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Vienna, Austria, 8 - 12 October 1973

EFFECT OF SITE FACTORS ON THE ECONOMICS OF PETRO-PROTEIN MANUFACTURE 1/

by

F. Fussman, G.D. Kerns*
P.G. Cooper, R.S. Silver**

* The Lummus Company, Bloomfield, New Jersey, U.S.A.
** Gulf Research and Development Company, Pittsburgh, Pennsylvania, U.S.A.

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SUMMARY

COMPARISON OF FOUR SELECTED SITES ON THE ECONOMICS OF PETRO-PROTEIN MANUFACTURE 1/

F. Fussman and G. D. Kerns*
P. S. Cooper and R. S. Silver**

Renewed active interest has developed in making synthetic protein from abundant, low cost materials such as hydrocarbons which, per se, have no direct nutritive value. Behind such interest are:

- The current worldwide rapid tightening of natural protein supplies causing prices to skyrocket.
- Projected worldwide growth of animal feed consumption at the rapid rate of 10% per year.
- Estimated doubling of world demand for all protein by the year 2000.

This paper analyzes the effects of specific plant sites in Algeria, Brazil, Finland and India on the economics of producing 100 million pounds per year of single-cell protein (SCP) for animal fodder. The process basis is Gulf Research and Development technology on fermentation of normal paraffins. The selected sites cover a wide range of climatic conditions, energy costs, labor costs and shipping distance from raw material sources.

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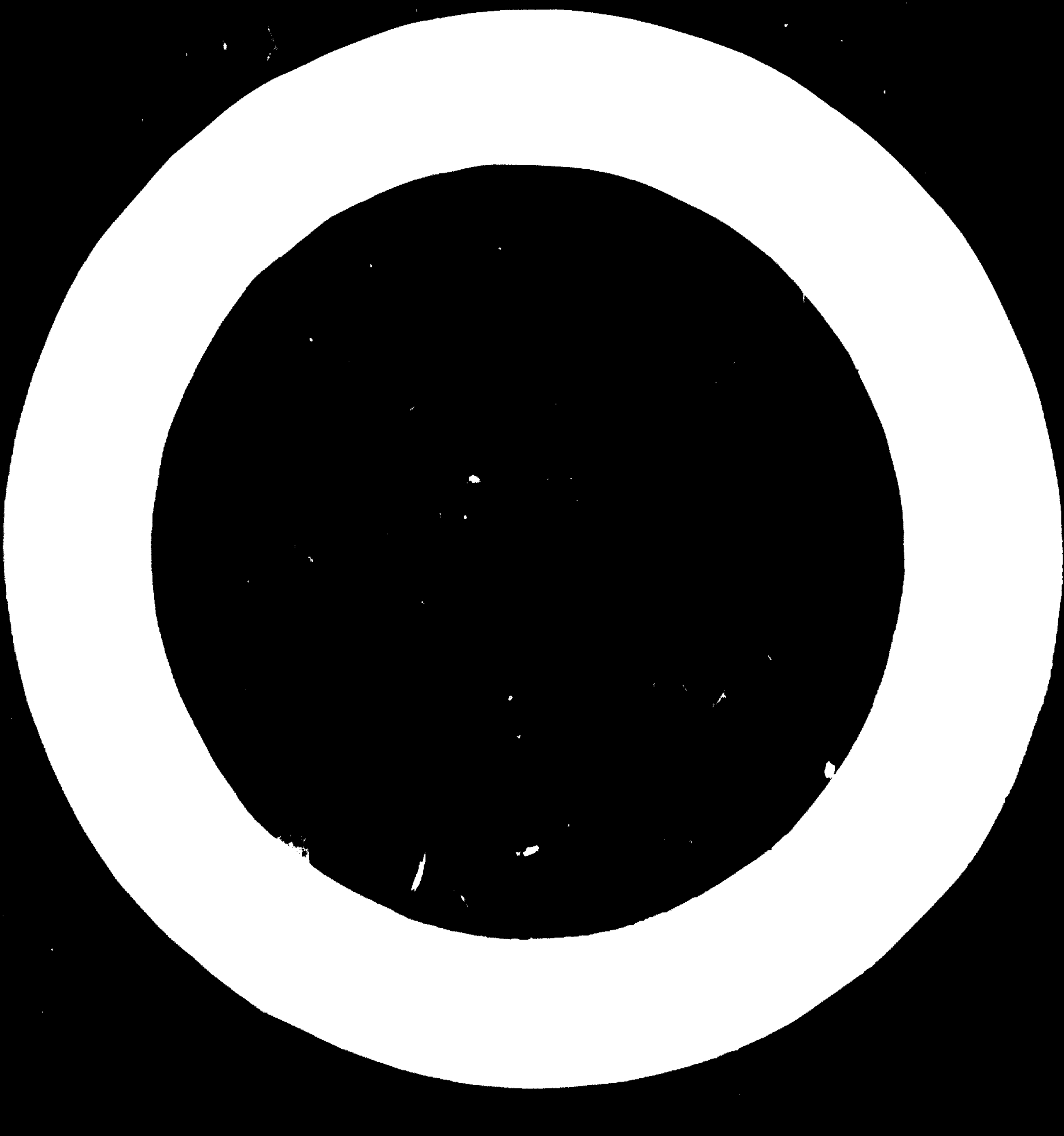
The impact at each site of key economic factors (feedstock costs, energy costs and capital investment) on the economics of SCP manufacture are presented. Climatic conditions are shown to have a significant effect on the capital and energy requirements for the refrigeration needed to remove the heat of fermentation at the temperature level for acceptable protein yield. Economics at the selected sites are compared using the discounted cash flow rate of return concept as an index of profitability.



CONTENTS

INTRODUCTION

Worldwide food shortages for both animals and humans continues to be a problem demanding our urgent attention. A growing body of informed sources does not expect that the food supply situation will improve in the foreseeable future.[1] A direct result of the recent tightening of natural protein supplies has been skyrocketing prices. The United Nations Food and Agricultural Organization has projected annual growth rate of 10% for animal feed, and a doubling of world demand for all protein by the year 2000.[2] In light of the above, renewed active interest has developed in making synthetic protein from abundant low cost materials such as hydrocarbons which, per se, have no nutritive value.

This paper will analyze the effects of specific plant sites in Algeria, Brazil, Finland and India on the economics of producing 100 million pounds per year of single-cell protein (SCP) for animal fodder. The selected sites cover a wide range of climatic conditions, energy costs, labor costs and shipping distance from assumed raw material sources.

The study is based on an unpublished preliminary engineering design for a 100 million pounds per year SCP plant prepared by The Lummus Company for Gulf Oil Corporation. This basis was chosen for convenience, since for a comparative study of the effect of site conditions, the same conclusions would probably be reached using other process designs as a basis.

Note: Numbers in parentheses refer to the corresponding numbers in the reference list at the end of the paper.

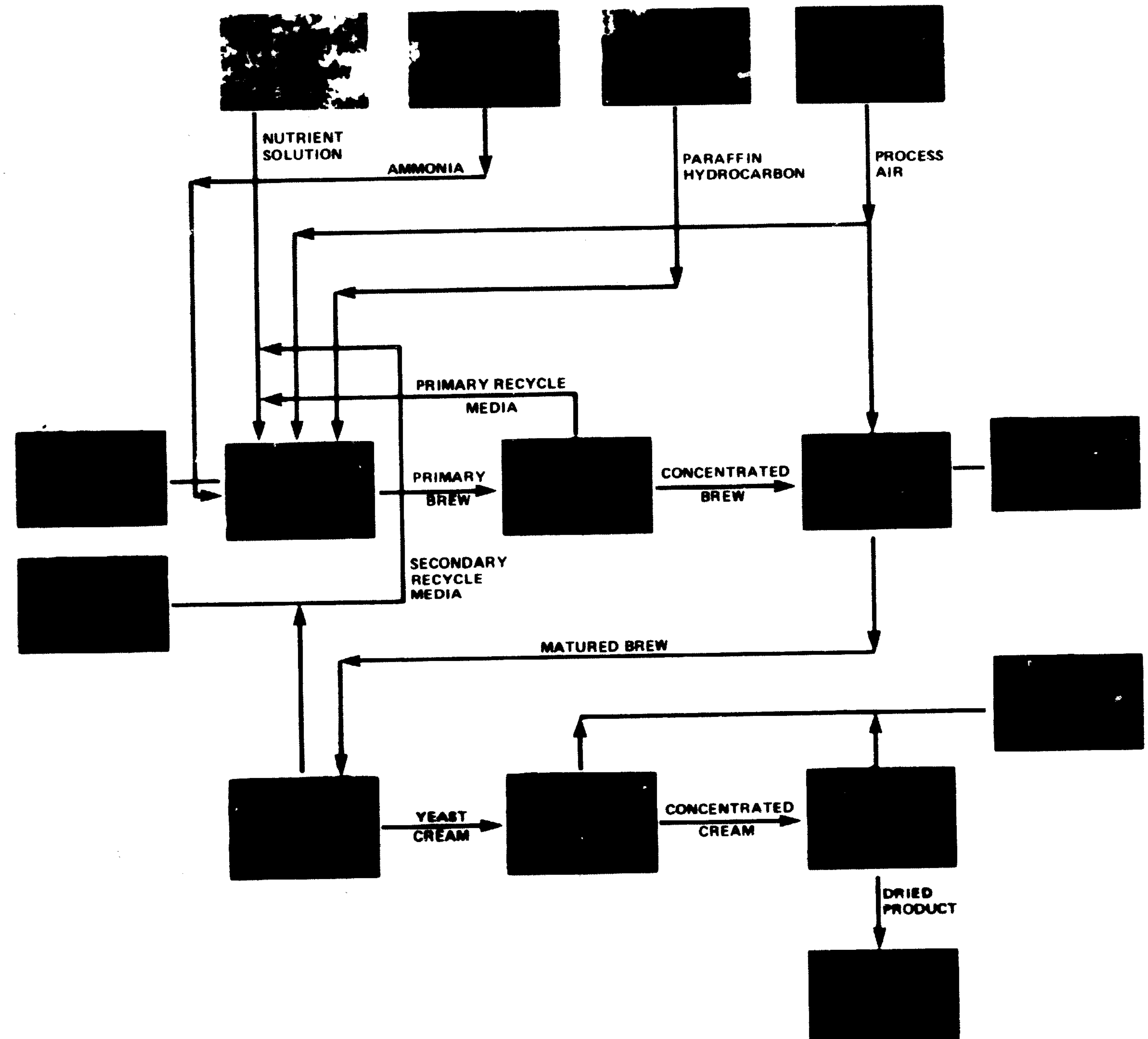
The Gulf technology (3), (4), (5), (6), (7), (8), (9), was developed in laboratory, pilot plant and semi-works operations over the period 1963 to 1970. All Gulf activities in SCP were terminated in 1971.

I. PROCESS BASIS

Conversion of normal paraffin, ammonia and nutrient salts to protein product is accomplished by the growth and reproduction of live yeast cells feeding on these reagents under aerobic conditions. This occurs in a continuous fermentation stage followed by continuous maturation, concentration, pasteurization and drying of the product.

Figure 1 is a block diagram showing the major process flow sequence. The paraffin hydrocarbon substrate is fed to the fermentor along with the nutrient medium (a mixture of process water, phosphoric acid, potassium chloride, magnesium sulfate and trace nutrients, and recycle aqueous media streams from two downstream points). Liquid ammonia is vaporized in the compressed air stream to the fermentor. The fermentor is started up by seeding with live cells. Most of the hydrocarbon and other nutrients are consumed and converted to yeast. By-product carbon dioxide and excess air are vented. A stream of this primary brew is continuously withdrawn and passed to the first stage centrifuges. Here, yeast is concentrated and sent to the maturation stage. Liquid recovered from the yeast in the centrifuges is returned to the fermentation stage as part of the aqueous media stream.

FIGURE I. PROTEIN MANUFACTURING FACILITY BLOCK FLOW DIAGRAM



In the maturation stage where the brew is contacted with a small additional amount of air, the residual n-paraffin in the brew is reduced to a low level, and the quality of the yeast protein is improved.

The discharge stream from this stage is fed to another set of centrifuges. The aqueous media which is removed at this point is partially rejected to prevent build-up of unused ions and by-products from the fermentation step. The remainder is recycled to the fermentor along with the other aqueous media feeds.

The yeast cream from the secondary centrifuges is further concentrated and pasteurized in wiped film evaporators. The concentrated cream is spray dried to a powder by contact with hot air.

Dry product is pneumatically conveyed, first to storage and subsequently to shipping.

II. SITE BASIS

Four plant sites were selected for analysis based on the following criteria:

- One site (Finland) has favorable climatic conditions for low overall refrigeration costs.
- Three sites (Algeria, Brazil, and India) are in developing countries.
- All four sites cover a wide range of climatic conditions, energy costs, labor costs and shipping distance from raw material sources.
- The familiarity of The Lummus Company with all sites.

Table 1 shows the pertinent site meteorological conditions which influence both operating and investment costs.

For purposes of this study, the following assumptions were made concerning all four sites:

- The SCP plant will be located adjacent to a large petroleum, petrochemical or other manufacturing facility, from which all utilities, except refrigeration, could be purchased across-the-fence.
- A clear and level site exists, requiring no piling.

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TABLE 1

PERTINENT SITE METEOROLOGICAL CONDITIONS

Local Area Country	Porvoo Finland	Skikda Algeria	Sao Paulo Brazil	Baroda India
Cooling Water Source	Sea	Sea	Lake	Cooling Tower
Cooling Water Design Temp., °F	57	77	82	93
Wet Bulb Design Temp., °F	–	–	–	85
Dry Bulb Design Temp., °F	70	95	90	93
Other Factors	Winterizing required	Earthquake Considerations	800 meters above sea level	–

III. UTILITIES DISCUSSION

Steam and cooling water requirements were calculated for each site on the following basis:

- Provide refrigeration for a closed loop 55°F chilled water system used in process cooling. As a conservative measure, we used this concept even at Porvoo, Finland where 57°F sea water is available. Thus, costly metallurgy for corrosion protection of the fermentor cooling surface is avoided. In addition, we eliminated a potential source of fermentor cooling surface fouling by sea water.
- Use 600 psig, 750°F condensing steam turbines to drive the refrigeration compressor and process air machine.
- 20°F temperature rise for cooling water.

<u>No attempt was made to optimize utilities at any site.</u>

Table 2 shows the effect of site climatic conditions on refrigeration and process air power requirements. It can be seen that the impact on refrigeration horsepower is substantial, while the effect on air compressor horsepower is small.

Figure II shows the relation between total steam requirement and cooling water temperature. Figure III shows the effect of cooling water temperature on flow rate.

TABLE 2

EFFECT OF SITE CONDITIONS ON REFRIGERATION AND PROCESS AIR COMPRESSOR HORSEPOWER

	Finland	Algeria	Brazil	India
Cooling Water Temp., ^{o}F	57	77	82	93
Refrigeration Horsepower	9,100	13,400	16,660	17,240
Process Air Compressor Horsepower	8,880	9,300	9,200	9,200

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FIGURE II
EFFECT OF COOLING WATER TEMPERATURE ON TOTAL STEAM REQUIREMENT

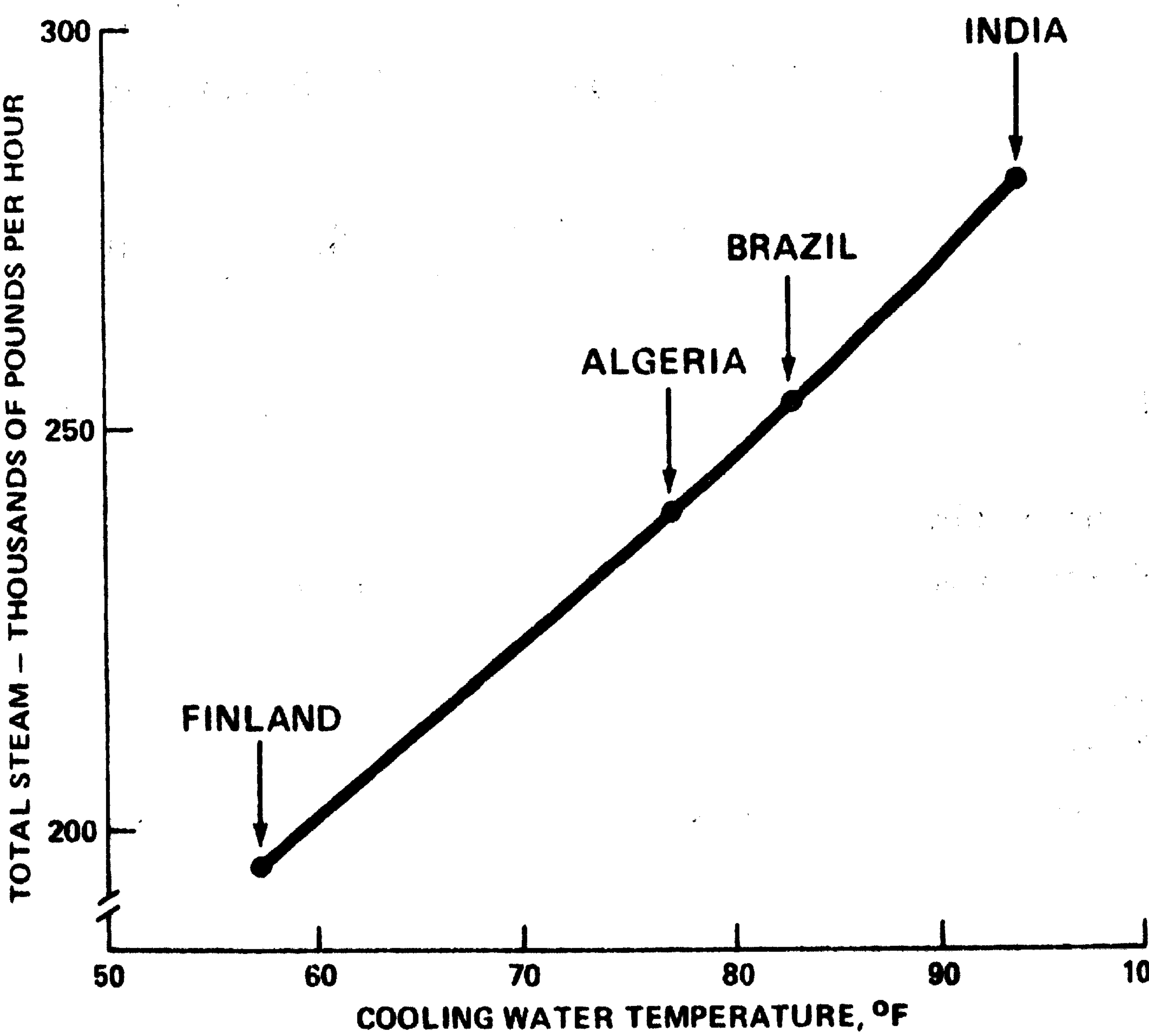
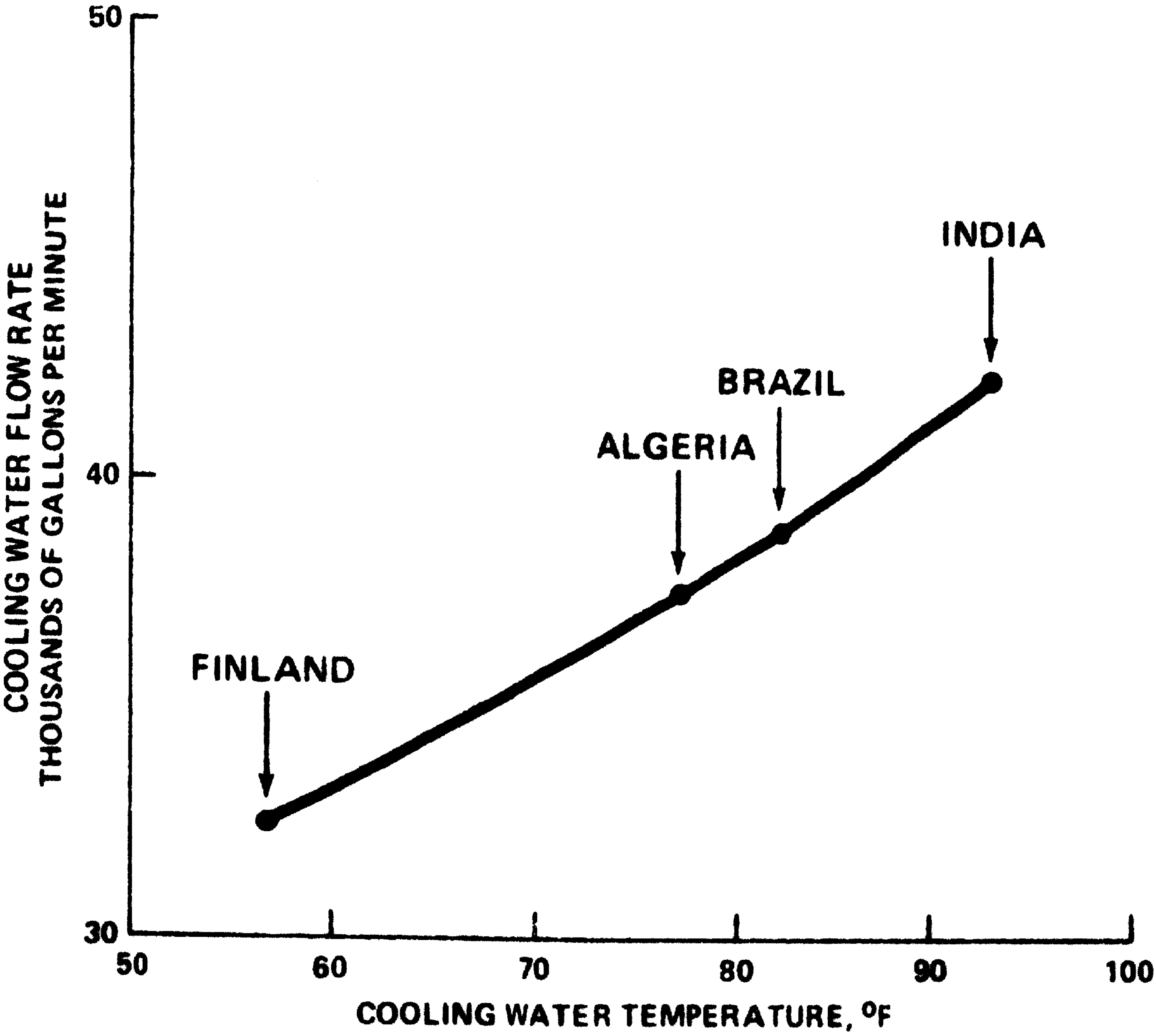


FIGURE III
EFFECT OF COOLING WATER TEMPERATURE
ON FLOW RATE



IV. CAPITAL INVESTMENT

The estimated total capital investment at each site is show in Table 3 in U.S. dollars, which is the monetary unit used throughout this paper.

The fixed capital investment includes:

- Applicable import duties
- Worldwide purchase of imported materials
- Cost of land (allowance of one million dollars at each site)
- Storage facilities for raw materials and product
- Spare parts
- Capitalized construction interest and pre-operational costs
- Refrigeration, process air and instrument air compression facilities. The refrigeration system includes a closed chilled water loop for process heat removal.

The basis for estimating working capital is as follows:

- One month raw material inventory
- One month product inventory
- One month accounts receivable and accounts payable
- One month's operating cost for cash-on-hand and consumable spare parts.

Table 4 shows the effect of cooling water temperature on refrigeration horsepower and investment. The refrigeration investment is also influenced by certain other local site factors (such as import duties, construction labor costs, etc.) which also affect the total fixed investment.

TABLE 3

TOTAL CAPITAL INVESTMENT
Million of Dollars (1973 Local Basis)

	Finland	Algeria	Brazil	India
Fixed Capital	20.9	26.1	23.2	23.5
Working Capital	3.3	3.3	3.5	3.7
Total Capital	24.2	29.4	26.7	27.2

TABLE 4

EFFECT OF SITE ON REFRIGERATION INVESTMENT

	Finland	Algeria	Brazil	India
Cooling Water Temperature, °F	57	77	82	93
Refrigeration, Tons	13,850	14,030	14,090	14,250
Horsepower	9,100	13,400	16,660	17,240
Investment, $MM	2.9	3.9	4.0	4.2
Investment as % of Total Fixed Investment	13.9	14.9	17.2	17.9

V. BASIS FOR ECONOMIC ANALYSIS

The basis for economic analysis at all four sites is as follows:

- The discounted cash flow (DCF) rate of return concept with continuous compounding is used as an index of profitability.
- Financing Plan
  - 70/30 debt to equity ratio
  - 8 year loan at 8% interest, with repayment starting in the first year of operation
- Depreciation - 15 years (straight line)
- Project life includes 3 years from planning through start up and 15 years of operation
- Production profile: 80% of capacity in first year of operation, 90% in second year, and 100% thereafter.
- 309 operating days per year
- Income tax rate of 50% assumed
- Annual property taxes and plant insurance, each at 1.5% of plant investment.
- Annual maintenance costs at 4.5% of plant investment.

- Feedstock unit costs and usage are given in Table 5. Based on a cost of 5¢/lb. in the assumed source countries, delivered paraffin costs were derived by adding shipping costs to each site. Feedstock is fully refined to the essentially aromatics-free specification given in previous publication.(4) No on-site processing is required.

- Nutrient unit costs and usages are given in Table 6. The costs (based on locally made ammonia and imported mineral salts) were the authors' best estimates from literature sources rather than suppliers' quotations. Further investigation does not appear justified at this time since such costs are not a major factor in manufacturing costs.

- Energy unit costs and range of utility usages are given in Table 7. Details of utility unit costs and usages at each site are given in Appendix A.

- Operating labor, supervision and overhead costs are given in Table 8.

TABLE 5

NORMAL PARAFFIN FEEDSTOCK USAGE AND UNIT COSTS

	Cents Per Pound			
	Finland	Algeria	Brazil	India
Source Country	United Kingdom	Italy	Trinidad	Japan
Base Cost	5.0	5.0	5.0	5.0
Shipping Cost	0.7	0.5	1.4	2.1
Delivered Cost	5.7	5.5	6.4	7.1

Feedstock usage is 1.048 lbs/lb SCP at all sites.

TABLE 6

NUTRIENT USAGE AND UNIT COSTS

Nutrient	Usage/lb SCP	Cents Per Pound			
		Finland	Algeria	Brazil	India
NH_3	0.0951	4.0	3.5	5.0	5.0
KCl	0.045	7.0	7.0	7.0	7.0
$MgSO_4$	0.0186	4.5	4.5	4.5	4.5
H_3PO_4	0.0768	14.0	14.0	14.0	14.0

TABLE 7

ENERGY UNIT COSTS AND RANGE OF UTILITY USAGES(1)

	Energy Unit Costs			
	Fuel(2) ¢/MMBTU	Electricity ¢/KWH	Range of Utility Usages per lb SCP	
Finland	65	1.1	600 psig, 750°F steam	0.00998 – 0.0163 M lb
Algeria	12	1.1	200 psig steam	0.00362 – 0.00364 M lb
Brazil	39	1.7	30 psig steam	0.00096 M lb
India	77	1.9	Cooling Water	0.144 – 0.188 M Gal
			Process Water	0.00588 M Gal
			Power	0.212 KWH
			Low Sulfur Fuel(3)	0.00223 MM BTU

Notes

(1) Details of utility unit costs and usages at each site are given in Appendix A.

(2) Basis for estimating the costs of purchased steam given in Appendix A.

(3) For product spray drying.

TABLE 8

OPERATING LABOR, SUPERVISION, AND OVERHEAD COSTS

	Finland	Algeria	Brazil	India
Operators per Shift	11	11	11	11
Dollars per Year per Shift Position	53,600	27,700	34,200	24,000

VI. ECONOMIC ANALYSIS

Table 9 shows the elements of manufacturing cost at each site, including depreciation but excluding financing costs. The latter will vary throughout the project life. Table 10 shows the range of the elements of manufacturing costs on a percentage basis.

Hydrocarbon feedstock cost is the largest element (45% to 46%) of manufacturing cost. Variations in feedstock cost stem from shipping distance differences between the assumed source country and the site.

Chemicals (nutrients) costs range from about 12% to 14% of manufacturing cost. The small differences in chemical costs are due to different energy-related ammonia costs at each site. The largest element of chemical costs is phosphoric acid at 1.08¢/lb. of SCP, based on 14¢/lb. acid.

Utility costs (a combination of energy, cooling water and process water costs) range from about 14% of manufacturing costs in Algeria to about 24% in India. These costs are highly dependent on basic fuel costs, which vary from 12 ¢/MMBTU in Algeria to 77¢/MMBTU in India. It is interesting to note that the relatively low refrigeration horsepower in Finland (with its low cooling water temperature of 57°F) is not sufficient to compensate for the low energy costs in Algeria, which has 77°F cooling water.

TABLE 9

SCP MANUFACTURING COSTS AT CAPACITY CENTS PER POUNDS OF SCP

	Finland	Algeria	Brazil	India
Variable Costs				
Hydrocarbon Feedstock	5.98	5.76	6.71	7.44
Chemicals	1.85	1.81	1.95	1.95
Utilities	2.38	1.77	2.73	4.03
Total Variable Costs	10.21	9.34	11.39	13.42
Fixed Costs				
Labor & Overhead	0.59	0.31	0.38	0.26
Maintenance	0.74	0.95	0.84	0.85
Insurance & Taxes	0.50	0.63	0.56	0.56
Depreciation	1.32	1.67	1.48	1.50
Total Fixed Costs	3.15	3.56	3.26	3.17
Total Manufacturing Costs	13.36	12.90	14.65	16.59

TABLE 10

RANGE OF SCP MANUFACTURING COST ELEMENTS ON A PERCENTAGE BASIS

	% of Total Manufacturing Costs
Feedstock	45 to 46
Chemicals	12 to 14
Utilities	14 to 24
Labor	1.6 to 4.4
Maintenance, Insurance, Taxes & Depreciation	17 to 25

Labor-related costs are seen to be a relatively small element (less than 5%) of manufacturing costs. Other fixed costs (maintenance, insurance, taxes, and depreciation) range from about 17% to 25% of manufacturing costs. The depreciation portion of the fixed costs is 9% to 13% of manufacturing costs.

Figure IV shows the relation between investor's DCF return rate and SCP product price at each site. It is evident that there can be a substantial impact of local site conditions on the economics of SCP manufacture. Table 11, derived from Figure IV, shows SCP price for 10% and 15% investor's DCF return rates.

Finland, with its low cooling water temperature, has only marginally better economics than Algeria, which has lower energy costs but higher capital requirements. However, the effects of relatively high energy and capital costs in both Brazil and India are reflected in their substantially higher SCP prices.

Figure V shows the sensitivity of SCP selling price to hydrocarbon feedstock costs at each site. For example, in India, a feedstock cost change from 7.1¢/lb. to 5¢/lb. (as might be the case for across-the-fence purchase) would decrease the SCP selling price from 22¢/lb. to 19.6¢/lb. for a 15% of investor's DCF return rate, or from 20.1¢/lb. to 17.8¢/lb. for a 10% investor's DCF return rate.

FIGURE IV
SCP PRODUCT PRICE VS INVESTOR'S DCF RETURN RATE

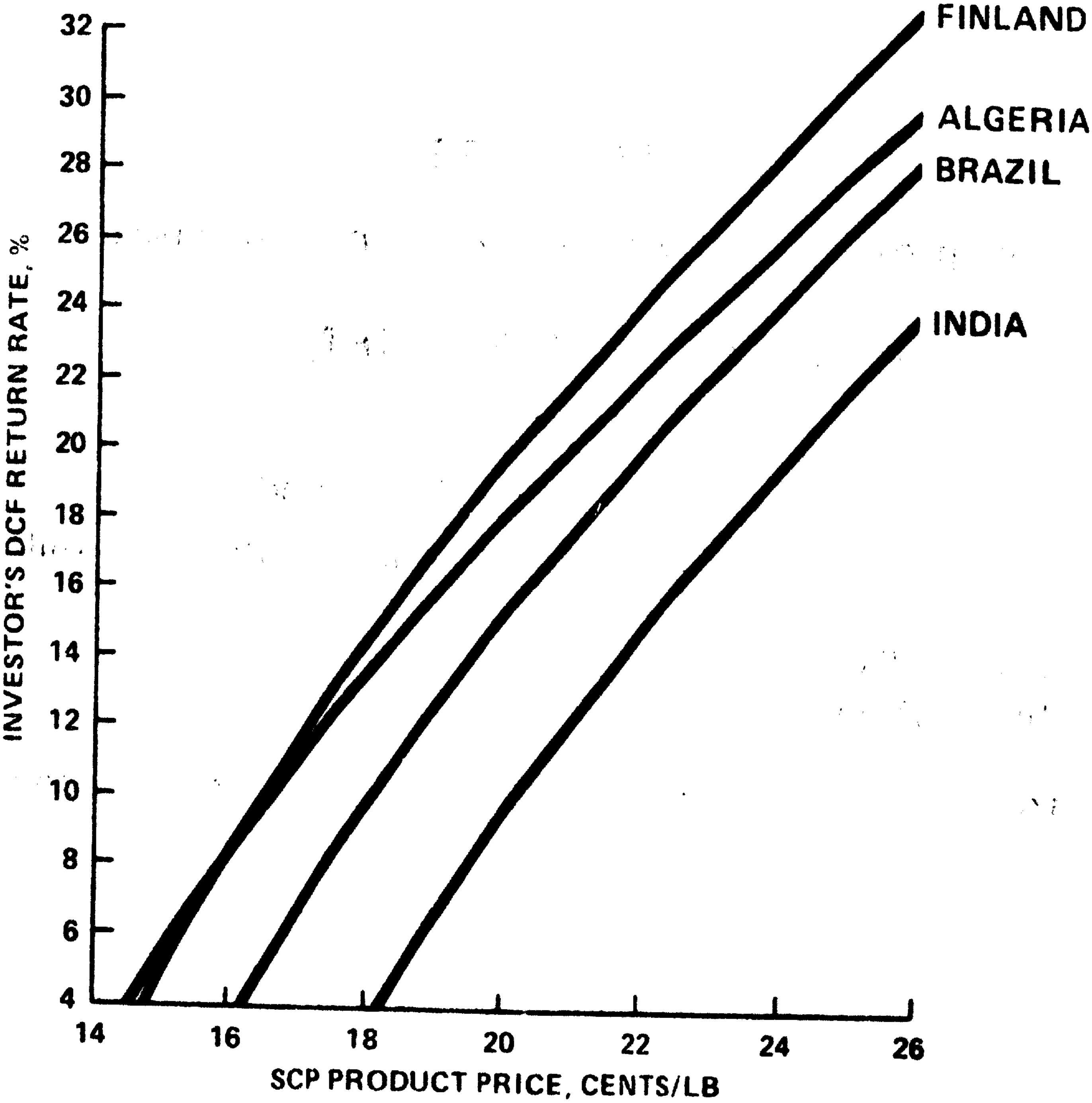


TABLE 11

SCP SELLING PRICE FOR 10% and 15% INVESTOR'S DCF RETURN RATE

	Cents Per Pound SCP			
Investor's DCF Return Rate	Finland	Algeria	Brazil	India
10%	16.5	16.6	18.1	20.2
15%	18.2	18.6	19.9	22.0

FIGURE V
SCP PRODUCT PRICE VS. N-PARAFFIN COST
FOR 10% AND 15% INVESTOR'S DCF RETURN RATES

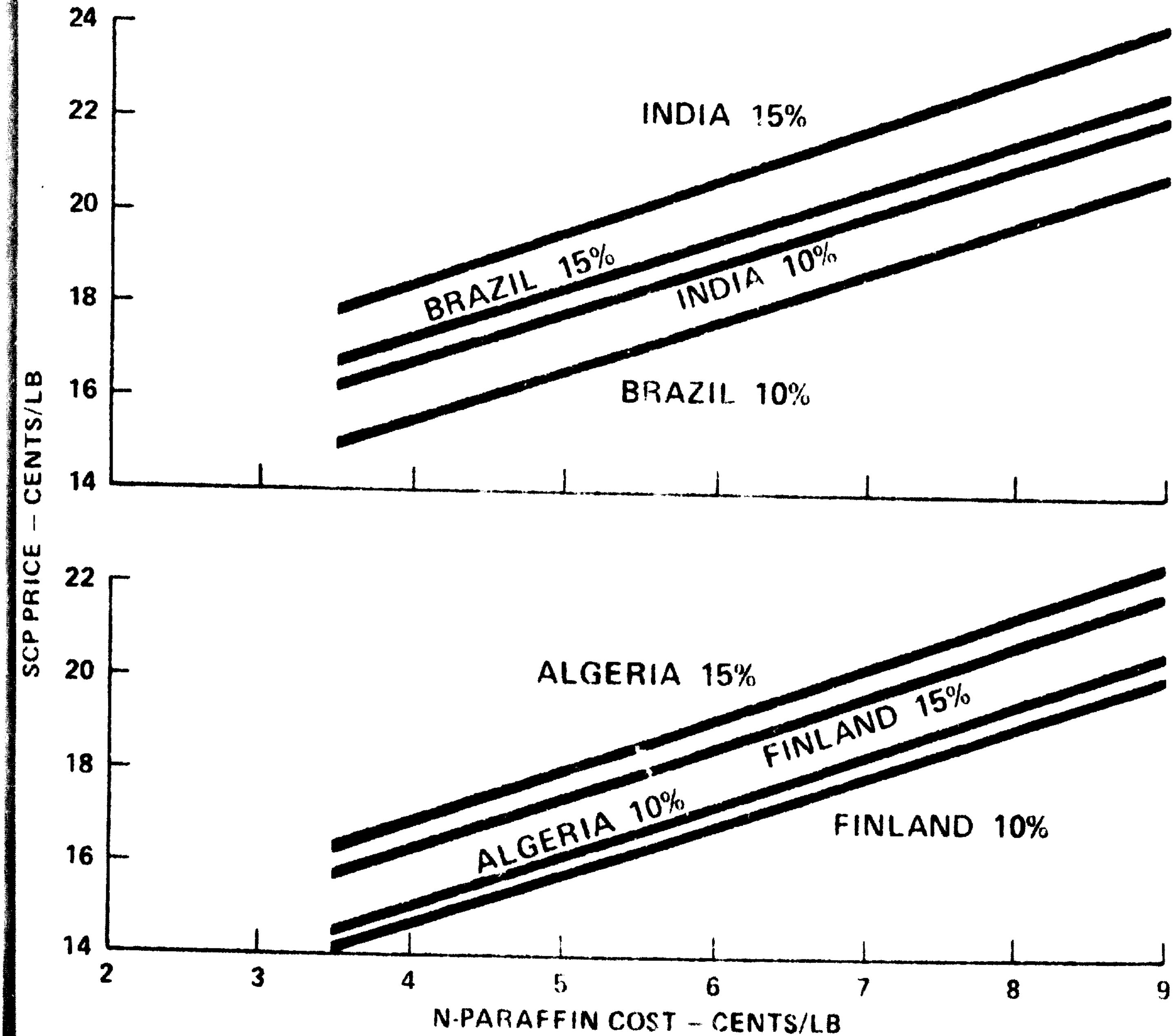
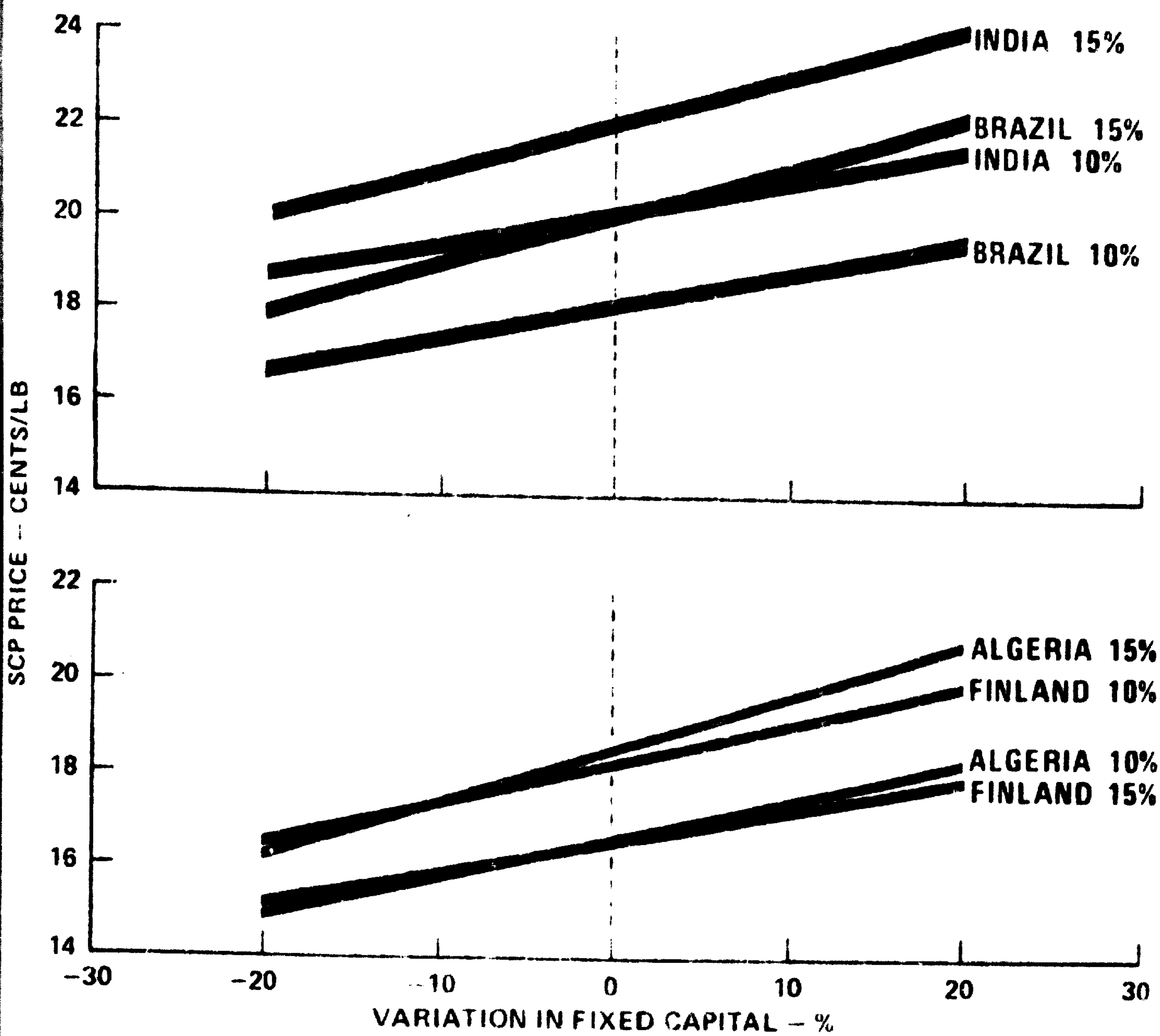


Figure VI shows the effect of fixed capital investment on SCP selling price at each site, based on n-paraffin feedstock costs given in Table 5. For example, a 20% reduction in fixed capital at the Brazilian site would decrease the SCP selling price from 19.9¢/lb. to 17.9¢/lb. for a 15% investor's DCF return rate, or from 18.1¢/lb. to 16.7¢/lb. for a 10% investor's DCF return rate.

FIGURE VI
EFFECT OF FIXED CAPITAL ON SCP PRODUCT PRICE FOR 10% AND 15% INVESTOR'S DCF RETURN RATES



VII. CONCLUSIONS AND RECOMMENDATIONS

The economic analysis of petro-protein production by the Gulf process at four selected sites reveals that local site conditions can have a considerable effect on the project economics. Hydrocarbon feedstock cost is the major element of SCP manufacturing cost and has a substantial impact on the economics at all selected sites. Thus, it is strongly recommended that the feasibility of local production of normal paraffin feedstock should be studied, with the view to eliminate shipping costs. Local production of feedstock would have the additional advantage of substantial savings in foreign exchange. For orientation purposes, this would require about 200,000 barrels per day of a typical Middle East crude for a protein project of this size. (10)

Capital costs are also significant in determining the process economics. Because two or more of almost all of the major process equipment items are used at the 100 million pounds per year level, economies of scale-up to larger capacity plants will not be outstanding. For example, doubling the plant capacity to 200 million pounds per year of SCP would reduce the manufacturing cost in Algeria (the site with the highest capital investment) by only 0.3 to 0.4¢/lb. of SCP.

The combination of local energy costs and climatic conditions are the major factors in determining the utility costs for SCP production. As noted in comparing Finland and Algeria, low energy costs in Algeria counterbalance the effects of low cooling water temperature in Finland.

Since the design sea water temperature of [illegible]°F in Finland is so close to the specified chilled water temperature of [illegible]°F, the question arises as to what would be the overall effect on the economics if the refrigeration-chilled water system in Finland was replaced by direct sea water cooling of the fermentation system. Such a scheme would eliminate about $3 million for refrigeration facilities investment, and also save about 0.6¢/lb. of SCP in associated utilities costs. The net effect of both saving would probably reduce SCP selling price by 1.5 to 2¢/lb. However, the use of sea water for direct process cooling might entail additional capital cost for heat exchanger materials of construction suitable for sea water service. Nevertheless, when considering a specific site in a cold climate, such a scheme would surely receive further study.

We expect that lower anticipated feedstock usage, and the results of optimized process design and utilities could combine to substantially reduce capital investment and manufacturing costs over those presented in this paper. While the amount of savings cannot be stated precisely without further study, we estimate the potential lowering of required product price for 10% to 15% investor's DCF return rate to be in the range of 1.5 to 3¢/lb.

Since the success of synthetic protein processes will depend on their ability to compete with natural protein sources, this definition of the key economic factors (feedstock costs, energy costs and capital investment) in SCP production should be helpful in assisting developing countries in their planning activiities in this field.

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APPENDIX A

UTILITIES USAGE AND UNIT COSTS

	FINLAND		ALGERIA		BRAZIL		INDIA	
	Usage per lb SCP	Unit Cost,¢	Usage per lb SCP	Unit Cost,¢	Usage per lb SCP	Unit Cost,¢	Usage per lb SCP	Unit Cost,¢
600 psig, 750°F Steam	0.00998 M lb	105	0.0133 M lb	41	0.0142 M lb	80	0.0163 M lb	130
200 psig Steam	0.00362 M lb	89	0.00363 M lb	35	0.00363 M lb	68	0.00364 M lb	110
30 psig Steam	0.00096 M lb	89	0.00096 M lb	33	0.00096 M lb	65	0.00096 M lb	105
Cooling Water	0.144 M Gal	3	0.166 M Gal	3	0.173 M Gal	3	0.188 M Gal	3.7
Process Water	0.00588 M Gal	20	0.00588 M Gal	53	0.00588 M Gal	45	0.00588 M Gal	21
Power	0.212 KWH	1.1	0.212 KWH	1.1	0.212 KWH	1.7	0.212 KWH	1.9
Low Sulfur Fuel (1)	0.00223 MMBTU	65	0.00223 MMBTU	12	0.00223 MMBTU	62	0.00233 MMBTU	85

NOTE: (1) For product spray drying.

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