The system would need less reserve capacity with ten OTEC's than with a nuclear plant. A substantial part of reserve capacity is provided with gas turbines which supply power quickly to meet peak loads. They have much lower capital costs (but higher fuel costs) than nuclear plants or OTEC's. In 1976 dollars, about 110 \$/KW is typical. For the example selected, the breakeven cost for an OTEC would be increased by about 40 percent added capacity credit, or 44 \$/KW in terms of gas turbines displaced.

APPENDIX D

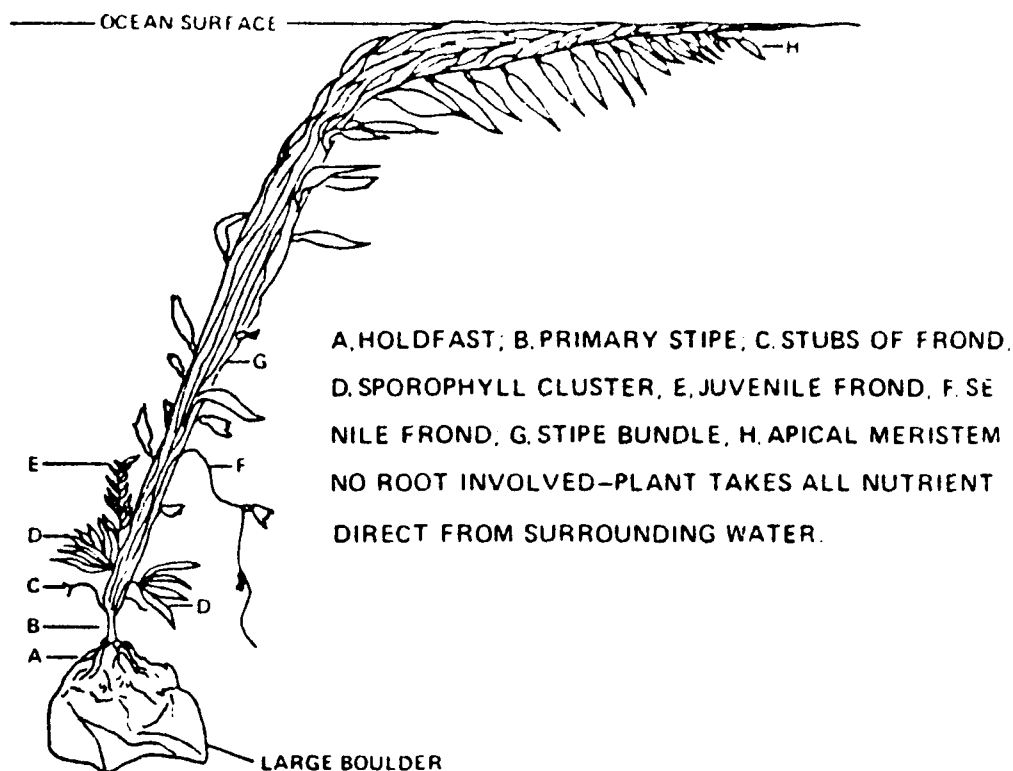
BACKGROUND ON OCEAN FARMING

The Naval Undersea Center (NUC) at San Diego is responsible for an Ocean Farm project, directed by Dr. Howard Wilcox and sponsored by ERDA, the American Gas Association, and others. The following description of the project is based upon reports by Wilcox (March 1976 and August 1976), and by Integrated Sciences Corporation (Budhraj, et al, 1976), except as otherwise noted.

Kelp Cultivation

Dr. Wheeler J. North, of the California Institute of Technology, is investigating the growth in open ocean environments of giant California kelp (*Macrocystis pyrifera*). This plant was chosen for several reasons: considerable knowledge already exists concerning its culture; harvested commercially in California for 60 years, there is an extensive record of operating experience and utilization; *Macrocystis* displays high productivity, usually being harvested two to three times annually; and *Macrocystis* populations create a forest-like habitat for many animal species useful to man.

Macrocystis pyrifera is a seaweed belonging to the order Laminariales (about 30 genera) of brown algae. A young adult plant is shown in Figure D-1. Found in cold ocean waters, the giant California kelp withstands temperatures down almost to freezing, and up to about 68°F (20°C). Mann (1973) reports peak growth rates of *Laminaria* off Nova Scotia as temperatures close to 0°C. Varieties capable of withstanding temperatures higher than 20°C are found along the coast of Mexico, but they have not been studied as intensively as *Macrocystis*. At a temperature of 20°C, *Macrocystis* will survive for perhaps one month; at 72°F (22°C),



Source: Wilcox, *Ocean Farming*, Bioconversion Conference, March 1976.

Figure D-1. Diagram of young adult *Macrocytis* plant.

about two weeks; and at 77°F (25°C), only two or three days.* Thus, an interruption in the supply of upwelled cold water could cause loss of the marine biomass crop if ocean-farming sites are in warm surface waters with strong sunlight for productive ocean farming (and most suitable for OTEC).

Nutrients are taken from surrounding water rather than from a local soil supply (Mann, 1973). The kelp plant is anchored to the bottom (or to an artificial substrate) by a holdfast (Figure D-1). Normally, the air bladders of the kelp plant produce an upward pull of one or two pounds (0.5 to 1 kg) on the holdfast; it is capable of withstanding greater forces, but is often pulled loose by coastal storms. Another threat is the sea

* Personal communication, Dr. Wheeler J. North, October 1976.

urchin which feeds on kelp and may eat away the holdfast, decimating a kelp bed as a group of urchines moves through.

The NUC Ocean Farm project has made several important findings by constructing and operating three small marine farms in depths of 150 to 500 feet (46 to 160 meters) with kelp plants moored on artificial substrates 20 to 40 feet (6 to 12 meters) beneath the water surface. The most important finding as reported by Dr. North (1976) is that *Macrocystis* appears unable to accumulate sufficient dissolved nutrients from surface waters to support normal growth rates in deep sea settings. (See also Othmer and Roels, 1973.) Other findings are that kelp nourished with sea water collected from depths of 250 to 1,000 feet (75 to 300 meters) display high growth rates. No evidence of toxicity has been found (North, 1976). Production of cultivated kelp is projected to be an annual 340 tons per acre (125 MT per hectare), wet weight, compared to a maximum productivity in coastal beds of 100 tons per acre (45 MT/ha) per year. Based on insolation per acre (0.4 ha) of 20 billion BTU (21 terajoules) per year, up to 2 percent may be captured and stored--400 million BTU/acre/year (171 GJ/ha/annum).

The Naval Undersea Center proposes to construct an experimental 100,000-acre (40,500 ha) ocean farm, located 100 miles (63 km) off the coast of Southern California. Either mature kelp would be transplanted to the ocean farm or young plants cultured in a laboratory would be emplaced (Figure D-2). To support the kelp plants, triangular substrates 1,000 feet (300 m) on a side (roughly 10 acre (4 ha)) would be formed from polypropylene lines, maintained in tension by diesel-powered propulsors of 2.3 hp per acre capacity (1 hp per hectare). The propulsors also provide dynamic positioning, at a speed of 1 knot (1.9 km/hr). Wave-or wind-actuated pumps upwell water from a depth of 300 feet (100 m) to be distributed through the kelp for nourishment and cooling. Five acre feet/acre/day ($2,500 \text{ m}^3/\text{ha}/\text{day}$) of deep water would be upwelled and distributed, which is expected to require less than one horsepower per acre-foot ($1,234 \text{ m}^3$) of water per day.

Harvesting

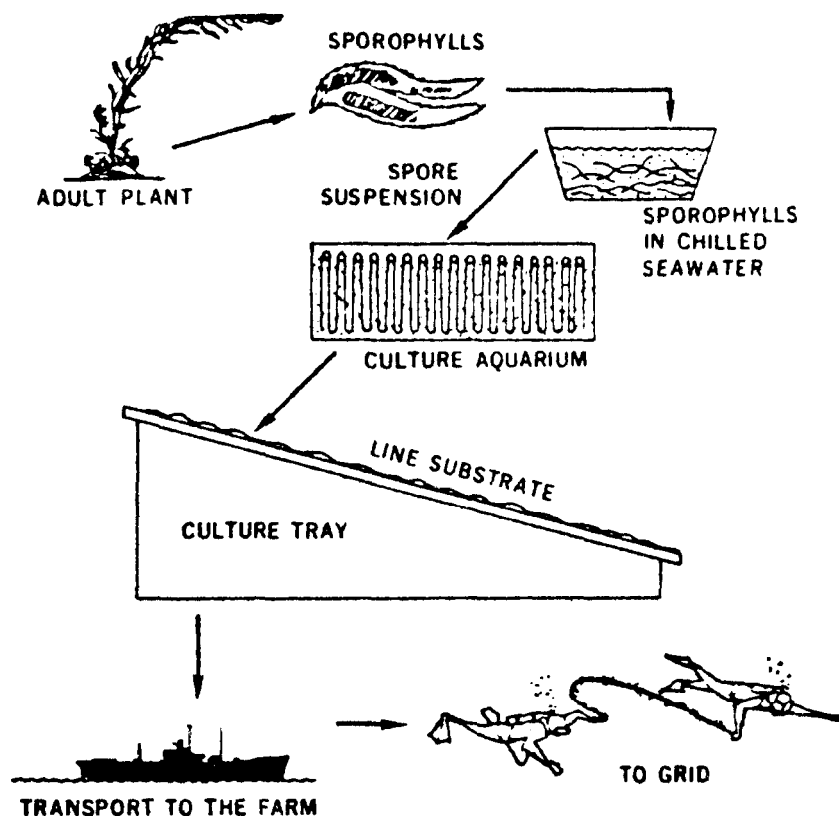
Macrocystis reaches lengths of over 200 feet (60 m) and can reproduce its own weight every three to six months. Following normal practice in coastal kelp beds, harvesting would be carried out by special vessels which cut off the upper portion of the fronds (Figure D-1) at a depth of three to five feet (1 to 2 m) and bring the cut kelp aboard over the stern. With shading from the upper fronds thus reduced, sunlight available to produce growth is increased. Some authors have characterized harvesting of coastal kelp to foraging, as compared to systematic farming (Beleau, Heidelbaugh, and Van Dyke, 1975).

Harvesting frequency would be four to six times per year, about twice as often as in coastal California kelp beds. Ocean-farm harvesting vessels would be large, about 25,000 DWT (or MT) in size. The vessel would chop the kelp after cutting it, and transport it to shore.

Processing

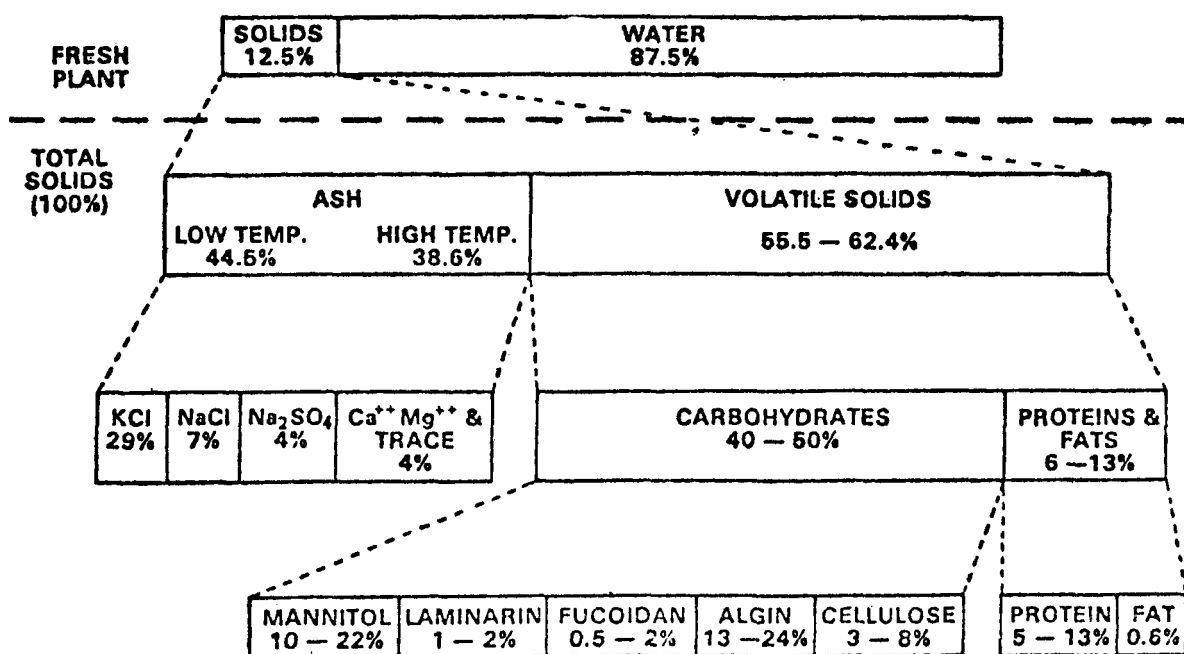
Giant California kelp has been harvested commercially for 60 years or more. It is a source of minerals and of algin, useful to prevent crystallization and as a suspending and emulsifying agent in the ice cream, baking, rubber, and paint industries. Alginates are also used as suspending agents in a wide variety of pharmaceuticals (Vestal, 1971).

The composition of raw kelp is shown in Figure D-3 and Table D-1. The processing strategy is diagrammed in Figure D-4. Basic to the processing strategy is the utilization of low temperature, low pressure anerobic digestion technology to reduce capital costs and energy loss. The relatively low energy content of kelp (590 Btu per fresh pound or 0.33 kcal per fresh gram; 4,700 Btu per dry pound or 2.6 kcal per dry gram) indicates that the energy expended in processing must be kept to very low levels. One of the keys to successful conversion is low-cost salt removal, leaving an energy-rich raw material of high organic polysaccharide and protein content. (All of the carbohydrates in the plant, except mannitol, are polysaccharides.)



Source: Wilcox, *Ocean Farming*, Bioconversion Conference, March 1976.

Figure D-2. Kelp culture technique.



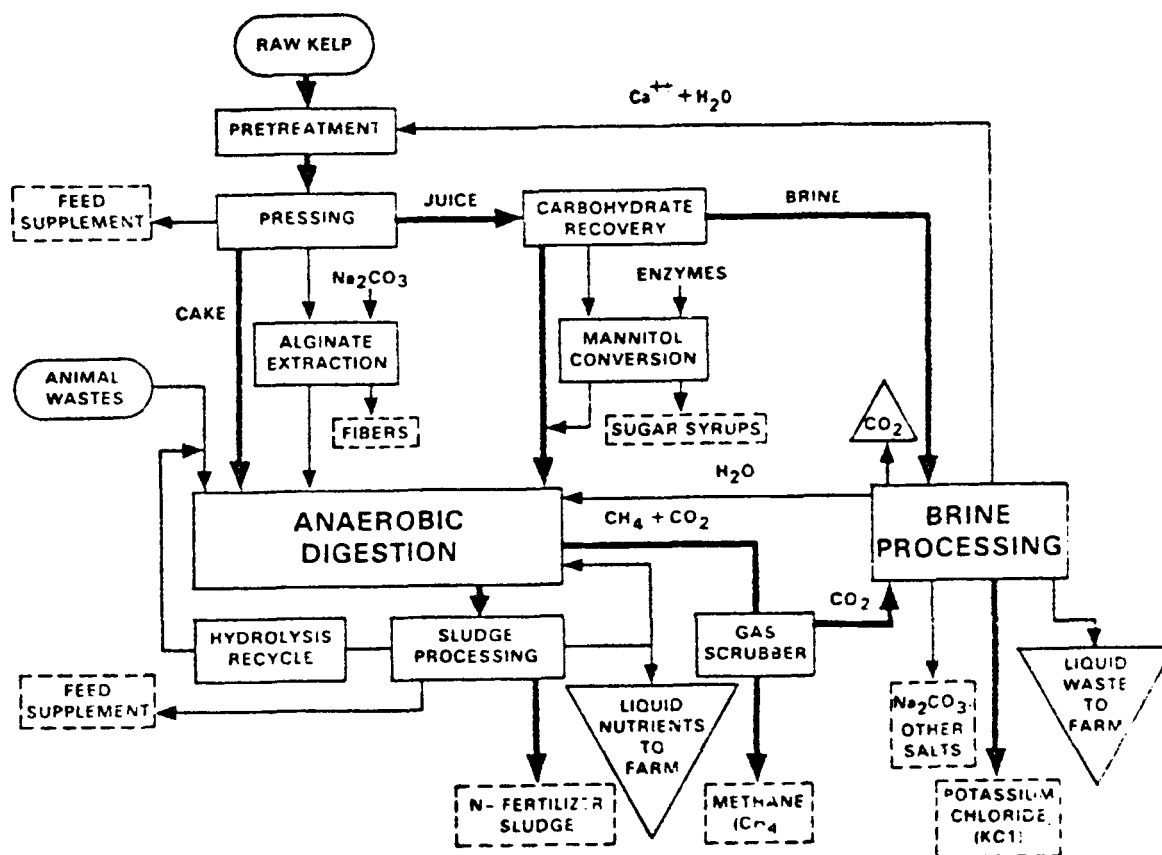
Source: Wilcox, August 1976.

Figure D-3. Raw kelp composition.

Table D-1. Major kelp constituents.

Kelp, Compounds	Sugar Residue	Formula	Heat of Combustion Btu/lb
Algin	Mannuronic Acid Guluronic Acid	$C_6H_8O_6$	7794
Laminarin	D-Glucose	$C_6H_{10}O_5$	6642
D-Mannitol	D-Fructose	$C_6H_{14}O_6$	6246
Fucoidan	Fucose	$C_6H_{10}O_5$	6732
Cellulose	D-Glucose	$C_6H_{10}O_5$	6732
Proteins	---	$(CH_2)_n(NH_2)_mO$	---
Macrocystis (overall)	---	---	4743 (1 Btu/lb = 2.3 joules/g)

Source: Wilcox, August 1976.



Source: Wilcox, March 1976.

Figure D-4. Kelp processing strategy.

Methane production from raw chopped kelp has been achieved by the Institute of Gas Technology and by the Naval Undersea Center. A digestion efficiency of about 50 percent is expected, using thermophilic (heat-loving) bacteria. Conversion may be achieved in three to five days of retention time. Because the carbon/hydrogen ratio in kelp is approximately 6.28 by weight, hydrogenation is not required when converting kelp into pipeline-quality SNG. As a rule, raw materials used in synthetic fuel processes (e.g., coal) have relatively high carbon/hydrogen ratios and require substantial processing: hydrogenation by pyrolysis, by direct reaction with hydrogen, or by indirect hydrogenation using water as a source of hydrogen (Hammond and Baton, 1976, p. 409). Biological processing raw kelp is a low-energy approach to convert the kelp constituents from an oxidized state to the reduced state characteristic of gaseous or liquid fuels.

To optimize capital costs, the anerobic digesters will be sized for economically efficient gas production; conversions of 50 to 60 percent will be accepted. The remaining digester sludge will be composed primarily of refractory compounds which degrade only slowly in anerobic digestion, but are rich enough in energy and nutrients to be used as terrestrial or marine animal feed supplements, or as a low-to-moderate grade nitrogen fertilizer (without the virus hazards associated with sewage sludges).

Beleau, Heidelbaugh, and Van Dyke (1975) studied the composition and processing of kelp and its suitability as a feed for livestock. In digestibility trials reported by Garrett (1974), sheep were fed pelleted rations containing 20, 30, and 40 percent of the diet. The estimated digestion coefficients for various components of kelp varied from 17 percent for crude fiber to 62, 65, and 70 percent respectively for organic matter, crude protein, and nitrogen-free extract. Pilot plant trials by Beleau, Heidelbaugh, and Van Dyke tested potential methods for processing kelp. Chopped kelp was processed by flushing with a solution of hydrochloric acid (pH = 1.4) or by flushing with the acid solution followed by hot-water blanch flushing at approximately 150°F (65°C).

The product was then expressed in a belt platen press. The final

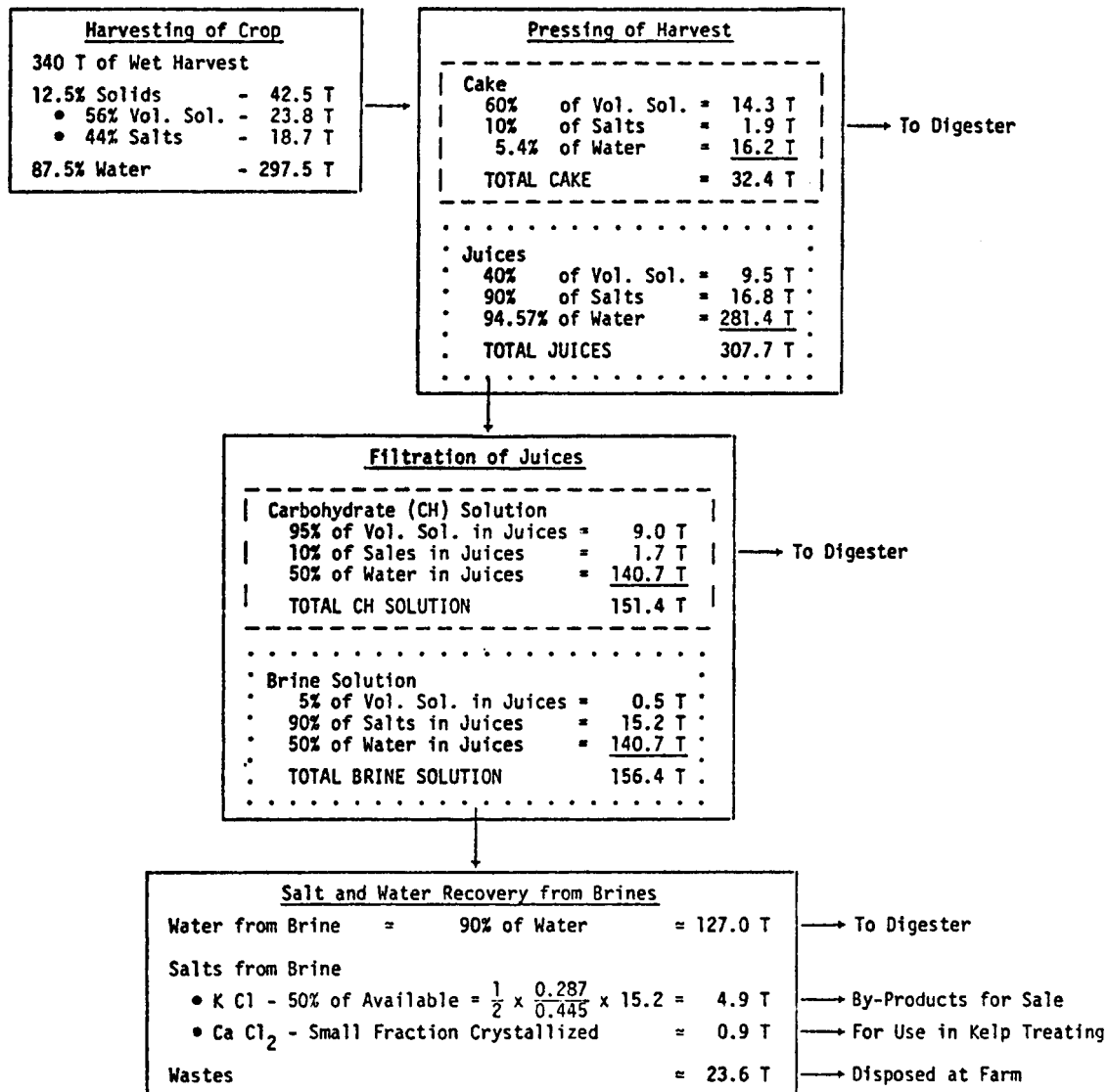
product was "a free-flowing, flaky, dark green mass resembling pressed alfalfa, having a faint, but pleasant, seaweed odor." The authors feel that the acid flush may be dispensed with, and only the hot water blanch used, to disrupt cell walls so that water can be expressed by mechanical pressure. (Until the energy crunch, processing of kelp involved heating to remove the 88-percent water content--an approach now too costly to consider.)

Tables D-2 and D-3 show the materials balance during pretreatment and during processing of kelp. The chopped kelp is transported via a pipeline from the shore, where it is brought by the harvesting vessel, to the inland processing plant. The processing plant is assumed to be sited in the California desert approximately 25 miles from the coast, to gain the advantages of readily available inexpensive land and a good influx of solar energy.* Tables D-2 and D-3 describe a "baseline design" whose configuration and operating characteristics were "finalized through a series of interactions with the project management and advisors." It is viewed only as a "possible design" for system study and economic analysis by Integrated Sciences Corporation to obtain order of magnitude estimates, and is not to be considered as necessarily the best or optimally configured design.

Table D-4 is Integrated Science Corporation's financial analysis of the baseline design of the 100,000 acre ocean farm (Budhraj, et al, 1976). The bottom-line, first-year cost of synthetic natural gas (SNG, \$12.3/ thousand cubic feet ($\$0.35/\text{m}^3$) is far too high to be competitive; however, even at \$4.91/thousand cubic feet or million BTU, the average SNG cost is much higher than the \$2.00/million BTU (adjusted from 1974

*The source of water presumably needed for mixing with the chopped kelp to transport it in slurry from through a 25-mile pipeline is not discussed by Budhraj, et al. If an amount of water equal in weight to the kelp were used to transport the 34 million tons per year of kelp expected from the 100,000 acre ocean farm, the 34 million tons of water would cost \$7.5 million/year if 25,000 acre-feet of fresh water at \$300 per acre-foot could be obtained and was used. If sea water is used, at 35 grams/ salinity, 1.2 million tons of salt per year would be carried to the processing plant.

Table D-2. Annual materials flow during pretreatment
(quantities in tons per acre of ocean farm).



Source: Budhraj and others, 1976, p 17.

To Transmission Pipeline

D-10



Table D-4. Summary financial analysis - baseline design
(10^5 acres - annual SNG output = 22.1×10^9 cu ft/yr).

<u>COSTS*</u> (In Million \$)	
Plant Investment	
Cultivation	260.9
Harvesting	133.8
Processing	156.9
Support	<u>18.0</u>
TOTAL	569.6
Farm Start-up Costs	177.2
Annual Operating Expenses	
Cultivation	11.0
Harvesting	17.4
Processing	24.1
Support	<u>8.9</u>
TOTAL	61.4
Working Capital	9.2
<u>ANNUAL BY-PRODUCT CREDITS</u> (In Million \$)	
	43.2
<u>SNG COST</u> (Utility Financing Method) †	
Average Annual SNG Cost = \$ 4.91/thousand cu ft	
First Year SNG Cost = \$12.53/thousand cu ft	
* All costs 1976 \$.	
† Including interest at 9 percent, income taxes at 48 percent, return on equity at 15 percent, operating expenses, depreciation, and insurance.	

Source: Budhreja, et al, 1976, p 31.

to 1976 dollars) for coal gas which is projected for the 1985-1990 time frame by FEA's Project Independence *Facilities* report (1974, p. VII-71). The economic feasibility is not apparent.

MARICULTURE

The mariculture subsystem is designed to be noncompetitive and non-interfering with the kelp farm. The design draws upon a considerable amount of analysis and experience, but little of the experience has dealt directly with open-ocean mariculture.

Ryther and others (1972) and Othmer and Roels (1973) discuss the potential returns from mariculture, and the limiting conditions; very large yields of animal life (e.g., 1 ton of trout per 14 m^3) can be obtained by circulating nutritious water through tanks, whereas plant

growth is limited by photosynthesis and available insolation, as on land. Roels (1975) describes successful culture on St. Croix Island of algae, shellfish, crustaceans, and red seaweed, using water pumped continuously from a depth of 2,800 feet (870 m) through successive pools and tanks. He urges that the economic value of mariculture be recognized, in the hope that those designing OTEC plants will keep in mind that antifouling compounds or construction materials such as copper used in OTEC, may "completely eliminate the possibility of mariculture and poison the existing marine environment." Contacted at Port Aransas, Texas, where he now directs the University of Texas' Port Aransas Marine Laboratory, Dr. Roels described experiments with discharging at the surface water from a depth of 2,600 feet (800 meters), at a rate of 3,500 cu ft/min (100 cu meters/min). Sinking and rapid dilution of tracer dye were observed from aircraft and by divers. Dr. Roels now believes that an open ocean "marine pasture" of plankton is infeasible; he concludes that containment of algal growths and marine animal crops is essential. Otherwise, the impact of the deep water on productivity will be insignificant. He plans to design and test floating containers. He firmly believes that OTEC and mariculture must be combined, to utilize cold temperature and nutrients of upwelled deep water, for either OTEC or open-ocean mariculture to make economic sense."^{*}

For the proposed NUC mariculture operations in conjunction with ocean farming, the two marine animal crops would be kelp bass and oysters. Kelp bass productivity has been estimated from studies of fish populations attracted to an artificial substrate placed in sandy bottom regions previously devoid of kelp bass. The standing crop was estimated to be 4.6 tons per acre (1.8 MT/ha) for all fish species. The kelp bass harvest is assumed to be 40 percent of the standing crop, or 1.84 tons per acre (0.74 MT/ha) per year. Oyster racks would be placed in a 12-mile (19 km) strip 110 yards (100 meters) wide along the down current edge of the farm. Based on experience with Japanese oyster culturing, a yield of about 36 thousand tons per year is expected, based on an uptake of the

^{*} Personal communication, October 1976.

equivalent of 3 percent of the upwelled nutrients. At a value of two-thirds of the ex-vessel price, credits are estimated to be \$83 million per year for kelp bass and \$54 million per year for oyster.

Table D-5 summarizes Integrated Sciences Corporation's financial analysis of the combined ocean farm and mariculture operations. The total expected SNG output is unchanged. The investment increases by 7 percent, or \$40.1 million. Start-up costs are not expected to change significantly. The operating costs, however, increase by almost 120 percent. This is attributed to the labor-intensive operation of the mariculture subsystem as well as the cost of procuring feed either from commercial sources or by purchase from the processing subsystem. The mariculture subsystem is then expected to contribute \$137.3 million in credits per year, or 320 percent more than the processing subsystem. The estimated reduction in SNG cost is 36 percent, to \$3.65/thousand cu ft, million BTU, or gigajoules.

Feed for the kelp bass will consist mainly of pellets manufactured from processed sludge, believed to be feasible but yet to be demonstrated commercially. Food for the filter-feeding shellfish (oysters) along the edge of the arm would be plankton, which are assumed to be present as a native background population (in contrast to being brought to the ocean farm as the kelp would be) and to take up 5 percent of the nutrients in the water.*

* Personal communication, Mr. Nicholas Anderson, October 1976.

Table D-5. Summary financial analysis - baseline design with mariculture
(10^5 acres - annual SNG output = 22.1×10^9 cu ft/yr).

<u>COSTS*</u> (In Million \$)	
Plant Investment	
Cultivation	260.9
Harvesting	133.8
Processing	156.9
Support	18.0
Mariculture†	<u>40.1</u>
TOTAL	609.7
Farm Start-up Costs	177.2
Average Annual Operating Expenses	
Cultivation	11.0
Harvesting	17.4
Processing	24.1
Support	8.9
Mariculture†	<u>74.0</u>
TOTAL	135.4
Working Capital	9.2
<u>AVERAGE ANNUAL BY-PRODUCT CREDITS</u> (In Million \$)	
Processing	43.2
Mariculture†	<u>137.3</u>
TOTAL	180.5
<u>SNG COST</u> (Utility Financing Method)‡	
Average Annual SNG Cost = \$ 3.65/thousand cu ft	
First Year SNG Cost = \$11.27/thousand cu ft	
* All costs 1976 \$.	
† Kelp bass and oyster mariculture only. Priced at two-thirds of ex-vessel price. Treated as a separate activity by the private financing method.	
‡ Including interest at 9 percent, income taxes at 48 percent, return on equity at 15 percent, operating expenses, depreciation, and insurance.	

Source: Budhraj, et al, 1976, p 33.

OTEC, Ocean Farming, and Mariculture

Two elements required by ocean farming and mariculture that will be produced by OTEC have been identified in the foregoing and will now be discussed: deep water nutrients, and temperature conditioning. A third element which also deserves scrutiny, use of OTEC electrical energy for positioning and for upwelling, will then be discussed.

Cold Water Availability

A review of the cold-water systems of the University of Massachusetts desing (UMass, 1975) and of the Lockheed Missiles and Space Company (LMSC, 1975) shows that both systems pump very nearly the same amount of cold water per day. The UMass vessel is designed to produce 400 MW_e net output, the LMSC design 160 MW_e (40 MW_e net from each of four modules). The UMass design cold-water flow is $3.6 \text{ cu meters/MW}_e/\text{sec}$; LMSC, $11.3 \text{ cu meters/MW}_e/\text{sec}$. Converting these unit flow rates to units of total acre-feet per day (AF/day), at full capacity the UMass OTEC would pump 10^5 AF/day and the LMSC OTEC $1.25 \times 10^5 \text{ AF/day}$.

NUC's 100,000 acre (40,500 ha) ocean farm is expected to require five acre-feet of cold water per acre per day ($2,500 \text{ m}^3/\text{ha/day}$). Only about 20,000 acres (8,100 ha) of ocean farm could be "irrigated" by either the UMass or LMSC system. Even though the 20,000-acre farm would be only 5.6 miles (9 km) on a side, rather than 12.5 miles (20 km) on a side as for 100,000 acres, the distance to transmit and distribute cold water from an OTEC vessel would still be substantial.

Setting aside for the time being the important questions, not yet answered, about the cost of moving the entire cold-water discharge of an OTEC vessel or platform into an ocean farm—the required pump capacity, conduits, pumping energy, capital and operating expense—it is useful to consider whether OTEC would benefit by having a "market" for the cold-water discharge from condensers. Dr. S. Piacsek of the Naval Research Laboratory, Washington, D.C., is studying the fluid dynamics and near-field flow of warm and cold water around OTEC installations. Dr. Piacsek feels sure that mixing of the cold and warm waters will occur (an oversimplified condensation of his extensive investigations and reports on his work), and that there is a possibility of some benefit to the OTEC process if the cold water were piped away to an ocean farm. He agreed that analysis of this possibility would be workth considering.*

* Personal communication, October 1976.

Fate of Cold Water

A question of prime importance to the feasibility of utilizing deep, cold water to nourish and temperature-condition an ocean farm is: Will the cold water be sustained at or near the surface long enough to permit nutrients to be extracted? Various authorities, asked for an opinion, differed significantly in their answers.*

As mentioned earlier, one respected experimenter, Dr. Oswald Roels, has concluded that the cold water must be contained rather than being allowed to move downward. Dr. Norman Brooks of the California Institute of Technology is an internationally known authority on design of ocean outfalls to discharge waste water in an environmentally acceptable fashion; his work, and that of his colleagues, is a basis for predicting behavior of plumes of warm water rising to an equilibrium level in ocean waters of varying temperature and density. Dr. Brooks points out that a density difference of few parts in ten thousand will induce vertical movement, because the ocean density is very stable; he would expect downward motion of cold water released at the surface.

Dr. Piacsek feels that horizontal motion will mix cold water with warm surface water -- presumably, the situation in distributing the cold water supply from an OTEC vessel to flow throughout a down current ocean farm -- and the mixture will be sustained for a considerable period of time. Dr. Wheeler North expresses much the same view, and comments that kelp can extract needed nutrients from the upwelled water in an hour or two. Dr. Howard Wilson at the Naval Undersea Center apparently has encountered the spectrum of viewpoints on whether cold water will be sustained at the surface, and reports NUC findings. Downward movement, according to Dr. Wilcox, is about an order of magnitude slower than would be expected from accepted theory. Experimentally, it has been found that dispersing the cold water horizontally, thus mixing it with warm surface water which is in motion due to wave action, and which

*What follows is a synopsis of expert opinions which is intended only to reflect what was said in brief, telephone discussions; it is not to be considered as verbatim reporting.

contains kelp plants, results in the mixture sinking to only about 20 feet (6 m) below the water surface. No theory or applicable model has yet been developed to fit these observations.

APPENDIX E

COST REDUCTION TREND PROJECTION METHODOLOGY

Estimates of early production costs of almost all innovations are higher than the costs expected when the product is mature and mass production experience has been gained. Frequently, the early production cost is greater than the price of competing products; in making a decision to enter a market, industry must rely with some confidence on a cost trend that will reduce costs to a competitive and profitable level before negative cash flows (investment) become excessive.

Advanced energy conversion means, such as the various forms of solar energy: photovoltaic, solar thermal, and OTEC have this problem. The current state of the art, used in small quantity production, will not give a cost competitive with the more mature products already available. Historic trends in related types of products can aid in estimating the amount of production experience required before it becomes competitive, and the amount of investment required to reach this point. The amount of investment required may be excessive for a single firm to consider so that consortia of firms, and joint support by industry, customers, and government are used to share the risk and the investment burden. Nuclear power and military/commercial aircraft are examples where shared investment has bridged the gap to where production costs are competitive.

Trend data on production costs received much attention during and after World War II under the name "learning curve." The emphasis was on the observed fact that the production cost, and particularly the direct labor cost in man hours required per aircraft, tank, or other equipment,

declined in a predictable way. The direct labor cost per unit varied with the cumulative production of the product or model as:

$$\frac{C_n}{C_{n_0}} = \left(\frac{n}{n_0} \right)^{-k} \quad (E-1)$$

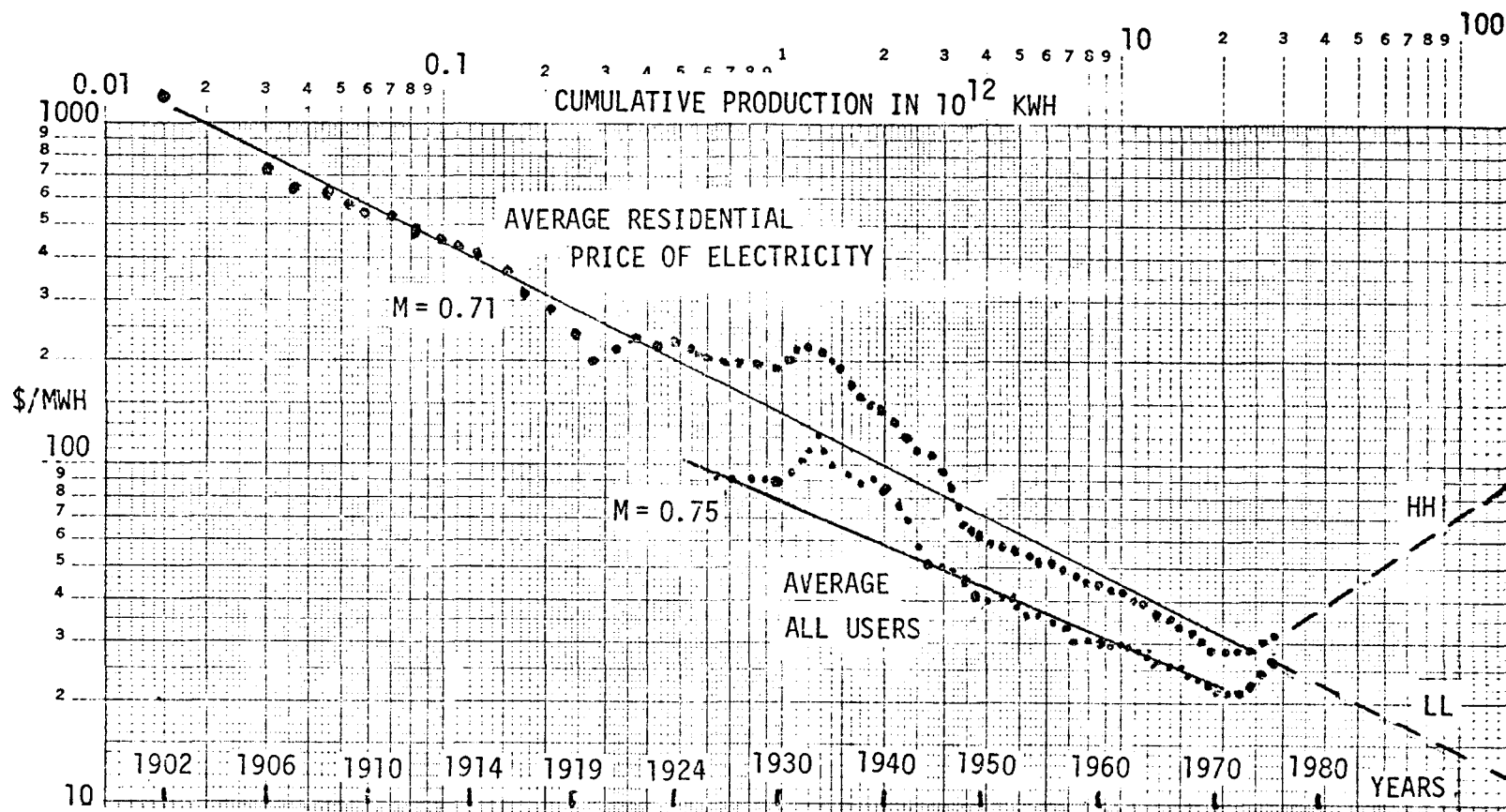
which on log-log coordinates is a straight line of slope $-k$. Here n is the cumulative production to date, n_0 may be 1 or some low production level by which start-up problems have subsided, and C_n and C_{n_0} are the direct labor cost of units n and n_0 .

The learning curve was often described by the factor m by which cost declined for each doubling of cumulative production to date. This factor M is related to k , by $M = 2^{-k}$, or $C_n/C_{n_0} = (n/n_0)^{\log M / \log 2}$. The literature of that period indicated values of m for various production aircraft of 0.6 to 0.95 (Asher, 1956).

For continued production of almost identical units, reduction in the direct labor component of cost is most noticeable, as caused both by improvements in skill of the labor force (learning) and improved jigs, fixtures, and other labor saving aids. A functional product modified over time by improved materials, design improvements increasing efficiency and decreasing weight, economies of scale, and even major technology changes shows similar cost reduction trends over much longer periods than the production run of a particular model. While this trend is sometimes still called the learning curve, such terms as "experience curve," production curve, and cost improvement curve have been used. Experience curve is used here to emphasize that all cost components, not just direct labor, are considered.

An example of historic trends in the price* of an unchanging product is shown in Figure E-1. The residential price of electricity and the

* Price data is often more easily obtained than production cost, and may be satisfactory if it can be assumed that profit, low or high, is a reasonably constant percentage of cost.



Source: Residential — EEI — Historical Abstracts Tables 61 and 10.
 All users — J.C. Fisher — *Energy Crises in Perspective*

Figure E-1. Historic experience on electricity prices (1975 dollars).

average price to all users are shown. The latter is described by J.C. Fisher (1974). The former was derived from Edison Electric Institute data and U.S. Department of Commerce (1960). Both are converted to real dollars (1975 base year) to remove long-term inflation effects. Fisher uses the GNP deflator, and for the residential rate the consumer price index (CPI) was used.

Over a 70-year period the value of M was 0.71^{*}, and the total decline in real terms is a factor of 30. While the delivered product, a kilowatt hour of electricity, did not change, the means of producing it showed continual changes in scale size of generating units, changes in fuel, improvements in efficiency, increased unit consumption by residences (changing unit distribution costs), and introduction of many new technologies such as nuclear and gas turbine plants. Fisher similarly shows values of M between 0.75 and 0.80 for cost of coal to utilities and the cost of processing crude oil and distributing it as gasoline.

There are perturbations in these experience curves. Most of them can be explained in terms of contemporary events. The large capital investment in utility plant gives annual costs that change more slowly than short inflation and deflation periods. The sharp inflation in 1918-1921 shows as a drop in the real cost of electricity. The deflation and reduced electricity demand in the 1929-1938 depression increased its real cost to consumers.

In view of the long historic trend it is a reasonable question to ask whether the future price of electricity will follow the recent trend since 1972, as shown by dotted line HH or will again become parallel to line LL. These extreme high and low scenarios probably bracket the range of future projections. Conservatively, a constant or slightly declining price projection for electricity is generally used by TEMPO and GE planning components. While such a decline faces OTEC and other new technologies with a moving target, it may be that OTEC will be a significant contributor to the decline when it is a mature product.

* Sometimes expressed as 29 percent decrease per doubling.

LEARNING CURVE FUNDAMENTALS

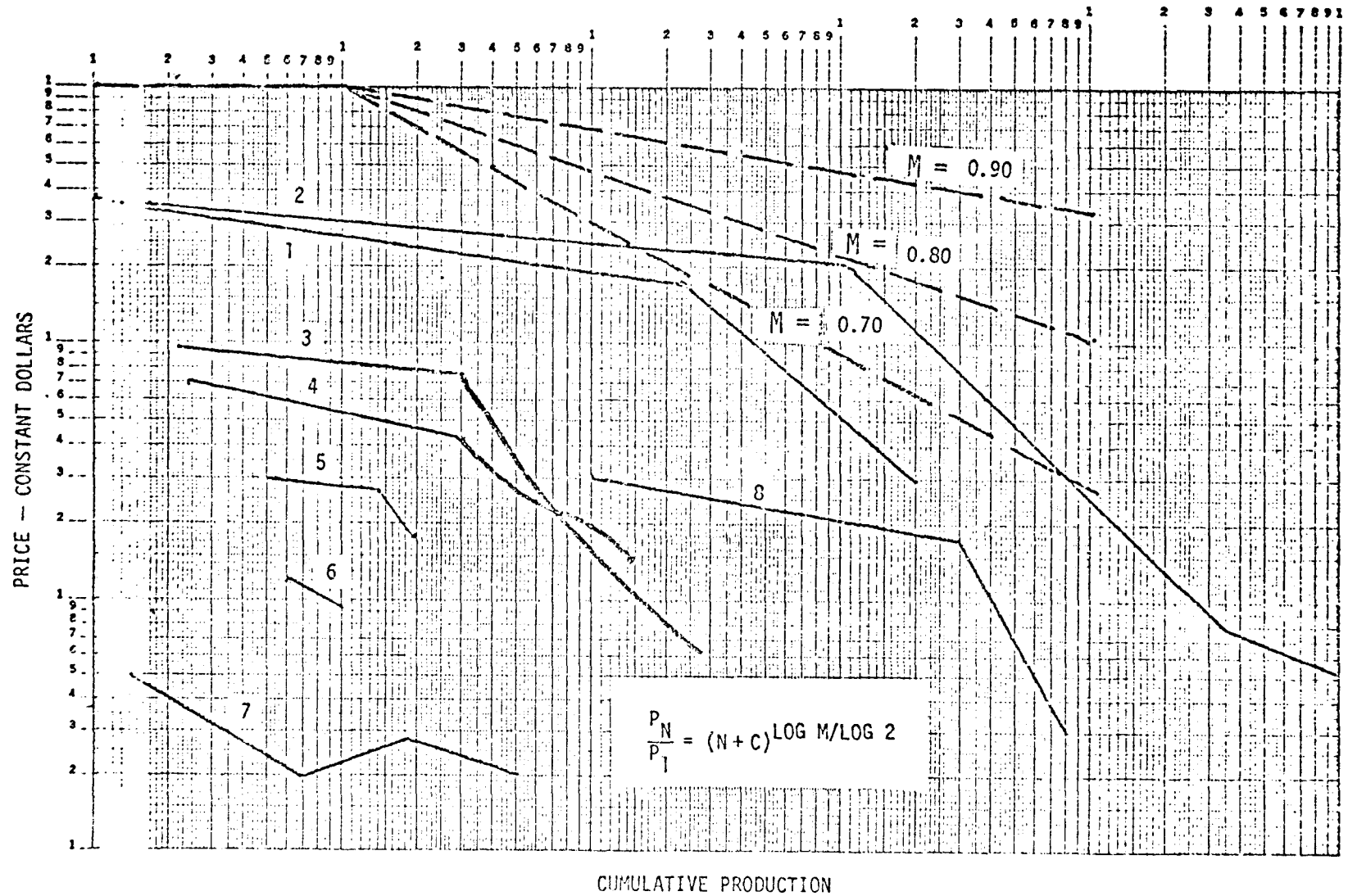


Figure E-2.

Some perspective on the values of M found for a wide range of components and products, and the factors governing the shape of experience curves are best explained using Figure E-2. A number of actual experience curves from various sources are approximated by straight lines that closely match the actual point data. The curves, identified by numbers, represent:

1. Germanium Transistors
2. Silicon Transistors
3. Germanium Diodes
4. Low Density Polyethylene
5. Free Standing Electric Ranges
6. Refined Sugar
7. Primary Aluminum
8. Photovoltaic Cells

That is, a variety of materials, components and consumer products. Most of these curves comes from the Boston Consulting Group (197_) which treats the experience curve as an important management tool to be used in planning, in investment decisions, and in pricing policies. Since the production quantities and unit prices vary widely for these examples the scales should be considered as relative.

Some general observations about these curves are that it is not unusual to have more than an order of magnitude drop in price over many doublings, but seldom two orders of magnitude. There are undoubtedly exceptions in the computer field where the cost per multiplication or per memory cell has declined by many orders of magnitude over several generations of technology changes. Many of the curves have regions where the slope M is steeper than 0.70. These are often preceded and sometimes followed by regions with M between 1 and 0.9. For guidance the slopes $M = 0.90$, 0.80 , and 0.70 are shown.

Users of the experience curve as a planning tool warn against expecting a steep curve to start with unit 1. The first 10 or 20, or thousands in the case of small components, may be erratic and both increase and decrease in cost. They are a small statistical sample, design changes are likely, mistakes are made and corrected, and

research and development costs are fairly arbitrarily allocated among them. Another perhaps more significant cause of an almost flat region in early production is that many parts of the product are not completely new. They may represent prior experience that effectively makes them unit 10, 100, or 1000. The first 100 units produced, which represent over six doublings starting from unit 1 will represent only three doublings starting from unit 10, one from 100, and a small fraction of a doubling from unit 1000. However, going from unit 1000 to unit 8000 represents almost three doublings for all of these parts.

Stanford Research Institute (Asher, 1956) has suggested that:

$$\frac{P_N}{P_1} = (N + C)(\text{Log } M / \text{Log } 2)$$

is often a better fit. Here P_N is the price of unit N (or C_N for cost), and a constant C has been added to indicate that the average effect of prior experience is equivalent to starting with unit (C - 1).

Also observable on curves 2 and 8 is an eventual leveling off, ie, decrease in slope.* The occurrence of technological breakthroughs are undoubtedly one cause of cost reduction. A fairly smooth curve may reflect many small improvements; a major breakthrough in a component that represents a large part of the system cost causes a steep region. As the cost of this system component is reduced to where it is no longer a dominant part of the cost, a return to the smooth curve of accumulated minor improvements can be expected.

* The anomalous rise and fall for aluminum is not explained. Since most of these show price rather than cost, this may represent market fluctuation rather than cost changes.

APPENDIX F

BACKGROUND ON POLITICAL AND INSTITUTIONAL FACTORS

In the complex world in which OTECs will have to compete economically with other electric power generation systems; conventional economic considerations must be supplemented by a careful examination of their political and legal environment. These have the potential of impacting heavily on the economic viability of the OTECs.

We will divide our discussion into the high seas and the 200-mile economic resource zone. We will assume throughout this report that the 200-mile ERZ will be a fact of international life by the mid-1980s when the first OTECs will be deployed. While this is an important assumption, we believe that it has a very high probability of being realized. According to Mr. George Taft of the State Department's Office of the Law of the Seas, there are some serious disagreements about the precise form of the 200-mile economic resource zone, but there is widespread agreement that such a zone should exist. Dr. Norman Wolf of the NSF, expert on Law of the Seas, concurs that the ERZ concept will almost certainly become an accepted reality within a few years.

Although there are many factors which will differentiate operations on the high seas from those which are deployed in the ERZ, there are a few which are common to all American-manufactured OTECs. The most immediate of these will be the construction requirements imposed as a mechanism for environmental control. Other common factors are the import laws, onshore support and secondary developments, and a potentially dramatic increase in employment levels in selected East Coast shipyards.

Construction Standards

One of the primary methods of controlling pollution of the oceans from vessels has been through design requirements. For example, recent international requirements^{*} that new tankers have separate holds for ballast and for oil is a near certain means of controlling the old problem associated with the pumping of the bilges. In addition to domestic and international environmental controls, there currently exist a number of stringent domestic requirements for hull design and the handling of pressurized and/or flammable liquids which would be applicable to the OTECs.^{**}

One of the factors determining the applicability of these and other laws is the classification of the OTECs. According to Higgins,^{***} they will fall under the classification of a "vessel". Higgins states, "Although some courts have held that the watercraft must be practically capable of being used for transportation and must not be permanently located in one spot, the general rule followed by the courts in construing the term 'vessel' has been to give a very broad meaning to the term 'vessel'".

As a vessel (and more specifically an ocean going barge), the OTECs would have to meet existing Coast Guard structural requirements regarding hulls, decks, crew accomodation, etc.^{****} This is not likely to be a significant problem, however, since there will be very strong economic motivation to meet and exceed the standards of the American Bureau of Shipping. The OTECs will be quite expensive, relatively immobile, and located in hurricane prone areas. Thus they will have to be capable of withstanding heavier weather than is normally the case for most ocean-going vessels.

* International Convention for the Prevention of Pollution from Ships, 1973.

** 46 C.F.R. Part 92 (1974), 46 L.S.C. 170 (Supp 1975), and 14 U.S.C.

*** Higgins, James C., "Ocean Thermal Energy Conversion Plants: Federal and State Regulatory Aspects" in Legal, Political, and Institutional Aspects of Ocean Thermal Energy Conversion forthcoming.

**** Ibid.

Similar considerations also apply to OTECs' internal piping, etc. While they will be subject to Coast Guard requirements, the immobility of the OTECs and the associated servicing costs will create a strong motivation to provide a large safety margin. Probably the most significant federal regulations concerning the construction of the OTECs will be those relating to the presence of dangerous substances on board. The OTECs generating electricity and transmitting it back to land will incorporate freon, propane, and/or ammonia in their basic designs. OTECs used to manufacture various products will have numerous additional dangerous substances on board; such as, ammonia, chlorine, and liquid hydrogen. Federal law gives the Coast Guard authority to regulate the construction of any vessels carrying such substances. It can be anticipated that this authority will be exercised for all OTECs and particularly those for which there is a high probability of accidental spills of hazardous materials. By the powers given them by 14 U.S.C. 2, the Coast Guard can regulate the handling of such dangerous materials both through policing action and construction regulations both within the territorial seas and beyond. This latter power is supplemented by the 1958 convention of the high seas in which each nation has responsibility to regulate pollution of its own flag ships anywhere on the oceans.

Import Regulations

Because nations have jurisdiction but not sovereignty over the ERZ, all products passing from it to a port have crossed a boundary and are theoretically subject to import duties. Conceivably, this would apply not only to products such as aluminum or fertilizer manufactured on the high seas or in the ERZ, but also to electricity generated beyond the territorial waters and cabled back to the land. However, precedent, would indicate that this will be no problem for U.S. OTECs. Standard U.S. policy has been to exempt products manufactured at sea or extracted from the sea by U.S. flag vessels from import duties as long as there has not been an intermediate stop at a foreign port prior to unloading the product on U.S. land.* Thus as long as the OTECs shipped or transmitted their pro-

* Conversation with Dennis Wilner, Office of International Fisheries, Department of Commerce.

ducts directly to the U.S. there would be no reason to expect any import duties with which they would have to contend.

While there will be no import duties, states will have the right to tax transmission of electricity to a power grid on their land. The only limit on this tax is that it must not be so high that it discriminates against the OTECs. This condition is defined in section 1322 of the Federal Tax Reform Act. "No state...may impose or assess a tax on or with respect to the generation or transmission of electricity which discriminates against out-of-state manufacturers..." (emphasis added). The implication of this law is that non-discriminatory taxes are permitted. From this we can conclude that OTECs can expect neither a tax penalty nor a tax benefit as a result of operating out of state.

Related Onshore Developments

The impacts of OTECs on the onshore developments could well be the most serious problem which the proponents will have to face. The experience with the offshore oil rigs has shown that the associated onshore activities are at least as disruptive as the rigs themselves. Certainly if OTECs become widely used, they will face the same situation. The onshore development is, of course, a two-edged sword. It can provide a valuable economic stimulus to the local economy. However, the development, if not handled properly, can be chaotic and damaging to the quality of life in the community.

The most immediate onshore impact will be in the construction of the OTECs. Based on equivalent shipbuilding estimates from the Maritime Administration, it would appear that there would be approximately 1,500 to 2,000 manyears of shipyard labor per OTEC not including the effort to construct the fertilizer, aluminum, etc. factories to be linked with the power generation plants. If there are to be 80 to 100 OTECs built between the years 1985 and 1995, the effort is roughly the equivalent of one large nuclear carrier per year for ten years, costing approximately

10 billion dollars. This would be a very sizable infusion of money into the shipbuilding industry. If it were not handled carefully, this type of activity could easily create a disastrous boom town type of reaction. Inadequate housing for the workers, unprepared schools for the children, roads insufficient to bear the burden of increased trucking are the kinds of problems which will have to be faced.

In addition to the impact on the shipbuilding industry, the secondary industry problem is likely to be sizable (perhaps even larger than the shipbuilding impact). These will come from the factory OTECs. Immediately, of course, there will be the necessity for onshore storage and distribution of the products made on the OTECs. For example, if fertilizer were to be produced in large quantities, it would be necessary to build additional facilities for its distribution to the farming areas. The storage of chlorine or liquid hydrogen would be far from a trivial matter. Similarly, other sea chemicals would have to be stored and/or distributed.

More importantly, if there are to be sizable quantities of products; such as, sea chemicals, plastics, chlorine, or liquid hydrogen available at low cost near seaports, it is nearly inevitable that secondary industries utilizing them will develop. As with the shipbuilding industry, this will mean a need for careful planning so that any anticipated developments can be handled with a minimum disruption both to the environment and to the growth of the cities affected. Here again developments of this sort can have severe impacts on the environment, local transportation, schools, housing, sewerage, and other city services. While the growth may be a welcome stimulus to the economies of these areas, the short-term demands may outstrip the short-term increases in revenue.

Fortunately, as a result of the offshore oil development, the Department of Commerce now has a program to provide economic assistance to areas which are similarly affected. We were told in conversations with the cognizant legal representative of the Department of Commerce, Mr. Daniel Hoidish, that the regulations stipulate that the assistance

is available to those communities affected by off-shore energy projects. Therefore, any OTEC affected communities affected by off-shore energy projects would qualify.

In general, the development of stimulation of the local economies would be an asset. However, it should be recognized that the experiences of the oil rigs have sensitized both the government and a large number of environmental groups to these types of associated problems.* The operational impact is that these expansions will have to be planned carefully, insuring that schools, roads, noxious byproducts, housing, etc. meet reasonable demands by local residents.

Aquatic Environment

All international environmental issues will apply equally to OTECs located in international or territorial waters. International pollution regulations apply to any discharges on the oceans. The 1973 IMCO Convention for the Prevention of Pollution from Ships contains regulations pertaining to the discharges of noxious liquid substances carried in bulk. Appendix II of the report of that convention** lists the substances subject to regulation. If necessary, this list can be altered. It is clear that the OTECs will be subject to these regulations.

Additionally, it will be necessary to prepare an environmental impact statement (EIS) for all OTECs whether in international or territorial waters. The precedent has already been set to give potentially affected countries the right to comment on the statement.***

* See William Futrell, "Oil and Trouble in the Louisiana Wetlands" Sierra Club Bulletin, July/August 1974.

** Article 2 (4).

*** See Robert Stein "Cannikin" in International Responsibility for Environmental Harm, forthcoming, and Wilderness Society Vs. Morton 463 F.2d 1261 4 ERC 1101 (C.A.D.C. 1972).

The Environmental Impact Statement

One of the more difficult legal and institutional problems to be faced by the developers of OTECs is likely to be the preparation of Environmental Impact Statements (EIS). The deployment of an OTEC within the ERZ will require the writing and defense of an EIS showing that the OTEC will not cause unacceptable environmental degradation. Discussions with major researchers in the area^{*} indicate that there do not appear to be serious problems associated with upwelling or thermal pollution as long as the deployment is held within reasonable numerical bounds. Yet the experiences with unfavorable weather changes in Europe and Africa are nearly certain to demand very strong evidence supporting the contention that the OTECs will not alter water temperatures and particularly those related to the Gulf Stream. Additionally, we can expect that there will be numerous difficult questions relating to the potential for reduced bio-oxygen demand (BOD) levels in the areas surrounding the OTECs or the generation of excessive phytoplankton. Since the "red tide" results from a toxin-produced by phytoplankton, the specter of a perpetual "red tide" is certainly to be raised.

It must be recognized that the OTECs are a new technology about which there would be immediate environmental skepticism under any circumstances. The fact that they will be going into the oceans, now regarded as one of the last and most important environmental preserves only makes matters worse. Thus, benign as they may be, it is not unlikely that there will be a rather hostile response to the OTECs. Their acceptance will be precedent setting as a form of high technology placed in the oceans where the impacts could be felt by states and individuals far from the immediate occurrence of the act of pollution.^{**}

^{*} Dr. Oswald Rode of the University of Texas is studying the biological/ecological problem. Dr. Stwin Piacsek of the Naval Research Laboratory is the director of a project studying the thermal pollution effects of OTEC.

^{**} See also Hornbug, C.D., Lindal, B., and Ramley, "Preliminary Research on Ocean Energy Industrial Complexes" Final Report DSS engineers, 1976.

Other problems which are likely to occur in the U.S. economic resource zone must be attended to but are less likely to create serious problems.

Fishing

Several of these will involve the siting of those OTECs which are moored to the sea bed within the ERZ. The Corps of Engineers will probably have primary authority over the siting of these OTECs. This authority derives from the River and Harbor Act of 1899^{*} and the Outer Continental Shelf Lands Act.^{**} This jurisdiction is not certain because of the ambiguous State of Regulations concerning the ERZ outside the territorial sea. It is possible that principal authority could rest with the Department of Interior.

It can be anticipated that the major concerns of the siting will revolve around potential conflicts with fishing, environmental concerns, and navigation. The first two of these will be closely tied to the Environmental Impact Statements. If the location of an OTEC or set of OTECs were to lead to environmental degradation including the destruction or displacement of fish, the OTEC site could be denied. The Environmental Protection Agency would have this authority. Since OTECs require very deep water in tropical or subtropical climates, the opportunity for conflict with fisheries is not too severe. For example, although there is an extensive shrimp industry in the Gulf of Mexico where many of the OTECs are to be located shrimp fishing is done in shallow waters (less than 200 meters) where it would be impossible to site an OTEC.

The OTECs will probably share the same area of the seas with the tuna industry. Thus there is a potential conflict between the two. Because of the characteristics of actual operation of tuna fishing, it is not likely that there would be a serious problem of damages to nets or

^{*} 33 U.S.C. 402 (Supp. 1975).

^{**} U.S. Federal Register, 31319 (July 25, 1975).

fishing gear. However, if it were the case that the OTECs had an adverse effect on the tuna population, a conflict probably would develop. This conflict would most likely occur during the hearings for the EIS. If EPA were convinced that there were a reasonable chance of a negative effect on the tuna population, it would have the option of denying the siting permit. While we are not implying that such an effect is likely, we cannot emphasize too strongly that these types of questions will arise during the EIS hearings and the proponents of the OTECs will have to have strongly defensible answers.

Navigation

The other class of siting problems will center around navigation. Since the moored OTECs will have minimal means of controlling their locations within the radius of their tethers, they could become a serious navigational hazard. They do, however, have the advantage of being relatively distant from shore. Unlike an oil rig, they do not have a fixed location which can be charted on a map. Rather, they can drift extensively on their tethers. It has been estimated that when moored at 20,000 feet, the OTEC can drift on a 7,800-foot radius around the point at which it is moored. Clearly, if the OTECs were to be sited without taking navigational safety into consideration, the probability of collision would be increased.

The most obvious and reasonable approach would be to extend the safety fairway concept to the OTECs. A safety fairway is a shipping lane in which the captain of a ship can be assured that there will be no permanent man-made obstructions. The concept has been used successfully with the oil rigs in the Gulf of Mexico. Although it has no legal definition, Admiralty Courts have recognized them as reasonable guides to captains and have awarded damage suits accordingly. Since the Coast Guard currently issues monthly updates to its maps, ship captains could be kept informed of the locations of new OTECs.

Undersea transmission cable regulations present another OTEC deployment consideration. Even though the cables are to be buried, they could be snagged by the anchor of a large ship. We would not expect

that the transmission cables would create a serious problem unless the OTECs become numerous enough that there becomes a need to require designated anchorages. Even in the case of extensive use of OTECs, it would seem that in most cases, judicious selection of sites could resolve most anchorage conflicts.

The final navigational hazard refers to small craft. While major shipping vessels would be guided by the safety fairways concept, small craft could easily sail between the OTECs which will not be located any closer than three miles to each other. There has already been established the precedent of a 500-meter safety zone surrounding oil rigs. This basically means that no vessel may come within 500 meters of the OTEC unless it is servicing the OTEC.

Having outlined the expected regulations surrounding the OTECs, it is perhaps well that we discuss the probable configuration of the sites of a number of OTECs. Our own research indicates that because of the need for a maximum temperature gradient, OTECs down current from each other must be separated by a minimum of 30 miles. Otherwise the ΔT changes created by the upcurrent OTEC will decrease the efficiency of the one down current. Assuming a minimum of one-half knot current, the OTECs need be separated by only the sum of the lengths of their mooring cables across the current.

A possible configuration of OTECs is shown in Figure F-1. Here we see parallel lines of OTECs separated by 30 miles in direction of the current. Against the current, they are separated only by the length of the radius of movement on their tethers plus the 500 meter safety zone. Normally, the OTECs will not all be extended exactly in the direction of the major current because of winds and local variations in the current. The heavy dotted lines will designate the boundaries of the safety fairways. While large ships would not be prohibited from entering this region, they would do so under the risk of incurring damage suites were they to collide with an OTEC while outside the boundaries of the safety fairway. The small circles immediately surrounding the OTECs are the 500-meter safety zones within which passage

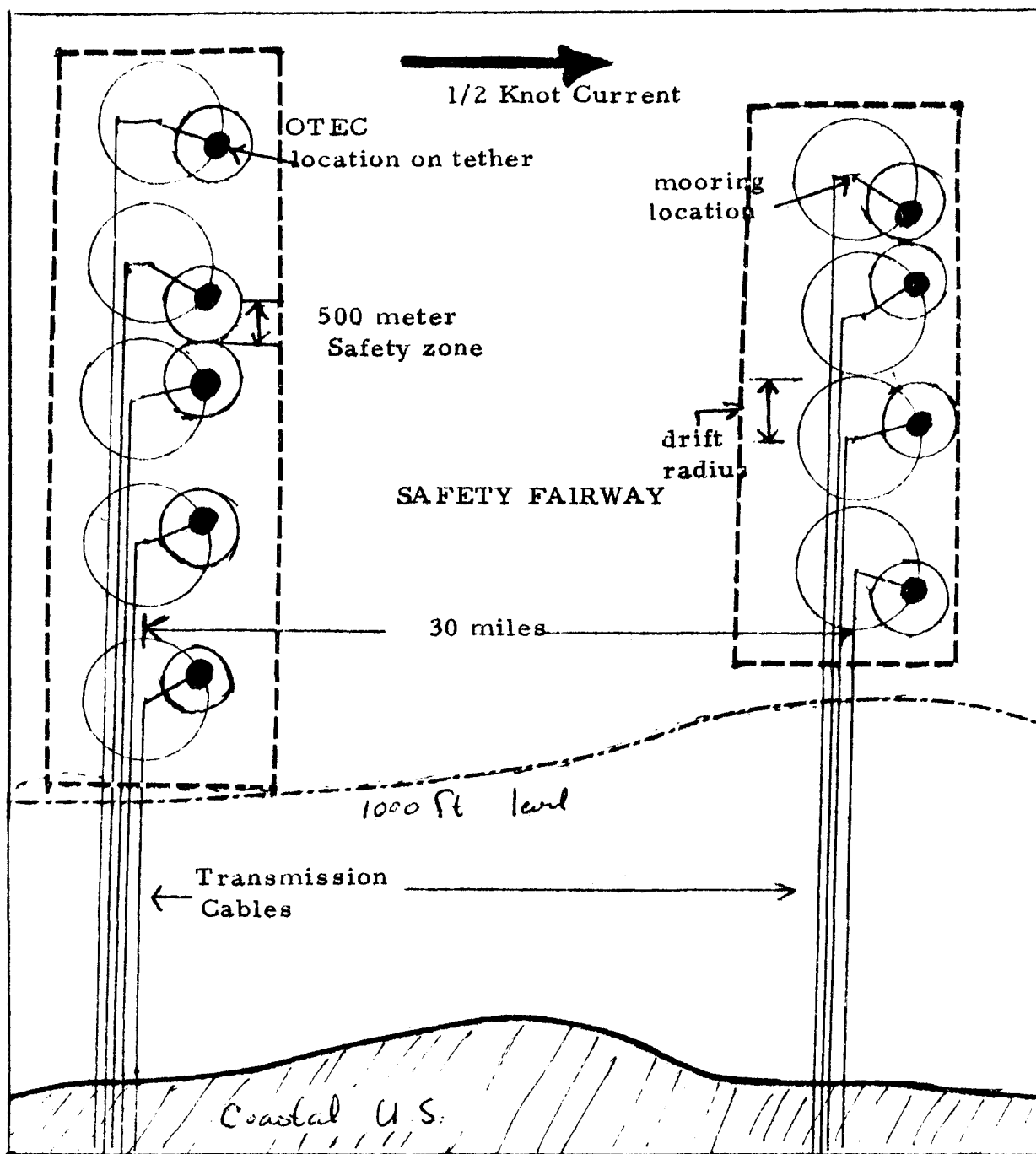


Figure F-1. A Possible Safety Fairway Deployment Configuration.

is restricted to those vessels servicing the OTEC. Finally, the transmission cables are clustered together so that interference with anchorages is minimal. There are other alternatives to the location of the transmission cables. They could, for example, meet halfway between the two sets of OTECs and then be run to shore in one cluster between the two cluster shown in Figure 1. This would have the effect of reducing the number of impediments to anchorages close to shore, but creating more obstacles beyond the 1,000 foot depth region. It would also increase the length of cable which in some instances would mean serious decreases in the efficiency of the OTEC.

It would appear that configurations of OTECs, something like that shown in Figure F-1, should permit even reasonably dense deployment without serious interference with navigation, anchorages, or fishing.

In concluding this section, we would argue that there do not appear to be any insuperable legal or institutional impediments to locating the OTECs within the U.S. economic resource zone. The most difficult problems will be the environmental questions and the development and defense of satisfactory environmental impact statements. Proponents of OTECs cannot assume that they will receive a warm response by those inside and outside the government who are concerned about the possible degradation of the oceans. The other concerns centering around navigation and conflicts with fishing would appear to be easily manageable given the range of the number of OTECs currently being considered.

The Legal Ramifications of Deployment of OTEC Systems on the High Seas

Because of improved temperature gradients, there are advantages to placing OTECs on the high seas in the equatorial zones.* Generally, the maximum temperature gradient is located $\pm 20^\circ$ of the equator. The legal and political implications of placing an OTEC on the high seas are nowhere clearly explicated and are somewhat a matter of speculation. To the present, efforts at such speculation have consisted primarily of attempts to closely examine the language of present Law of the Sea provisions and traditional International Law. In general, these studies

* Locating OTECs in the Economic Resource Zone of another nation would be a matter of bilateral negotiation. We will not make any estimates of the types of restrictions which might be forthcoming from such negotiations.

indicate that only the flag state would have any jurisdiction.* This is generally an accurate reflection of current Law of the Seas and of all major considerations at UNCLOS. This jurisdiction could extend to the enforcement of safety and construction standards through the appropriate licensing facility. The OTECs would be subject to roughly the status of a large ocean-going barge.

Attempts have been made to examine other provisions such as those designed for deep sea bed mining for possible connection to the OTEC issue. Such investigations also tend to support the minimum jurisdiction idea. For example, the developing countries argue that the minerals contained in the sea bed are the common heritage of man, and hence belong equally to all nations. From such a base, LDC's have proposed several schemes under which they would gain a share of the ocean's mineral wealth. This argument cannot be extended to the OTEC question, however. As Gary Knight states: "This concept (The Common Heritage of Man) does not extend to the superjacent waters, not even explicitly to minerals in solution, and it certainly does not extend to the sun's heat stored in those water."** While these studies provide fairly clear answers to questions surrounding the current legal status of high sea OTECs, it might not provide the correct answer to the question of whether OTECs will be subjected to any major international fees of any sort. The major deficiency of these legal studies is that they assume no further development of codified law on the subject. While it is possible that OTECs will escape the limitations of all further legal developments, that prospect is neither certain nor even probable.

* Hollick, A. "The International Political Implications of Ocean Thermal Energy Conversion Systems" in Legal, Political and Institutional Aspects of Ocean Thermal Energy Conversion, forthcoming.

** Knight, H. Gary, "International Jurisdictional Issues Involving OTEC Installations" in Legal, Political, and Institutional Aspects of Ocean Thermal Energy Conversion, forthcoming - The American Society of International Law).

One of the more pronounced trends which has recently been established in the development of International Law is that of the increasing role played by the developing nations. Indeed, any attempt to form an educated guess as to the legal status which OTECs will enjoy in the future must be sensitive to this trend of increased power by developing nations. To argue, for example, that the deadlock in the current UNCLOS indicates a treaty is not forthcoming is risky. In the case of the UN charter on the duties and rights of states the special committee analogous to the UNCLOS failed to form an agreement with the adopted consensual scheme. At that time, the developing nations forced the issue to a vote in the General Assembly. The subsequent official document on the New Economic Order strongly favors the developing nations. Clearly, the developing nations could do the same for Law of the Seas if they thought it in their interest to do so.

To argue that OTECs will escape legislation by virtue of their relative obscurity is also risky. OTEC devices are already specifically referred to in the SNT (Part II, Article 45, Paragraph Ci) giving coastal states exclusive jurisdiction with regard to production of energy from the water within the exclusive natural resource economic zone. It is also additionally clear that such provisions do not apply to the high seas questions. In fact, scholars in the area agree that jurisdiction under any of the present schemes would not extend to the high seas.

It is clear that the developing nations have the power to affect change in the codification of international law. There are two major questions related to this capability: (1) Is the U.S. likely to obey unfavorable international law codified by the developing nations, and (2) do the less developed nations (LDCs) have the motivation to attempt to legislate OTECs?

The United States has consistently supported the development of international law of the seas to regulate the exploitation of the oceans. The general position has been that regulation is necessary in order to avoid an international aquatic gold rush. The State Department has consistently opposed unilateral action as a mechanism for developing international LOS particularly for the high seas.*

Within the U.S., however, there have been pressures to ignore the UNCLOS and to exploit the high seas without regard to the rest of the world. Testimony to this effect has been given to Congress,** and there are pieces of draft legislation authorizing independent action by U.S. companies with the support of the Federal government. This legislation is not supported by the administration according to George Taft.

It is our judgment that the U.S. would be unlikely to violate any international accords with regard to OTECs. The political (and possibly economic) costs of openly opposing the LDCs over such relatively minor issues as OTEC or the mining of the deep sea bed are unlikely to be worth the economic advantages which would be gained. We think the U.S. would attempt to achieve as advantageous a position within the scope of the UNCLOS as is possible and would obey any reasonable subsequent international law once it is formed. The major possible deviation from this would most likely come from a substantive issue rather than a procedural one. For example, the U.S. might refuse to recognize the authority of an International Oceans Authority formed by the General Assembly.

* For an excellent discussion of the need for international agreement, see Nye, Joseph, "Ocean Rule Making from a World Perspective," in Perspective on Ocean Policy, National Science Foundation Grant # GI 39643. Also see Henry Kissinger, Speech to Foreign Policy Assn, April 1976.

** See "Hearings before the Subcommittee on Oceanography of the Merchant Marines and Fisheries," House of Representatives 94th Congress on H.R. 1220, H.R. 6017, H.R. 11879.

On the question of motivation, the LDCs would have a number of alternatives depending on the circumstances. Perhaps the easiest way to approach the question is by trying to identify some major factors which could affect the developing states' motivation and internal alignment.

It seems clear that if the OTECs become sufficiently salient to the developing nations, there is a good chance that they will want to exert pressure to receive some of its benefits. It should be recognized that despite the great potential power of the developing nations to formulate international law, the coordinated effort requires considerable energy on their part. Thus, the spectre of the developing nations whimsically banding together to formulate international law is not a high probability event.* Thus, were OTECs to sit benignly in the ocean causing little problem and offering little potential benefit to the developing nations, there would be little likelihood that they would be affected by international law (unless they accidentally fell under the umbrella of some other form of technology).

The prospect for OTECs would, however, appear to hold more promise than that. Particularly with respect to the production of fertilizers, the developing nations could become highly motivated. If fertilizer becomes as critically scarce as some experts predict,** land-based production sources could become highly overtaxed. Most of the technological advances in the area of agronomy which offer the developing nations some hope in lessening their hunger and starvation problems rely heavily on the increased use of fertilizers. Accordingly, the fertilizer supply issue might become as important to the developing nations as the energy supply issue is to the developed nations.

* See for example Robert Keohane and Joseph Nye, "World Politics and the International Economic System" in C. Fred Bergsten (ed), The Future of International Economic Order, 1973, Lexington, Mass., Heath and Co., or Seyom Brown, "New Forces in World Politics," Washington, D.C., the Brookings Institution, 1974.

** Meadows, Dennis, First Report of the Club of Rome.

To the extent that OTEC products have a significant impact on the economies of the LDCs, the relative successes of the ventures become critical. One could easily imagine the unfolding of a situation which would represent the worst case for the developed nation's OTEC enterprises. In this situation, OTECs would be successful enough to motivate the LDCs in use of their respective political power bases for the passage of provisions* which would give the developing states some share in the OTEC operation. As in the area of deep sea mining, this share could take several forms. On the one hand, the provisions could require a substantial fee to be paid to an International Monetary Development Fund. This fund could then be used for the construction of OTEC operations for the developing nations. On the other hand, the developing states could demand a percentage of the OTEC's production, either a flat amount or a requirement that some set proportion of the output be made available to developing nations at a fixed price. These solutions are similar to those which have been discussed both in regard to the deep sea mining operations and in regard to programs for the new economic order. It is likely that within twenty years, the LDCs will possess this kind of power in the international arena. Despite the desires of some U.S. companies, it is unlikely that the U.S. would openly oppose international laws for such a modest economic advantage as they might realize by placement of OTECs in equatorial regions.

In the case of enterprises sponsored by United States nationals, some alternatives to opposing international law do exist. Some of the water in the U.S. exclusive economic zone is suitable for OTEC placement. Were the international costs too high, U.S. nationals simply might move their OTECs into the U.S. economic resource zone. Few other developed nations which

*This could be accomplished either by extending the present provisions, or by the creation of a new and independent set of provisions. It would not take a great imagination to foresee an attempt to take an extreme position on the Common Heritage Argument.

might possess the technology and capital to sponsor OTEC activity have this alternative.

In general, it comes down to a bargaining game for the LDCs. Ideally, they would want as large a share in OTEC profits as they could take and still allow OTECs to remain a viable economic prospect on the high seas. In the recent past, the tendency of the developing nation has been to over use their power. However, with time, the developing nations are becoming more and more sophisticated bargainers. They are increasingly aware of how far they can push an issue and what laws they have at their disposal. All in all, the question of OTEC placement on the high seas is not as simple as some would have us believe. It relies not only on the interpretation of recent provisions which might apply to OTEC operation, but on an understanding of the trends of the entire political and economic realities in which international law is formed and international behavior takes place.

APPENDIX G

OTEC FINANCING WITH MARITIME SUBSIDY

One of the critical concerns of successful production and deployment of ocean thermal energy conversion systems (OTEC) rests with the availability of low cost financing. In view of the large fixed cost of OTEC systems and the uncertainty surrounding their competitive potential in traditional domestic and international product markets, innovative plans for financing OTEC construction and operation will be necessary to attract the funds requisite to the OTEC operation.

Financing techniques presently available to the maritime industry through the U.S. Maritime Administration may offer, with minor modification, methods for channeling capital funds to specific OTEC applications. Direct and indirect aids presently used by the U.S. shipping and shipbuilding industry for which OTEC programs may be eligible include: construction subsidies, operating subsidies, trade-in allowances, official low-interest loans, interest subsidies, official loan guarantees, accelerated depreciation, tax-free reserve funds, and duty-free imports of materials needed for ship construction. These financing options are discussed briefly below. While there is no explicit reference to the OTEC program's use of these techniques, presumably, these options would be available to the OTEC operator upon the resolution of the considerable uncertainty currently shrouding the legal status of the OTEC system.

Title XI Financing Guarantees

The basic aid of the Federal Ship Financing Program, established pursuant to Title XI of the Merchant Marine Act, 1936, as amended, "provides for a full faith and credit guarantee by the United States Government of debt obligations issued by United States citizen shipowners for

for the purpose of financing or refinancing United States Flag Vessels constructed or reconstructed in United States shipyards."*

The guarantee of the Federal Government under this program provides for the timely payment in full of the interest on and the unpaid principal of any guaranteed obligation in the event of default by the shipowner and, thereby, enables owners of eligible vessels to obtain long-term financing on favorable terms and conditions and at interest rates that are usually not available to the average shipowner.

The amount of the obligation guaranteed by the Government is based on the "actual cost" of the vessel as determined by the Secretary for Maritime Affairs. The "actual cost" of a vessel is computed to include those items which would normally be capitalized as ship costs under conventional accounting practice, such as, the cost of construction, reconstruction, or reconditioning (including designing, inspecting, outfitting, and equipping of the vessel, together with concomitant fees and interest on the related loan during the period of construction. Legal and accounting fees, print-costs, guarantee fees, vessel insurance and underwriting fees, and interest on borrowings for the shipowner's equity in the vessel(s) are not, however, included in "actual cost" for the purposes of the program.

Under the existing law, the secretary is authorized to guarantee an obligation which does not exceed 75 percent of the actual cost of most eligible vessels. However, if certain requirements are fulfilled, the guaranteed obligation may equal as much as 87 1/2 percent of the "actual cost" of the vessel.

The Federal Ship Financing Program is a guarantee program and not a direct loan program. Accordingly, funds secured by the guaranteed debt obligations and used for financing of the vessel(s) are obtained in the private sector. Historically, the main sources for such funds have been banks, pension trusts, life insurance companies, and bonds sold to the general public.

* U.S. Department of Commerce, Maritime Administration, "Federal Ship Financing Program" 1974, p. 1.

"The maximum guarantee period is 25 years from the date of delivery; however, if the vessel has been reconstructed or reconditioned, the life of the guarantee may be extended by the Secretary to include the remaining useful years of the vessel. Amortization in equal payments of principal is usually required; however, other amortization methods such as level debt (equal payments of principal and interest) may also be approved if sufficient security is offered such as long-term charters, reduction of the amount of guarantee and/or length of guarantee period."*

Under the existing ship financing program, an investigation fee of approximately one-eighth of one percent of the principal amount of the obligation to be guaranteed is charged to the applicant. The law also prescribes an annual guarantee fee of not less than one-half percent or more than one percent per annum of the average principal amount of the outstanding obligation, or not less than one-fourth of one percent or more than one-half of one percent per annum, of the principal amount of an obligation relating to a vessel under construction, reconstruction, or reconditioning.

Construction Differential Subsidy

In addition to the Title XI ship financing program, aid is given by the United States in connection with ship construction and acquisition. The basic form of this aid is the construction-differential subsidy, or CDS, available for the construction of new ships or the reconstruction of existing ships. This construction differential subsidy authorized by Title V of the Merchant Marine Act of 1936, is intended to stimulate the expansion of both the U.S. Merchant Marine and the U.S. shipbuilding industry and, thereby, to guarantee a degree of national self-sufficiency in these industries.

"CDS itself can be defined as the difference in costs between having a ship constructed in a foreign shipyard and having the same ship constructed

* Ibid., p. 4.

in a U.S. shipyard. Due to the cost differential, subsidy is necessary to place the construction costs of ships built in the United States on a parity with foreign construction costs.*

Under the statute, CDS assistance is limited to 35 percent when the contract price is arrived at by negotiation. However, if the construction price is arrived at by competitive bidding, a maximum CDS rate of 50 percent is permitted.

To qualify for the Title V subsidy, the prospective CDS applicant must meet the following general eligibility requirements:

- 1) The prospective purchaser must be a citizen of the U.S.;
- 2) The ship must be built for use in the foreign commerce of the United States;
- 3) The shipyard which will construct the ship must be located in one of the 50 states or Puerto Rico;
- 4) The prospective purchaser must possess the ability, experience, financial resources, and other qualifications necessary for the acquisition, operation, and maintenance of the proposed new ship; and
- 5) The ship to be constructed must meet the requirements of the foreign commerce of the United States, be capable of aiding the promotion and development of such commerce, and be suitable for use by the United States for national defense.

In addition to the foregoing eligibility requirements, ships constructed with the aid of CDS, are subject to the following restrictions:

- 1) A ship must be documented under the laws of the United States for 25 years;
- 2) All members of the crew must be citizens of the United States; and
- 3) Except for specific exemptions, the ship must be operated in the U.S. foreign commerce.

* U.S. Department of Commerce, Maritime Administration, "Construction-Differential Subsidy." 1975, p. 1.

Operating Differential Subsidy

In addition to ship mortgage financing and construction differential subsidy, an operating differential subsidy is available to qualified U.S. flag shipping companies. Title VI of the Maritime Act, 1936, as amended, provides for an operating differential subsidy aimed at equalizing the disparity in operating costs between those of American ships and their foreign competitors with respect to the wages of officers and crews, insurance, and maintenance and repairs not compensated by insurance.

Grant of operating differential subsidy is conditional on the applicant's demonstration of:

- 1) U.S. citizenship;
- 2) The ability, experience, and financial resources necessary to conduct the proposed operations in an efficient and economical manner;
- 3) A minimum working capital in an amount equal to 50 percent of the average annual voyage expenses for each of the ships covered by the ODS; and
- 4) Net worth in an amount equivalent to 25 percent of the "owners actual cost" of all ships involved in the subsidized operation.

Continued payment of ODS is also contingent upon:

- 1) Replacement of average ships as required;
- 2) Payment of annual dividends in conformity with a conservative dividend policy; and
- 3) Refraining, without special permission, from operating in the domestic trade, engaging in certain business transactions with related companies, and owning, operating, or acting as agent for foreign flag ships.

Tax Deferrals

Tax deferral privileges are also available to qualified members of the maritime industry under the provisions of the Capital Construction Fund (CCF) program. The Capital Construction Fund was established pursuant to section 607 of the Merchant Marine Act of 1936, as amended, for the purpose of providing replacement vessels, additional vessels, or

reconstructed vessels built in the United States and documented under the laws of the United States, for operation in the United States foreign, Great Lakes, or non-contiguous domestic trade or in the fisheries of the United States.

In outline, "section 607 provides for the deferment of federal income taxes on certain deposits of money or other property placed into a CCF. A party may establish a fund by entering into a CCF agreement with the Secretary of Commerce. The fund, as well as earnings accumulated from the investment of the fund, may be used to construct vessels and certain related equipment in American shipyards and factories."*

"Section 607 specifies that an applicant for a CCF must be a citizen of the United States; own or be the lessee of one or more eligible vessels (defined as any vessel constructed in the United States; and if reconstructed, reconstructed in the United States; documented under the laws of the United States; operated in the foreign or domestic commerce of the U.S.; engaged primarily in the waterborne carriage of men, materials, goods, or wares, and designated in the agreement as an "eligible agreement vessel"); have a program which furthers the purposes of the Act; provides for the acquisition, construction or reconstruction of a qualified vessel; and demonstrates the financial capabilities to accomplish the program.**

The key benefit of the CCF program is the reduction in the operator's taxable income by the amounts of net income and capital gains relating to the ships and income on deposits in the fund.

An additional advantage is the broad coverage of the program which includes unsubsidized operators and operators not exclusively engaged in foreign commerce.

* U.S. Department of Commerce, Maritime Administration, "Capital Construction Fund," 1975, p. 2.

** Ibid, p. 2.

In addition to the tax deferral benefits provided for by the Capital Construction Fund, tax deferral benefits to U.S. flag operators are also authorized by the Construction Reserve Fund. The Construction Reserve Fund permits eligible parties to defer the gain attributable to the sale or loss of a vessel, provided the proceeds are used to expand or modernize the U.S. merchant fleet.

As defined by the Act, "the primary purpose of the CRF is to promote the construction, reconstruction, reconditioning, or acquisition of merchant vessels which are necessary for national defense and to the development of U.S. commerce."*

In brief, Section 511 provides for the non-recognition of, for purposes of Federal income or excess profits taxes, gain from sales, or actual constructive total loss of a vessel. To defer taxation on the gain, the taxpayer must deposit in the CRF an amount equal to the net proceeds of the sale or to the net indemnity with respect to the loss and make a proper election on his Federal income tax return. Both ordinary income gain and capital gain may be deferred in this manner.

Under the statute, "a CRF may be established by any citizen of the United States who owns, in whole or in part, a vessel or vessels operating in the foreign or domestic commerce of the United States or in the fisheries."**

The broad coverage and flexibility of the construction reserve fund has enabled various fund holders to build larger, better equipped new vessels, to reduce mortgage debt on new vessels, or to build a greater number of vessels than would have been possible without CRF assistance.

Maritime Trade-In Allowance

"Financing the acquisition of a new asset with an old one is a time-honored American custom that is confined neither to shore nor to private

* U.S. Department of Commerce, Maritime Administration, "Construction Reserve Funds, 1976, p. 1

** Ibid., p. 2

interests. Under specified circumstances, obsolete merchant ships can be "traded-in" to the government in return for an allowance on new construction."^{*}

"In order to be eligible for trade-in, the "obsolete" ship: (1) must have been owned by United States citizens for three years immediately preceding the date it is traded in, (2) must be of not less than 1,350 gross tons, and (3) in the judgment of the Secretary of Commerce, should, by reason of age, obsolescence, or otherwise, be replaced in the public interest."^{**}

If the vessel under consideration meets these requirements, the statute authorizes Maritime to allow what it determines as the "fair and reasonable" value of the ship, taking into consideration the ship's scrap value, its depreciated book value based on a life of twenty years (tankers) or twenty-five years (dry cargo vessels), and its market value for operation in world trade as well as the foreign or domestic trade of the United States.

The statute further requires that a ship to be acquired in place of an obsolete one traded in to Maritime must be constructed in a United States shipyard and be documented under the United States flag.

The Federal Government aids to merchant shipping described briefly herein represents a large potential source of funds for the construction and operation of OTEC systems. While the legal status of OTEC devices is surrounded by a considerable degree of doubt, the resolution of this doubt may very well open an avenue to this not insignificant source of funding. It would seem that with the clarification of OTEC's relation to the Merchant Marine Act, and with some modification of the provisions of that Act, the OTEC program would be able to avail itself of the construction differential subsidies, the Title XI guarantees, the investment tax credits, the capital construction funds, and the operating differential subsidies presently available to the merchant fleet.

^{*} Odell, Kominers, "Federal Government Aids to Merchant Shipping" 47 Tulane Law Review (1973), p. 675.

^{**} Odell, Kominers, p. 696.

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U.S. Department of Commerce, Maritime Administration, "Operating-Differential Subsidy," 1975.

APPENDIX H

MARKET PENETRATION PROJECTION

A market penetration scenario is a projected schedule of entry into a market. The estimated market for OTEC in the application of direct supply of electricity by cable to utilities is the base-load capacity additions needed by the utilities serving the South Atlantic and Gulf Coast States, i.e., the Reliability Councils, SERC, ERCOT, and SWPP.

It is unlikely that OTEC will ever achieve 100 percent of this market. Diversity even among base-load types of generating capacity is a wise and necessary policy to protect the utility and the public from exogeneous events affecting particular types of power: drought for hydropower, price escalation for oil and gas, environmental constraints on coal, and delays, constraints, and threatened moratoria on nuclear power. There will be a saturation share for OTEC with the rest split among conventional plant types and other new technologies, e.g., wind, solar thermal, and photovoltaic energy.

The saturation share will not be attained in a few years. It takes time for acceptance to develop as a function of experience and improved economic competitiveness.

Historic trends on other innovations give some guidance on the pattern of buildup from commercial introduction to saturation. The literature on the subject generally describes the S-shaped curve of growth, calling it sigmoid or the "logistic curve," and for predictive purposes suggests an equation to fit this pattern. J.C. Fisher and R.H. Pry (1971) do so with a substantial data base of substitutions: past innovations that have over a period of years partly or fully replaced the previous process or material used to make a commodity. They find that

the fractional share, f , of the potential market versus time can be described by

$$f = e^{a(T - T_0)} / (1 + e^{a(T - T_0)}) \quad (H-1)$$

where $T - T_0$ is the number of years before or after T_0 , the year that the 50 percent saturation point is reached ($f = 0.50$), and exponent a can be related to the "takeover time" ΔT , defined as the length of time between $f = 0.10$ and $f = 0.90$, by the relationship $a = 4.4/\Delta T$. In Table H-1, Fisher and Pry's data on 17 different innovations is described by the T_0 and ΔT that best fit the data. The overall data on these innovations is displayed in Figure A-14(A), with a horizontal scale normalized by T_0 and ΔT . The expected S-shape of f is clear.

For the equation H-1, it is possible to use a logarithmic plot by plotting $f/(1 - f) = e^{4.4 T/(T - T_0)}$ as shown in Figure H-1 (B). Here the excellent fit of data from 0.01 to 100 gives confidence that the model has considerable credibility.

There are some weaknesses and problems with the Fisher-Pry model, to be understood before applying it as a projective tool. T_0 , and the time history of the total market are only known retrospectively. However, the slope, and parameters a and ΔT , are evident early in the growth pattern as a constant annual growth rate. It will slowly decline as the saturation of the market increases. Some examples of the annual growth factor $f(T + 1)/f(T)$ are:

<u>Takeover Time</u> <u>ΔT</u>	<u>Annual Growth Rate</u> <u>Factor</u>	<u>% per Year</u>	<u>At $f = 0.50$</u> <u>% per Year</u>
5	2.410	141.0	41.3
10	1.552	55.2	21.6
15	1.341	34.1	14.6
20	1.246	24.6	11.0
30	1.158	15.8	7.3
40	1.116	11.6	5.5

Table H-1 . Takeover times (ΔT) and substitution mid-points (T_0) for a number of substitution cases.

Substitution	Units	ΔT , years	T_0 , year
Synthetic/Natural Rubber	Pounds	58	1956
Synthetic/Natural Fibers	Pounds	58	1969
Plastics/Natural Leather	Equiv. Hides	57	1957
Margarine/Butter	Pounds	56	1957
Electric Arc/Open-Hearth Specialty Steels	Tons	47	1947
Water-Based/Oil-Based House Paint	Gallons	43	1967
Open-Hearth/Bessemer Steel	Tons	42	1907
Sulfate/Tree-Tapped Turpentine	Pounds	42	1959
TiO ₂ /PbO-ZnO Paint Pigments	Pounds	26	1949
Plastic/Hardwood Residence Floors	Sq. Ft.	25	1966
Plastic/Other Materials for Pleasure Boat Hulls	Hulls	20	1966
Organic/Inorganic Insecticides	Pounds	19	1946
Synthetic/Natural Tire Fibers	Pounds	17.5	1948
Plastics/Metal for Cars	Pounds	16	1981
BOF/Open-Hearth Steels	Tons	10.5	1968
Detergent/Natural Soaps (U.S.)	Pounds	8.75	1951
Detergent/Natural Soaps (Japan)	Pounds	8.25	1962

Source: Fisher and Pry, 1971,
pp 304-306.

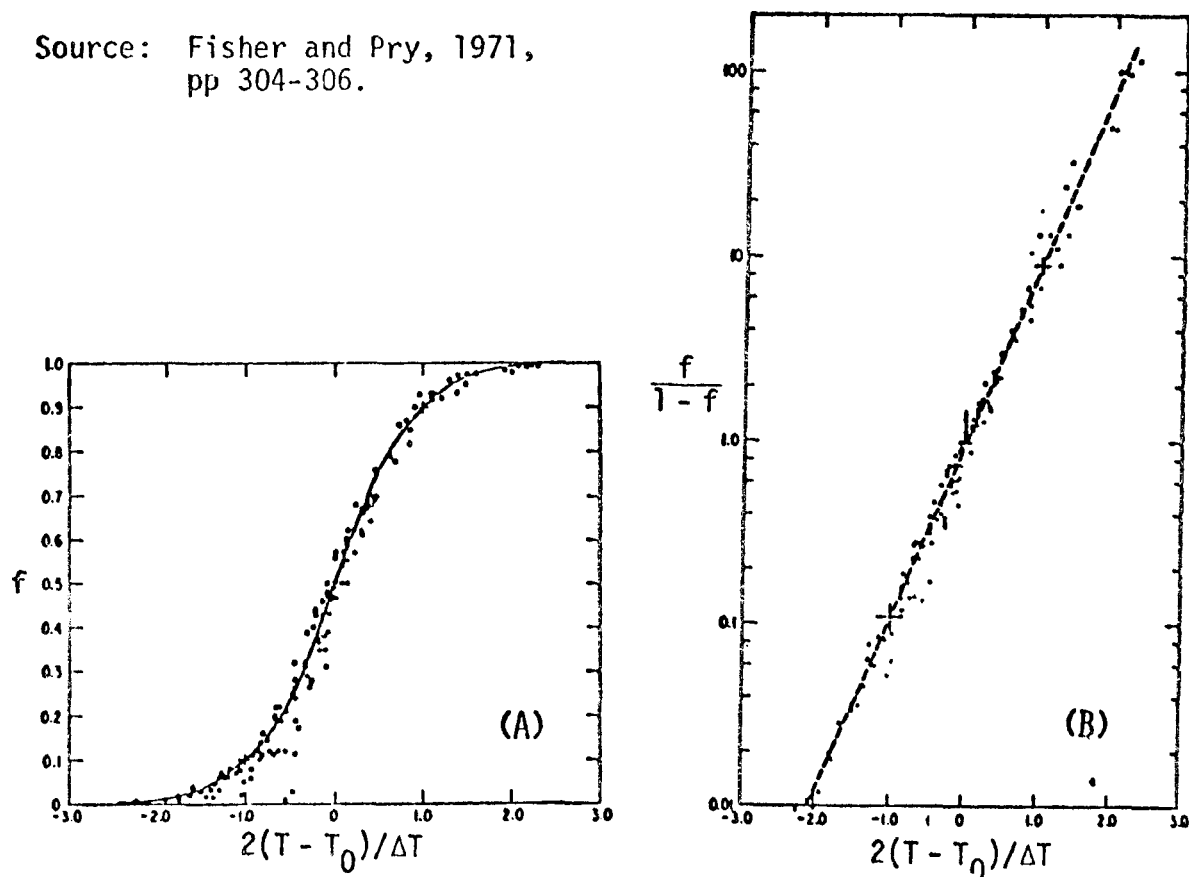


Figure H-1. Fit of substitution model function to substitution data for all 17 cases versus normalized units of time.

It will be noted that Fisher and Pry analyzed only commodities: materials replaced by a new material or made by a new process, not the capital goods required to make the material. In studying innovations like OTEC, there are at least four echelons in a hierarchy of markets.

- Cumulative electricity to date made by OTEC (barrel of oil saved)
- Electricity (MWH) made annually by OTEC (barrels/year saved)
- OTEC annual additions (MW)
- Drydocks/shipyards/plants built annually to make OTECs

Fisher and Pry's commodities are at the second level. Of primary concern in this study is the annual market for OTECs at the third level. Each level represents a cumulative total of the echelon below it; i.e., is proportional to the integral of it. Conversely, each is proportional to the derivative to the one above it. It is easy to see by integrating or differentiating Equation H-1 that the functional form of all four is not the same. Yet during the early growth years when f can be approximated by e^{at} , all four have the same annual growth rate.

Another reason to consider all four echelons in a penetration scenario is that they may represent different constraints on the market penetration of OTECs during different phases of growth. Diversion of available drydocks/assembly lines to OTEC may suffice in early growth, but additional facilities will be needed at higher penetration levels. The time lag for construction of shipyards must be considered as well as the time lag to construct OTECs. As OTECs approach saturation, the annual additions required may decrease in absolute numbers as well as in percentage growth rate. This can be a strong deterrent to building a new manufacturing plant that will not be used near full capacity for its lifetime. The magnitude of this effect depends on the growth rate of the total market for the commodity (electricity) which was not projected to continue to grow exponentially at the historic rate.

The conclusion drawn from the Fisher-Pry data is that there have been unsubsidized innovations with takeover times and annual growth rates of 10-40 years and 55-11 percent per year during their early pene-

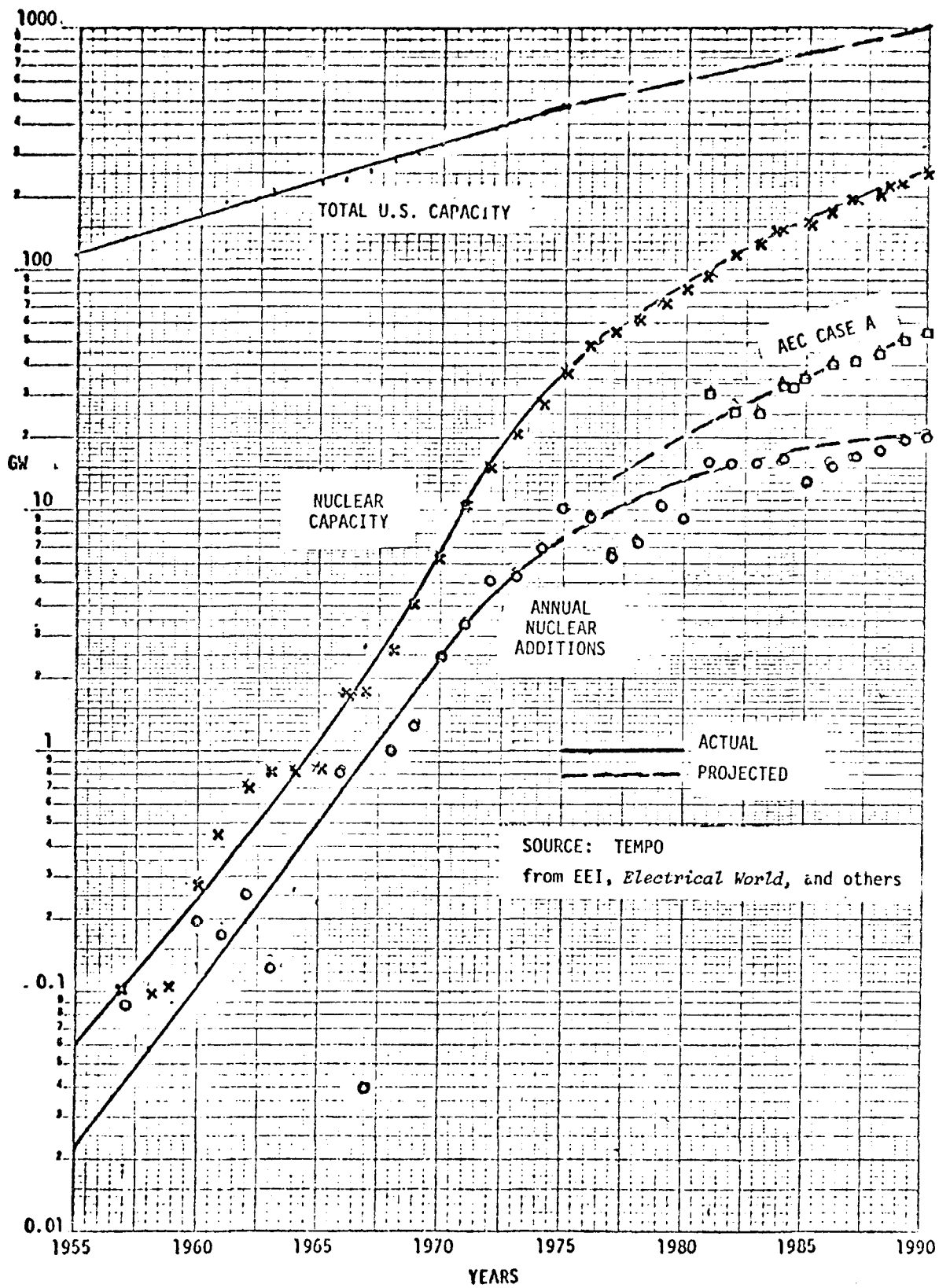


Figure H-2. History and trend of nuclear growth.

tration. Items of high growth rate and short takeover times were fairly clear-cut cases of considerable economic advantage or customer preference for the new over the old. Unless strong incentives are supplied OTEC (and other solar energy innovations as well) are more likely to have a 40-year takeover time than a 10-year time. If a point is reached through incentives where a clear cost advantage can be foreseen, a self-sustaining growth at a lower (than 40 years) takeover time is likely.

Another substitution scenario that is more directly relevant is that of nuclear energy. Figure H-2 combines data from EEI, Nuclear News, and Electrical World (September 15, 1976) to show both the annual net additions and the cumulative capacity installed to date. In the period before 1967 there is considerable scatter in points representing annual additions; usually single units and often with gaps of years with no additions. The data are actual to the end of 1975 and the Electric World's projections beyond this. Even in the projection period there is roughness in the pattern of multiple annual additions, in part because of the long planning cycle required and the uncertainties of future demand. An alternative projection by the Atomic Energy Commission, the lowest (Case A) of three alternative projections described in WASH 1139(74), is shown for comparison. It projected double the annual additions in the late 1990's that are now projected by the industry.

There is also considerable scatter in the cumulative nuclear capacity to date during the years before 1967, but in subsequent years a steady growth was experienced to 1975 and is projected to 1990.

For a reference, the actual (59 1975) and projected total U.S. generating capacity appears at the top. It appears that nuclear capacity is projected to saturate at about 30 percent of total capacity, or 60 to 75 percent of base load capacity.

The steep part of the growth curves in additions and total capacity can be reasonably fit by straight lines with slopes of 37 to 48 percent growth rate per year. To express this as f , the fractional share of the potential market, the market growth rate must be subtracted from this.

Over the rapid nuclear growth period, the growth rate of total capacity was 7 percent. The range of f then is determined by the annual growth factors 1.30 to 1.41 which correspond to takeover times ΔT of 17 and 13 years.

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