DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DOE/ET/27197--T1

DE82 015583

ENERGY AND PROCESS SUBSTITUTION
IN THE FROZEN-FOOD INDUSTRY:
GEOTHERMAL ENERGY AND THE RETORTABLE POUCH

Martin W. Stern
W. Michael Hanemann
Katherine Eckhouse

MASTER

Revised December 1981

Giannini Foundation of Agricultural Economics
University of California, Berkeley

EAB

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

RET2AM This report was prepared under Agreement No. AT03-79ET27197, Contract No. AS03-76SF00034, for the United States Department of Energy. Neither the United States nor any of its employees, contractors, subcontractors, or their employees, makes any warranty, expressed or implied, or assumes any legal liability to third parties for the content hereof. All opinions, findings, conclusions, and recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the Department of Energy or of those who supplied the information upon which this report is based.

We would like to record here our great indebtedness to our colleague Dr. Eric Thor for his tireless support of this research. He originally conceived the idea for the project, and he generously assisted us with information and advice during its execution. We are shocked and deeply saddened by his recent and untimely death. We also would like to acknowledge the assistance and support of DOE personnel in Washington, DC, and Oakland, CA, in funding and administering this project. Finally, we are extremely grateful to the numerous persons in the food industry who graciously provided us with advice and assistance in the course of our research.

TABLE OF CONTENTS

	<u>Page</u>
CHAPTER I. INTRODUCTION	1
CHAPTER II. POTENTIAL INNOVATION IN THE FOOD PROCESSING INDUSTRY . .	3
A. Frozen Vegetable Processing	4
1. The Frozen Food Industry.	4
a. Historical Trends	4
b. Current Status	6
2. Study Definition.	9
a. Focus on California	9
b. Selection of Specific Crops	12
c. Broccoli.	14
d. Broccoli Production in California	17
3. Produce Flow for a Frozen Vegetable from Farm to Retail Shelf	22
4. Broccoli Processing	25
B. Energy Substitution: Geothermal Energy	29
1. Brief Process Description	29
2. Potential Advantages and Disadvantages	32
3. Location of Known Geothermal Resource Areas (KGRAs) in Relation to Agriculture in California	34
4. Specific Application in the Imperial Valley Region	37
C. Process Substitution: Retortable Pouch	43
1. Brief Process Description	43
2. Potential Advantages.	44
3. Potential Disadvantages	47
4. Operating Experience and Current Status	47

	<u>Page</u>
CHAPTER III. STUDY METHODOLOGY	53
A. The Standard Process.	54
1. Flow Diagrams	54
2. Materials Flow	54
3. Energy Flow	55
4. Value Added	58
B. Process Substitution.	60
C. Energy Substitution	61
CHAPTER IV. ENERGY AND PROCESS SUBSTITUTION	62
A. Standard Process.	63
1. Materials Flow	63
2. Energy Flow	65
3. Value Added	78
4. Sensitivity Analysis.	85
B. Energy Substitution	97
1. General Framework	97
2. Assumptions Regarding Water	98
3. Assumptions Regarding Costs	103
a. Well Capital Costs	103
b. Absorption Refrigeration Plant Capital Costs.	105
c. Energy Savings	105
d. Operating Costs	106
4. Bid Price	107
5. Asking Price.	109
C. Process Substitution.	111
1. Materials Flow	114
2. Energy Flow	114

	<u>Page</u>
3. Value Added	121
D. Combination of Energy and Process Substitution	126
CHAPTER V. SENSITIVITY ANALYSIS FOR ENERGY SUBSTITUTION	129
A. Frozen Product	129
B. Pouched Product	135
CHAPTER VI. CONCLUSIONS	139
A. The Frozen Product	139
B. The Pouched Product	140
C. Geothermal Energy	142
FOOTNOTES	146
BIBLIOGRAPHY	148
PERSONAL COMMUNICATIONS	155

LIST OF TABLES

	<u>Page</u>
1. Value and Quantity of Frozen Food Production in the United States 1969-78	5
2. 1978 Estimated Poundage and Value of All Frozen Foods	7
3. 1969-1978 Volume and Dollar Value of Frozen Vegetables	8
4. Total U.S. Frozen Vegetable Pack and Major Frozen Vegetables, 1969 Average	10
5. Geographic Distribution of Frozen Fruit and Vegetable Processing Plants	11
6. Major Vegetables for Freezing	13
7. Schedule of Major Crops - Planting and Harvest - Imperial Valley	16
8. Broccoli: U.S. Per Capita Consumption 1959-1978	18
9. Broccoli: California Harvested Acreage by County and Season, 1978	19
10. Estimated Energy Potential, Imperial Valley Region KGRAS	39
11. Heber KGRA: Agricultural Production Within 50, 100 and 150 Miles	41
12. Geothermal Brine Composition	42
13. Assumptions on Economic Life	69
14. Assumptions on Energy Embodied in Materials	70
15. Assumptions on Energy Content and Efficiency of Energy Forms	71
16. A Few Useful Conversion Factors	72
17. Energy Expended in Producing Sales of 1,000 Lb. of Frozen Broccoli	74
18. Contributions to Energy Expended (10^6 BTU) by Various Activities	76
19. Assumed Initial (1979) Prices for Various Energy Forms	81
20. Assumed Rates of Return	82
21. Value Added in Frozen Food Processing Chain	84
22. Lower Assumed Rates of Return	86
23. Cost and Embodied Energy Component of Capital Equipment	90
24. Performance Characteristics for Absorption Cooling	100

	<u>Page</u>
25. Geothermal Water Flow Requirements (GPM)	104
26. Pouch Materials, Capital and Labor Requirements	113
27. Energy Expended in Producing Sales of 1,000 Lb. of Pouched, Overwrapped Broccoli	118
28. Contributions to Energy Expended (10^6 BTU) by Various Activities .	119
29. Value Added in Pouch Processing Chain	123
30. Cost and Embodied Energy Component of Capital Equipment, by Economic Life	125

LIST OF FIGURES

	<u>Page</u>
1. Process Flow Schematic	23
2. Materials Flow - Broccoli - Imperial Valley - Conventional Methods (Per acre input)	64
3. Materials Flow - Broccoli - Imperial Valley - Conventional Methods (Per 1,000-Lb. Nominal Output)	66
4. Energy Flow - Broccoli - Imperial Valley - Conventional Methods (In Various Units)	67
5. Energy Flow - Broccoli - Imperial Valley - Conventional Methods (Per 1,000-Lb. Nominal Output)	73
6. Pie Chart Showing Contributions to Energy Expenditures	77
7. Value Added - Broccoli - Imperial Valley - Conventional Methods (In Various Units)	79
8. Value Added - Broccoli - Imperial Valley - Conventional Methods (Per 1,000-Lb. Output)	80
9. Comparison of Value Added Along the Process Chain (1979)	87
10. Contribution of Energy Cost to Value Added in ¢/Lb.	96
11. Geothermal Water Utilization (GPM)	102
12. Major Modifications in Materials Flow for Pouch	115
13. Energy Flow Modifications for Pouch Processing	117
14. Estimated Contributions to Energy Expenditures	120
15. Value Added - Broccoli - Imperial Valley - Retortable Pouch Process	122
16. Application of Geothermal Energy in Frozen Food Processing (I)	131
17. Application of Geothermal Energy in Frozen Food Processing (II)	132
18. Application of Geothermal Energy in Pouch Processing	137

I. INTRODUCTION

This study is an assessment of two potential innovations which confront the frozen food industry. One is the switch away from increasingly expensive conventional fossil fuels to new energy sources, in particular to geothermal energy which may be fairly abundant in California and in some of the other Western states where major sections of the food processing industry are located. The other is the possibility of process change from conventional freezing (and canning) to packing in an aseptic retortable pouch. This technology, which was first introduced more than twenty years ago and is now quite widely used in Europe and Japan, is currently receiving considerable attention in the U.S. Although there have recently been several engineering studies of the pouch process, relatively few have detailed analyses of its economics and their sensitivity to future changes in energy prices. Therefore, we believe that the present study is most timely.

The conjunction of energy substitution and process change in this study is by no means accidental: rather it reflects our conviction that a radical change in the food processing industry away from conventional fossil fuels will be accomplished not so much through the retrofitting of existing production facilities as through the construction of new facilities embodying new food processing technologies. We believe that the main force for change in the food processing industry over the next decade will be the introduction of new food technologies such as the retortable pouch. If this occurs it will require the construction of a new generation of production facilities, which would provide a significant opportunity for changing the energy input in food processing. Thus, the dynamics of process change and energy input substitution will be intertwined over the next decade. This is the premise of our study.

In order to keep the study within manageable bounds we will focus on one particular commodity in one particular location — the production of frozen broccoli in the Imperial Valley, CA. Although our quantitative analysis pertains only to this commodity, we believe that similar conclusions would be obtained for certain other commodities such as frozen spinach, asparagus, cauliflower, carrots and string beans (but not necessarily frozen potatoes or formulated frozen meals) because of the essential similarity of the production processes. The study is organized as follows. Chapter II provides background information on the current status of the frozen food industry, the nature of geothermal energy as a potential substitute for conventional fossil fuels, and the engineering details of the retortable pouch process. Chapter III describes the analytic methodology by which the energy and process substitution will be evaluated. The detailed evaluation is presented in Chapter IV, where we conduct a four-way comparison of the economics of the frozen product versus the pouched product, and conventional fossil fuels versus geothermal energy. The results for the energy substitution are subjected to a sensitivity analysis in Chapter V. Our conclusions are summarized in Chapter VI.

CHAPTER II

POTENTIAL INNOVATION IN THE FOOD PROCESSING INDUSTRY

In this chapter we present some background information on the current state of the frozen food processing industry and provide background data on two possible sources of innovation which confront the industry. One is the switch away from increasingly expensive conventional fossil fuels to new energy sources, in particular to geothermal energy. The other is the possibility of process change from conventional freezing (and canning) to retortable pouch packing.

This chapter is divided into three parts. Part A summarizes the recent history of the frozen food processing industry and provides technical information on broccoli processing, which is the particular commodity selected for our study. Part B contains background information on the potential of geothermal fluids as a heat source for food processing and the location of geothermal resources in California. Part C describes the technology of the retortable pouch and explains its potential advantages and disadvantages as a substitute for freezing.

A. FROZEN VEGETABLE PROCESSING

1. THE FROZEN FOOD INDUSTRY

a. Historical Trends

The frozen food industry has grown tremendously since World War II; both the value and the output of commercial frozen foods in the United States have grown in each year since 1942 except 1947 and 1958. Total commercial output of frozen foods rose from 623 million pounds in 1942 to over 20,000 million pounds in 1978. Value of all frozen foods rose from \$162 million in 1942 to over \$20 billion in 1978. Since as recently as 1969, total output by weight has risen 40 percent and value has risen 167 percent (See Table 1).

Until recently, the frozen food industry has been one of the fastest-growing segments of the U.S. food industry. The U.S. consumes more frozen food per capita than any other nation — approximately 83 pounds per person per year (1976 data). In Sweden, the second highest country, annual per capita consumption was 46 pounds; Denmark ranked third with 39 pounds and Great Britain fourth with 28 pounds. Frozen foods are valued because they offer a close approximation of "farm-fresh" quality in a convenient form with little or no waste. They also provide the luxury of specialty items year-round.

Virtually every conceivable commodity and food product can be found in frozen form, but certain categories of frozen foods dominate both in poundage and dollar value. The largest frozen food segment by dollar value is prepared frozen foods — products which have been either cooked or converted into a processed or convenience item. Examples include: processed frozen potatoes, breaded fish and shellfish products, bakery foods, ethnic dishes, vegetables in sauce, precooked poultry, seafood specialties, entrees, and complete dinners. Simple frozen vegetables, including potato products, rank first in

Table 1

VALUE AND QUANTITY OF FROZEN FOOD PRODUCTION IN THE UNITED STATES
1969 - 1978

<u>Value of All Frozen Foods</u>	<u>Output</u> <u>Commercial Frozen Foods</u> ¹
(dollars)	(millions of pounds)
1969 7,641,114,000	1969 14,619
1970 7,931,000,000	1970 15,389
1971 8,128,000,000	1971 15,535
1972 9,230,000,000	1972 16,578
1973 12,178,000,000	1973 17,303
1974 13,087,444,000	1974 17,418
1975 14,329,851,000	1975 17,891
1976 16,712,044,000	1976 19,071
1977 18,824,605,000	1977 20,154
1978 20,442,355,000	1978 20,533

Source: Quick Frozen Foods, October 1979, Vol. 42, No. 3,
p. 104.

1/ Includes imports.

poundage, but third in dollar value (see Table 2). They have a lower unit value than prepared frozen foods because they require less processing and simpler packaging. This study will focus on the frozen vegetables category in general, and on frozen broccoli in particular.

Although food processing has been a viable commercial industry since the early 1900s, successful commercial vegetable freezing is of considerably more recent origin. The first experimental work on the freezing of vegetables was performed in 1917. The freezing of vegetables did not attain commercial importance until 1939, when the total output of commercial frozen vegetables, including imports, was a paltry 70 million pounds. The industry grew slowly during the 1930s and 1940s, hampered by the lack of venture capital and by the lack of distribution and storage facilities throughout the entire marketing system. The per capita consumption of frozen vegetables has risen substantially since World War II (see Table 3). Annual per capita consumption rose to 28.44 pounds (processed weight) in 1978, up almost 900 percent from a 2.86-pound average in 1947-49 (USDA, ESCS, 1979). For many crops this increase in per capita consumption of frozen products has been associated with a corresponding reduction in the consumption of fresh or canned products. Between 1969 and 1978, for example, per capita consumption of frozen potatoes rose over 78 percent, from 9.84 pounds to 17.57 pounds (processed weight). Total consumption of potato products, however, rose only 6 percent in the same period. The consumption of green peas in fresh form has declined to near zero.

b. Current Status

At least 30 vegetable crops are commercially frozen. The single most important vegetable crop preserved by freezing is the potato, which accounted for roughly 40 percent of total frozen vegetable production. Other important frozen vegetables are green peas (442 million pounds), cut corn and corn-on-the-cob (310 and 269 million pounds respectively), broccoli (299 million

Table 2

1978 ESTIMATED POUNDAGE AND VALUE OF ALL FROZEN FOODS, RETAIL AND INSTITUTIONAL,
BY CATEGORY (All figures in millions)

PRODUCT	POUNDAGE			VALUE		
	RETAIL	INST.	TOTAL	RETAIL	INST.	TOTAL
Prepared Foods	4,051	1,136	5,387	4,255	1,256	5,511
Fish & Seafoods	551	1,189	1,740	1,237	4,031	5,268
Vegetables	1,929	4,349	6,278	1,037	1,854	2,891
Poultry	1,678	750	2,428	1,296	630	1,926
Meat*	440	930	1,370	650	1,700	2,350
Juices & Drinks	1,873	826	2,699	1,466	569	2,035
Fruits	63	568	631	50	411	461
TOTAL	10,585	9,948	20,533	9,991	10,451	20,442

*Meat total does not include production for large fast food chains such as McDonald's, Burger King.

Source: Quick Frozen Foods, October 1979, Vol. 42, No. 3, p. 103.

Table 3

1969 - 1978 VOLUME AND DOLLAR VALUE OF FROZEN VEGETABLES

<u>Year</u>	<u>Value</u> (\$ millions)	<u>Volume</u> (billion pounds)
1969	1,057	3.9
1970	1,169	4.3
1971	1,220	4.6
1972	1,492	4.9
1973	1,755	5.2
1974	2,416	5.5
1975	2,394	5.2
1976	2,399	5.5
1977	2,796	6.2
1978	2,891	6.6
1979	N/A	6.9

Source: Quick Frozen Foods, Vol. 42, No. 3 and
American Frozen Food Institute, 1979.

pounds), green beans (263 million pounds), spinach (181 million pounds), cauliflower (101 million pounds), baby limas (82 million pounds), and Brussels sprouts (61 million pounds). These ten vegetables have constituted approximately 92 percent of total frozen vegetable production in the United States since 1969 (see Table 4).

2. STUDY DEFINITION

a. Focus on California

This study is limited to California for several reasons. First, California is the leading producer of fresh, processing, and dual-use¹ vegetable crops in the United States. In 1978, California produced 43.6 percent of the total poundage of fresh-market vegetables and 46.3 percent of the value. For the major processing vegetables, California produced 48.6 percent of the poundage and 42.9 percent of the value (USDA, ESCS, 1979).

California is a major producer of many vegetables important in frozen food processing. Although vegetable processing occurs throughout the United States, commercial freezing occurs in relatively few states and is concentrated in the Western states. According to the Census of Manufactures, the main centers of frozen fruit and vegetable production are California, Florida, Idaho, Washington, Oregon, Michigan, Maine, New York, Minnesota, Texas and Pennsylvania. In 1977 these eleven states accounted for 82 percent of the establishments and 90 percent of the value of production in the U.S. frozen fruit and vegetable industry (see Table 5). The four Western states — Idaho,

Table 4

TOTAL U.S. FROZEN VEGETABLE PACK AND MAJOR FROZEN VEGETABLES
1969 AVERAGE, 1975-1979 ANNUAL

Product	1969-1971 Average	1975	1976	1977	1978	1979	1969-1979 % Change
- - - - - 1,000 pounds - - - - -							
Potatoes	2,339,305	3,000,983	3,335,051	3,622,823	3,848,810	4,089,732	+75%
Green peas	353,420	400,587	340,366	333,954	357,717	442,612	+25%
Cut corn	244,066	288,067	282,391	260,773	303,155	310,648	+27%
Corn on cob	87,232	183,381	187,582	265,183	307,079	269,422	+200%
Broccoli	176,180	191,638	201,513	314,395	276,519	298,618	+69%
Green snap beans	240,395	214,172	190,947	246,155	279,912	281,921	+17%
Carrots	155,893	165,869	181,277	263,769	238,415	263,080	+69%
Spinach	136,622	129,399	160,247	167,766	147,389	181,279	+33%
Cauliflower	65,728	76,056	67,807	96,670	127,513	101,130	+54%
Baby limas	76,490	85,670	43,854	92,154	81,145	82,775	+8%
Brussel sprouts	43,980	54,422	44,845	56,642	71,161	61,353	+39%
Subtotal	3,919,311	4,790,244	5,035,880	5,720,284	6,038,815	6,382,570	+63%
Total Pack	4,268,774	5,212,966	5,491,035	6,245,809	6,560,733	6,890,310	+61%
Percent of Total U.S. Pack	92%	92%	92%	92%	92%	93%	

Source: American Frozen Food Institute, 1974 and 1979.

Table 5

**GEOGRAPHIC DISTRIBUTION OF FROZEN FRUIT AND VEGETABLE PROCESSING PLANTS:
NUMBER, SIZE, AND VALUE OF PRODUCTION, 1972 and 1977**

<u>Geographic Area</u>	<u>Number of Establishments</u>		<u>Number of Employees</u> (1,000)		<u>Value of Production</u> (\$ million)	
	<u>1972</u>	<u>1977</u>	<u>1972</u>	<u>1977</u>	<u>1972</u>	<u>1977</u>
United States	209	266	42.9	47.2	1,852.4	3,332.5
Maine	10	10	2.3	1.7	72.9	64.9
New York	10	15	1-2.4	1.2	(D)	90.3
Pennsylvania	5	9	.25-.49	.7	(D)	52.9
Michigan	18	20	1-2.4	1.9	(D)	123.5
Minnesota	5	5	1.2	.9	42.7	44.1
Florida	26	35	over 2.5	6.9	(D)	1,059.0
Texas	3	6	.25-.49	.8	(D)	23.6
Idaho	9	12	over 2.5	6.6	(D)	329.2
Washington	32	34	5.0	5.7	175.0	363.5
Oregon	22	30	4.9	6.2	140.2	325.7
California	32	43	8.5	10.1	282.3	535.4

Source: U.S. Bureau of the Census, Census of Manufacturers 1973 and Preliminary 1977

(D) Withheld to avoid disclosing individual operations.

Washington, Oregon, and California — had 45 percent of the establishments, 60 percent of the employees, and 47 percent of the value of U.S. production in 1977. California alone accounted for 16 percent of the establishments and 16 percent of the value of production in 1977.

California is also generously endowed with geothermal resources, offering the potential for substitution of geothermal energy for electricity and natural gas in food processing. The escalating costs and the sometimes uncertain availability of conventional energy resources make the application of new technologies attractive. The use of geothermal steam and hot water to provide thermal energy for process heat and absorption refrigeration in food freezing is one possible technological development. Many of California's most geothermally active areas are in close proximity to agricultural production. The coincidence of agricultural production and geothermal resources will be discussed further in section B.4.

b. Selection of Specific Crops

The initial intent of the study was to follow, from the farm to the retail shelf, several vegetables prominent in the frozen food sector. The following criteria were used to select the vegetables:

- 1) Did the crop enjoy a relatively stable or growing market?
- 2) Were both production and dollar volume high in California and the eleven Western states with substantial geothermal resources?
- 3) Was a substantial portion of the crops sold in frozen form?
- 4) Did the harvest seasons of the various crops dovetail to maximize efficient use of the geothermal resource and capital equipment?
- 5) Was the retortable pouch technology potentially applicable?

After perusal of agricultural production statistics (see Table 6) and

Table 6

Major Vegetables for Freezing: U.S. Annual Production for Fresh and Processing Markets, Percent of U.S. Total Produced in California, Percent of U.S. Total Freezing Done in California.

Crop	U.S. Total Annual Production ¹ (tons)	% of U.S. Total in California	% of U.S. Total Freezing Done in California
Green peas	461,000	2.2	4.8
Broccoli	287,000	95.6	95.9
Green snap beans	860,100	3.6	12.0 ²
Spinach	179,950	52.6	41.7
Carrots	981,500	43.8	43.3
Cauliflower	203,450	80.6	75.9
Brussels sprouts	36,900	100.0	100.0
Baby lima beans	82,650	54.4	71.3

¹Fresh and processed.

²1973-75 weighted average. Separate data for later years not available.

Source: USDA "Agricultural Statistics," 1978 and American Frozen Food Institute, "Frozen Food Pack Statistics," 1973-79.

discussions with representatives of the frozen food processing industry, seven vegetables were initially chosen: baby lima beans, broccoli, Brussels sprouts, carrots, cauliflower, green beans, snap beans, and spinach.

A deliberate decision was made to eliminate corn and potatoes from consideration, although both are important frozen vegetables. Corn in various forms represents about 8.5 percent of U.S. frozen vegetable production; 80 percent of the total U.S. frozen pack was processed in the West. California, however, does not produce significant quantities of sweet corn for processing.

Potatoes constitute 40 percent of the U.S. frozen pack, but were not considered for several reasons. First, California produces potatoes for tablestock (fresh market) and potato chips, but its potatoes are not considered suitable for freezing. Second, processed frozen potatoes are more akin to prepared processed foods than to simple commodity items since they are most commonly deep-fried. Therefore, potatoes would not be representative of other vegetable products. Finally, considerable research has been done on the feasibility of alternative energy sources for potato processing; examples include Ore-Ida's geothermal project and Heinz's solar French fries (Ore-Ida, Inc. 1977).

c. Broccoli

As the study progressed, it became clear that our objectives could be satisfied by focusing our in-depth analysis on one vegetable crop. For our model vegetable we chose broccoli. Broccoli has been used as the prototype for vegetable processing because, although there are differences in treatment of different vegetables, the main elements are the same. Crops are hauled in large trucks to the processing plant where they are washed, sorted, cut, blanched, packed, and frozen. Although broccoli

spears are hand-packed in retail cartons, other styles of broccoli are mechanically packaged; thus, a diversity of processing techniques is represented. Broccoli is a fairly simple vegetable to process since it does not require lye-bath peeling (carrots) or brine flotation (lima beans), but it remains a good representative. Major elements such as freezing equipment and storage facilities do not change. Throughout this study, we have assumed the existence of "shadow vegetables," requiring approximately the same processing treatment, but possessing different harvesting periods to round out the processing year and increase the plant's utilization factor.

Broccoli is currently grown in the Imperial Valley, where geothermal resources are abundant. Its long harvesting season from the end of November to the beginning of March would permit good utilization of plant facilities in conjunction with other crops. Carrots, for example, are harvested from the middle of January to the middle of April; cabbage from the middle of December to late March; okra from early April to the middle of November; sweet corn from the end of April to the middle of June; summer squash from late October to early December; and winter squash in November and June (see Table 7).

Virtually all processed broccoli is frozen and virtually all processing occurs in California, which grows over 95 percent of both fresh marketed and processed broccoli in the U.S. The use of broccoli is divided almost evenly between fresh market and processed, although the value of fresh market broccoli is far greater (e.g., \$426 per ton for fresh compared to \$291 per ton for processed in 1978). In 1978, 52 percent of total U.S. broccoli production was processed; in 1977 the proportion was 55 percent, and in 1976, 48 percent (USDA, 1978).

Table 7

SCHEDULE OF MAJOR CROPS - PLANTING AND HARVEST - IMPERIAL VALLEY

Preparation & planting

Cultivation, growth & lay-by

Harvest

Seed Crops follow seasonal cropping.

Cattle feeding is a major operation throughout the year.

Lamb feeding - October through March.

Per capita consumption of broccoli in the U.S. has increased greatly over the past two decades. Total consumption almost tripled between 1969 and 1978, rising from 1.18 pounds to 3.26 pounds per capita per year (fresh equivalent basis). Consumption of frozen broccoli rose 138 percent, while consumption of fresh broccoli grew more rapidly, by 225 percent (see Table 8). This increase in per capita consumption of frozen broccoli exceeds the observed increase in consumption of most commodity-type frozen vegetable products. According to the magazine Western Grower and Shipper (May 1980), broccoli is California's most rapidly growing crop; between 1975 and 1979, production rose by 46 percent.

d. Broccoli Production in California

Broccoli production in California is concentrated in the Central Coastal area. In 1978, Monterey County had 63 percent of the state's harvested acreage (see Table 9); Santa Barbara, San Luis Obispo, Ventura and Imperial Counties also produce large quantities of broccoli. Because Imperial County produces a considerable amount of broccoli and also possesses a substantial geothermal resource base, this study will focus on that area.

Broccoli yields in California range from two to seven tons per acre. When the market price for fresh broccoli is high, fields are often harvested two and even three times, resulting in high yields. When prices are low, fields may be only incompletely picked, giving low yields. Most processing crops are grown and harvested under contract; the farmer has a fixed price and harvests the field once. Yields are lower than for fresh market broccoli for two reasons: (1) the heads are cut with a 5- to 7-inch stalk rather than the 10- to 12-inch stalks common for fresh market and (2) multiple harvesting is not practiced.

Table 8

BROCCOLI: U.S. PER CAPITA CONSUMPTION, 1959 - 1978

(POUNDS - FRESH EQUIVALENT BASIS)^{1/}

Year	Fresh	Frozen ^{2/}	Total
1959	0.40	0.78	1.18
1960	0.40	0.84	1.24
1961	0.40	0.78	1.18
1962	0.30	0.83	1.13
1963	0.40	0.79	1.19
1964	0.30	0.88	1.18
1965	0.30	0.90	1.20
1966	0.30	0.95	1.25
1967	0.30	1.03	1.33
1968	0.40	1.05	1.45
1969	0.30	1.11	1.41
1970	0.40	1.10	1.50
1971	0.40	1.19	1.59
1972	0.40	1.32	1.72
1973	0.50	1.41	1.91
1974	0.60	1.38	1.98
1975	0.90	1.27	2.17
1976	1.10	1.38	2.48
1977 ^{3/}	1.30	1.53	2.83
1978 ^{3/}	1.30	1.86	3.26

1/ Quantities of broccoli used in commercially produced soups, baby foods, and canned mixed vegetables omitted from these figures.

2/ Converted from frozen by multiplying by 1.33 (USDA, Economic Research Service, Conversion Factors and Weights for Agricultural Commodities and Their Products. Statistical Bulletin No. 362, June 1965):

3/ Preliminary.

Source: USDA, Economic Research Service, Vegetable Situation, TVS-205, August 1977 and TVS-213, August 1979.

Table 9

BROCCOLI: CALIFORNIA HARVESTED ACREAGE BY COUNTY AND SEASON, 1978

County	Winter	Spring	Summer	Fall	Total
	----- acres -----				
Monterey	6,300	13,000	10,400	10,900	40,600
Santa Barbara	2,170	880	2,100	4,100	9,250
San Luis Obispo	1,380	1,350	1,500	1,100	5,330
Ventura	2,000	460	—	2,000	4,460
Imperial	2,750	—	—	—	2,750
Orange	230	—	—	—	230
Riverside	—	—	—	120	120
San Benito	—	—	100	—	100
Other Counties*	170	210	100	1,080	1,560
Total	15,000	15,900	14,200	19,300	64,400

* Counties with 50 acres or less are included in other counties.

Source: California Crop and Livestock Reporting Service. California Vegetable Crops, Annual Summary. 1977 - 1978.

For this study, we assumed a yield for processing broccoli in Imperial County of 4.43 tons per acre. This reflects average yields in California and projected yields in Imperial County after adjusting for the lower yields associated with processing broccoli.

Imperial County

Imperial County had 4 percent of California's harvested acreage of broccoli in 1978. According to the County Farm Advisor, broccoli was not grown extensively in Imperial County before the 1960s. The development of a new variety, Green Duke Hybrid, permitted expansion of plantings (Mayberry, 1980, personal communication). In 1978, 2,740 acres of broccoli were harvested. Total production was 8,768 tons, with an average yield of 3.20 tons per acre. The average price per ton was \$567.17 for a total farm value of \$4,973,000. These low yields reflect in large part poor market conditions at the time of harvest. For a well-managed field, harvested in accordance with the common practice of multiple pickings, yields of six to seven tons per acre could be expected (Mayberry, 1979).

Cultural Practices

Broccoli is not unduly exacting in its climate requirements, but it is essentially a cool-weather crop. As the monthly mean temperatures rise above 60° F, yields and quality are very seriously reduced for most varieties. In Imperial County broccoli is grown as a cool-season crop. It is normally planted from August 25 to November 1. Harvesting begins November 25 and continues through March 5.

Although broccoli may be grown on a wide range of soils, well drained soil is preferable. Broccoli has greater salt tolerance than other vegetables such as lettuce, carrots and onions.

In California, all broccoli is direct-seeded with precision planters. Precision planting has reduced hand thinning requirements, but at an early stage of growth, plants are thinned with hand hoes to a spacing of 10 to 16 inches. The crop is irrigated during germination and emergence. In subsequent growth stages, the fields are furrow-irrigated approximately 8 times, using about 4-1/2 acre-feet of water. Usually each irrigation is followed by shallow mechanical cultivation.

Pesticides are used to control cabbage loopers, armyworms, salt marsh caterpillars, cutworms, sugar beet nematodes, and aphids. In general, eight applications of pesticides are made to each crop. Herbicides are applied prior to planting. Fertilizers (nitrogen and phosphorus) are applied broadcast prior to listing the beds. Broccoli does not require high nitrogen levels; lower nitrogen fertilizer levels may reduce the occurrence of hollow stem. A side dressing nitrogen is applied once during the growing season.

The broccoli grown in Imperial County is currently used for fresh market. Fields are harvested by hand once or twice during the season. In this operation, mature broccoli heads are hand-cut with 10- to 12-inch stalks and placed on a conveyor belt loader which carries them to a bulk bin. Trucks haul the bulk bins to a packing shed for sorting, trimming, and bunching. The heads are packed in 40-pound fiberboard cartons containing 14 to 18 bunches. The cartons are then cooled to about 32° F and kept cold.

In Imperial County average costs per acre for broccoli production in 1979 were \$1,749.52. Land preparation costs represented 6 percent (\$113.25), growing period costs 26 percent (\$454.50), and land rent and cash overhead 13 percent (\$221.77). Harvest costs, including customer harvest, packing, and hauling to cooler, represented 55 percent of the total (\$960.00).²

3. PRODUCE FLOW FOR A FROZEN VEGETABLE FROM FARM TO RETAIL SHELF

Figure 1 presents schematically the major steps common to the production of most frozen vegetables. No more than 13 separate stages bring the crop from the field to the supermarket shelf. Each stage requires inputs of energy, labor, and capital and has outflows of waste materials. Quantitative information on these various steps is presented in Chapter IV.

Vegetable crops are harvested in a variety of ways. Broccoli and cauliflower heads are cut by hand and placed on conveyor belts leading to truck bins. A number of processing vegetables are mechanically harvested. Peas and lima beans are harvested by mobile viners and threshers which leave the vines and pods in the field and deposit the peas or beans directly onto bulk trucks for transport to the processor. Carrots, too, are usually mechanically harvested. Unlike most processing vegetables except potatoes, carrots may be held in cold storage to extend the processing season (Somogyi and Kyle, 1978).

As a vegetable commodity is harvested, it is loaded into large trailers hooked to diesel truck tractors. Each truck can haul two trailers, each containing approximately 40,000 pounds. Some vegetables such as broccoli, cauliflower, and spinach are highly perishable; ice may be added to the load at the rate of one pound of ice for every three pounds of product to maintain quality.

Some, but not all, vegetables also undergo a "preprocessing" stage (see Step 3, Figure 1). Brussels sprouts, for example, are loaded, still attached to the stalks, and hauled to a separate facility. There the sprouts are cut from the stalks and deleafed mechanically. They are then loaded into bins, hydrocooled (soaked in chilled water) to preserve freshness, and hauled to the processing plant.

PROCESS FLOW SCHEMATIC

The distance from the farm to the processing plant is usually short, since freshness is important for high-quality frozen products. For the purposes of this study, we have assumed a one-way haul of 90 miles, taking approximately two hours (Cervinka, 1974, p. 127, and industry sources).

The first step at the processing plant is "receiving and preparation" (see Step 5, Figure 1). Upon arrival at the processing plant, trucks are weighed, and samples of the commodity are analyzed. The processor docks the grower for observed defects--overmaturity, insect infestation, damage, off color, excessive leaves or weeds. The grower is paid only for that portion of the load which the processor deems acceptable, but the processor usually pays hauling costs for the entire load.

The vegetables are unloaded manually or, usually, mechanically. After unloading, there is an extensive series of steps involving cleaning, sorting and grading. Many sophisticated mechanical tools are employed, but visual inspection by trained workers is still highly important. The vegetable is blanched and cooled, and then proceeds from the receiving and preparation stage to the pack/wrap/case and freeze stages.

The course followed by a product at this point depends upon its nature. Some vegetables — e.g., peas, sliced carrots, beans, chopped or cut broccoli and cauliflower — may go to an IQF (individual quick frozen) freezing line; after freezing they could be stored in bulk bins for packaging at a later date (see Figure 1). Alternatively the vegetables may be packed in retail and institutional packages and frozen after packing. They are then cased and sent to cold storage. Broccoli spears and spinach are among the items which are always packed prior to freezing.

Depending on the method used (see below), freezing takes from 10 minutes to 5 hours. After freezing, the product proceeds to cold storage. For broccoli,

residence time in processors' cold storage is four months on average, but may last up to a year.

After storage, the vegetable product is hauled in diesel trucks, carrying a total of 40,000 pounds in refrigerated trailers. Average hauling distance is approximately 1,800 miles one-way. The product is then stored in a distribution warehouse for an average of three weeks, before being hauled in diesel trucks with refrigerated trailers to the retail store. The average one-way distance is 50 miles. At the retail store, the frozen product is first unloaded into a "freezer box" at the rear of the store. Average residence time is two weeks. From the freezer box, frozen vegetables are moved to the sales area of the store, where they remain for an average of one week.

4. BROCCOLI PROCESSING

Virtually all processed broccoli is frozen. Broccoli is generally processed year-round, excluding the summer months of July and August and according to regional availability. Broccoli for freezing is hand-cut and trimmed in the field close to freezer specifications--six to seven inches in length with few or no leaves. The broccoli is taken directly from the field to the processing plant in 700- to 1,000-pound bulk bins. Since broccoli deteriorates rather rapidly, hydro-cooling or icing in bins is common.

At the plant, samples of broccoli are taken. The growers may be docked for any of the following defects: 1) over length (most broccoli is bought on the basis of a 7-inch cut and anything over this may be docked); 2) excessive leaves; 3) damaged heads; 4) insect infestation; 5) overmaturity; and 6) off-color. The processor deducts a certain portion of the load by weight and pays the grower only for the remainder, under the assumption that the docked portion represents unusable waste.

For the purposes of this study, the dockage rate is placed at 20 percent as an industry average.

The broccoli is dumped from the bins onto a conveyor belt and taken to a sorting line. Damaged, overmature (blossomed) heads, insect infested heads, and oversized leaves are removed. The broccoli is manually trimmed and quartered. Side shoots and good stems and pieces are saved and used for chopped broccoli. The main stalks are placed crosswise on a conveyor belt and passed under a knife which trims the stalk to the desired length, usually 5 inches. The stalks are split lengthwise to form uniform pieces.

After trimming, the broccoli cuts are dumped into a recirculating wash water tank that uses a high-pressure spray to remove soil and pesticide residues. After going through the washer, the broccoli is dewatered before entering the blanching process.

Blanching is the treatment of the product with hot water between 200° F and 210° F or steam at atmospheric pressure and 210° F. Blanching is performed for four main reasons: 1) deactivation of enzymes to prevent product deterioration during cold storage; 2) removal of gases trapped in the leaves or flower parts of the vegetable to facilitate packing; 3) reduction of bacterial count; and 4) setting of color for better visual appeal of product. Broccoli is blanched in either a hot water or a steam blancher. Common blanching times are 2 to 3 minutes in water or 3 to 4 minutes in steam. After blanching, the broccoli is put through a cooling cycle in a cold water flume or cold water spray. It is dewatered and undergoes a second inspection. Further hand trimming occurs and the broccoli is sorted for packaging as spears and chopped broccoli.

In the packaging process, spears are hand-packed; the boxes are individually weighed and then conveyed to a pack-and-wrap operation. The packages are

normally frozen in plate freezers or air-blast tunnels. Chopped broccoli may be conveyed directly to an individual quick freezer. These freezing methods are explained in greater detail below.

The convention in the frozen food industry is to refer to one subcategory of a product line as the "basic item." This basic item is used as the standard of comparison for the other components of the product line in computing costs of production. For broccoli, the basic item is grade A spears packed in 10-ounce cartons, with 24 cartons to one corrugated paper box. In this study, broccoli is assumed to be packaged in this manner. Broccoli may be processed and packaged in other ways. Individual containers may weigh from 8 ounces to 60 pounds. The styles are spears, cut, and chopped. However, spears are the most common form, accounting for 60 percent of poundage in both the retail and the industrial market (Quick Frozen Foods, 1979).

Cut (24 percent of the total pack) and chopped (16 percent) broccoli may be frozen by means of individually quick frozen (IQF) freezers. In the individual quick freezers, the product moves slowly on a perforated vibrating metal conveyor belt. Large fans blast -40° F air upwards through the belt, freezing the product in separate pieces. After leaving the IQF freezer, the frozen product is emptied either into large bins holding 1 to 2 thousand pounds or is immediately packaged for the retail or institutional market. Bulk storage in bins is common for three reasons: 1) the product may be repackaged during the off-season, expanding utilization of the facilities; 2) the processor can package the product in accordance with observed demand for different sizes of packaging rather than guessing during the processing season; and 3) the product may be shipped in bulk for reformulation elsewhere.

Broccoli spears are not considered suitable for IQF freezing and bulk storage and are packaged before freezing. Since the spears are large and

fragile, they are hand-packed in cartons to minimize product damage. The most suitable and common methods for freezing packaged products are plate freezers and air-blast tunnel freezers. In plate freezing, heat transfer occurs through conduction. The packaged food is placed on a slowly moving belt which passes between two plates held tightly against the package surface. Liquid refrigerant at -40° F circulates through the plates. Heat transfer is relatively rapid; freezing time is approximately $\frac{1}{2}$ to 2 hours (Rasmussen, 1968). In air-blast freezing, the packages are loaded on metal racks and placed in a freezing tunnel. Cold air at -40° F flows through the tunnel. Freezing occurs in approximately 3 to 5 hours (Rasmussen, 1968).

Each method of freezing has a different efficiency of refrigeration. This efficiency may be viewed as that fraction of actual refrigeration capacity which goes into heat removal from the product. Plate freezing is the most efficient method, rated at 70 percent efficiency. IQF freezing is estimated at 50 percent and air-blast tunnel freezing at 30 percent.

B. ENERGY SUBSTITUTION: GEOTHERMAL ENERGY

1. BRIEF PROCESS DESCRIPTION

Vapor-dominated ("dry-steam") geothermal resources (such as The Geysers in California) are scarce, and valuable for the generation of electricity. Water-dominated ("wet-steam") systems at intermediate temperatures ($\sim 300^{\circ}$ F) and pressures (~ 100 psig) are found (Penner, 1975) much more frequently (e.g., in the Imperial Valley), and are most suitable for process heating and other direct thermal applications. The water is pumped up and conveyed to a nearby location for use. It must be kept under pressure to prevent its flashing into steam. The steam admixed with the water, if separated out, may be of value for cogeneration of electricity and heat.

Since geothermal water cannot be conveyed far without excessive thermal loss and expense, a food processing plant taking advantage of this energy source must be located nearby, within say 1-2 miles. Geothermal water can then replace fossil fuels used in processing to provide hot water and steam, primarily for blanching, but also for washing and steam cleaning of equipment. It can also be used for freezing and cold storage of vegetables. Finally, the geothermal steam can be used for cogeneration, the electricity being harnessed for motive power, lights and space conditioning, the hot condensate being added to the partly spent geothermal hot water for further use. However, to simplify the present study, we shall not consider the substitution of geothermally-generated for fossil-fuel-generated electricity.

The application of geothermal hot water for blanching and cleaning is quite straightforward, except for the dissolved solids in the water which may make it unsuitable for direct contact with the vegetables. In that case

a heat exchanger has to be used, with acceptably clean water being heated by exchange with the geothermal brine. This raises problems about fouling (gradual coating by minerals) of the heat exchange surfaces, and about the availability of clean water at the geothermal site. These problems must be tackled and solved for any given site.

The application of geothermal hot water for freezing and refrigerated storage requires some explanation. Common refrigeration systems have a compressor which is powered by electricity or liquid fuel. The working fluid, a hot vapor following compression, is cooled and liquefied in the condenser. It then passes through an expansion valve into the freezer or refrigerator coils of the evaporator, where it vaporizes, absorbing heat from the surrounding space which is to be cooled. The vapor is then recompressed to complete the cycle.

In the geothermal energy application the compression refrigeration method is replaced by an absorption refrigeration method. That is, the working fluid vapor, following the evaporator, is dissolved or absorbed in a solvent. Subsequent to absorption the solvent is heated to drive off the dissolved vapor. With a suitable arrangement of valves, the vapor is absorbed at low pressure and driven off at high pressure, the geothermal heat providing the energy for this "compression." To quote (ASHRAE, 1972):

The absorption cycle and the mechanical compression cycle have in common the evaporation and condensation of a refrigerant liquid, these processes occurring at two pressure levels within the unit. The two cycles differ in that the absorption cycle uses a heat-operated generator to produce the pressure differential, where the mechanical compression cycle uses a compressor; the absorption cycle substitutes physico-chemical processes for the purely mechanical processes of the compression cycle. Both cycles require energy for operation:

heat in the absorption cycle, mechanical energy in the compression cycle.

A typical "single-stage" ammonia (NH_3) absorption refrigeration unit consists of four main components

- (1) A generator, which is a reservoir containing a "strong solution" of NH_3 in water, and to which heat is applied, raising its temperature to T_3 , at which NH_3 is driven out of solution, leaving a "weak solution" at the bottom of the reservoir;
- (2) A condenser, in which the hot, high-pressure NH_3 vapor is cooled to temperature T_2 and condensed to liquid form;
- (3) An evaporator at low pressure, into which the liquid ammonia passes through an expansion valve, and in which it cools to temperature T_1 and vaporizes by taking up heat from its surroundings;
- (4) An absorber, which is a low-pressure reservoir containing weak solution bled off the generator, and which is maintained at (approximately) condenser temperature T_2 where NH_3 is highly soluble in water.

Very little power is needed to pump the fluids and maintain the pressure differentials, since there is no vapor compression.

It should be noted that heat is added to two components: to the evaporator (from the refrigerated space), and to the generator (from the geothermal brine). Heat is removed from two components: from the condenser (the enthalpy corres-

ponding to the lowering of temperature, and the heat of condensation), and from the absorber (the enthalpy corresponding to the lowering of the temperature of the weak solution, and the heat of solution). At present absorption refrigerators are somewhat more expensive and less efficient than compression refrigerators, and their efficiency rapidly deteriorates for geothermal temperatures below 300° F; but they use a resource which is thermodynamically better matched to the task at hand, and less wasteful to produce.

2. POTENTIAL ADVANTAGES AND DISADVANTAGES

California possesses a very large geothermal potential: 70 percent of the estimated electrical energy potential for hydrothermal resources in the U.S. This is roughly 10 times the potential of Nevada and Oregon, the states with the next largest identified resources. The undiscovered hydrothermal resources in California could be 3 to 4 times those already identified by the U.S. Geological Survey (USGS). Also extant are hot-igneous and conduction-dominated geothermal systems which may contain more heat energy than the hydrothermal systems; however, the technology needed for their development is not available (Jet Propulsion Laboratory, 1976).

Most of the geothermal development interest and commercial activity in the state is focused on the hydrothermal resources, with particular emphasis on electrical power generation. The largest geothermal electrical generation facility in the world is located at The Geysers in Northern California; it has an installed electrical capacity of about 925 MWe.

Nonelectrical applications of geothermal energy are receiving increasingly favorable attention for several reasons. First, intermediate temperature geothermal systems (194° F - 302° F) are more abundant than the higher

temperature resources suitable for electrical power generation. These intermediate temperature systems may contain much more heat energy than higher temperature systems. They are greater in quantity and broader in geographic distribution.

Second, approximately 90 percent of the world's consumption of energy is for nonelectric purposes (Armstead, 1979). Intermediate temperature geothermal resources could be effectively used in nonelectrical applications such as industrial process heating, commercial and residential heating and cooling, aquaculture, and greenhouses.

Third, electricity is an essentially inefficient use of the enthalpy of geothermal resources, despite its great usefulness and transportability, due to inescapable thermodynamic constraints. The direct use of geothermal energy, on the other hand, can be highly efficient, since the losses incurred are not imposed by thermodynamic constraints, but by technological imperfections: these imperfections can be controlled within economic boundaries.

Geothermal energy can offer significant advantages for specific industrial applications. In food processing, for example, it can be used for absorption refrigeration systems to freeze produce (-40° F) and to keep it in cold storage (-4° F). These refrigeration systems operate with heat input temperatures of 300° F or less, compatible with the majority of hydrothermal resources (Harris et al., 1977). A temperature drop of 60° F to 100° F would be effected by powering the refrigeration system, leaving the remaining enthalpy available for other uses. An appropriate design would be a cascaded system in which the geothermal heat is used sequentially to power the refrigeration units and then deliver process heat and hot water. In frozen vegetable processing, process heat for blanching and hot water for cleaning of equipment could be provided by fluid below

230°F. Use of geothermal energy to power the refrigeration plant and provide process heat would eliminate or at least greatly reduce processors' requirements for electricity and natural gas.

Although energy costs constitute only a small percentage of product value, the total quantity of energy consumed by the food processing industry is substantial. The cost of energy is rising at a rate exceeding the rate of inflation. Available fossil fuel energy sources were formerly competitive with geothermal energy, but this relationship has been changing recently. Geothermal systems should not experience increasing cost trends to the same degree as fossil fuels; the rise in geothermal costs is more dependent exclusively on inflation in labor and capital goods costs than is the rise in fossil fuel costs, which is affected by scarcity and supply/demand pressure. Until the operations of a geothermal facility begin, all associated costs are subject to inflation; after operations begin, however, only overhead and maintenance costs are influenced by it.

3. LOCATION OF KNOWN GEOTHERMAL RESOURCE AREAS (KGRAs)

IN RELATION TO AGRICULTURE IN CALIFORNIA

In California there are five principal regions with identified potential as geothermal resource areas: the Eastern Sierra Region, the Northeast Region, The Geysers Region, the Central Coast Region, and the Imperial Valley Region.

The Eastern Sierra Region

The Eastern Sierra Region includes five KGRAs: Bodie, Coso Hot Springs, Mono-Long Valley, Randsburg, and Saline Valley; these are located in Mono, Inyo, and San Bernardino Counties. The Randsburg KGRA is located in San

Bernardino County, but as yet there is very limited evidence of significant usable geothermal resources. The other KGRAs are located in Mono and Inyo Counties. These counties are relatively unpopulated and their economies are heavily dependent on tourism. Cattle and sheep grazing is also an integral part of the local economy, but agriculture is limited by aridity, soil characteristics, and steep topography.

The Northeast Region

The Northeast Region contains five KGRAs scattered through a five-county region. The KGRAs are Glass Mountain, Lake City, Surprise Valley, Lassen, Wendell Amadee, and Beckwourth Peak. The counties are Siskiyou, Modoc, Lassen, Tehema, and Plumas.

Agriculture is the mainstay of the regional economy. Livestock and field crops related particularly to livestock (hay, pasture, barley) are important commodities. Onions and potatoes are also grown.

The Geysers Region

The Geysers Region includes The Geysers-Calistoga, Knoxville, Little House Mountain, Lovelady Ridge, and Witter Springs KGRAs and comprises parts of Colusa, Lake, Mendocino, Napa, Sonoma, and Yolo Counties. The bulk of the geothermal resource lies in Lake County, but most development has occurred in Sonoma County.

The five counties included in The Geysers Region have economies which are strongly influenced by agricultural production. In addition, Lake County receives significant revenues from tourism; Napa County has a significant working population employed in the governmental market sector (29 percent); and Sonoma and Mendocino Counties have large forest products industries. Although vegetables are grown in this area, it is not a significant producer of either fresh market or processing vegetable crops.

The Central Coast Region

The following counties form the Central Coast Region: San Mateo, Santa Cruz, Monterey, San Luis Obispo, Santa Barbara, Ventura, Santa Clara, and parts of Stanislaus and Merced. This region includes some of the richest agricultural land in California.

The only KGRA in this region is Sespe Hot Springs, in northeastern Ventura County. This was designated a KGRA because of the special geology of the region, which is marked by many thermal springs. However, there has been little exploration to date and no commercial resources have yet been discovered.

Further north, the Diablo Range east of Gilroy shows promise as a potential geothermal area. Although it has not been designated as a KGRA, private organizations have shown interest in exploring and developing the geothermal potential of the area. The area of interest includes parts of three counties: Santa Clara, Stanislaus, and Merced. Diablo Exploration, Inc., a private company, was planning in 1976 to explore the area and study the feasibility of piping hot fluid from potentially productive wells to the Gilroy area for use by the canning industry.

The Imperial Valley Region

The Imperial Valley Region contains seven KGRAs: Brawley, Dunes, East Mesa, Ford Dry Lake, Glamis, Heber, and Salton Sea. All are in Imperial County except Ford Dry Lake which is in the southwest corner of Riverside County. With the exception of Ford Dry Lake, these KGRAs are all located in a closed-drainage basin with all drainage into the Salton Sea. The area is rather flat, arid, and surrounded by rugged mountains (Jet Propulsion Laboratory, 1976).

The area has a characteristic desert climate, with hot, dry summers and mild winters. Temperatures of over 38° C typically occur more than 100 days each year, and precipitation averages less than 3 inches annually, occurring largely in the fall and winter months.

The principal land use and industry in the Imperial Valley is irrigated agriculture. Agricultural products comprise a variety of field, vegetable, seed, and nursery crops as well as apiary, livestock, and dairy products. Water from the Colorado River, delivered through the All-American Canal System, supplies roughly 500,000 acres in the Imperial and Coachella Valleys.

4. SPECIFIC APPLICATION IN THE IMPERIAL VALLEY REGION

In terms of total value of agricultural products marketed, Imperial County ranks as the fourth most important agricultural county in California. In 1978, the total value of agricultural products in Imperial County was \$584,414,000. The major field crops are cotton, alfalfa hay, wheat, sorghum grain, sugar beets, and sudan grass. Dairy and beef cattle and sheep are the principal livestock commodities raised in Imperial County; hogs and fish are also raised. The major fruit crops grown in Imperial County are lemons, grapefruits, and oranges; dates, tangerines, limes, and tangelos are also grown.

The Imperial Valley is a major source of fresh vegetables in the United States, particularly for winter produce. Approximately 20 varieties of vegetables and melons are grown in Imperial County. Total value of vegetable crops in 1978 was \$148,835,000. These crops included asparagus, broccoli, cabbage, cantaloupes and other melons, carrots, cucumbers and squash, garlic, lettuce, onions, tomatoes for canning and

fresh market, celery, corn, and parsnips.

The total land area of the seven KGRAs in the Imperial Valley is 262,523 acres. The 254,827 acres of KGRAs within Imperial County occupy about 9 percent of the county's land area. Approximately 30 percent of the county's irrigated agricultural land is also designated as KGRAs (140,000 out of 475,000 acres).

The geothermal resources in the Imperial Valley are all liquid-dominated systems (Layton and Ermak, 1976). When the geothermal fluids are produced they are 10 to 30 percent water vapor by weight; the remainder of the fluid is in liquid form. The temperature of the resources ranges from 135° C in the Glamis, Dunes, and East Brawley KGRAs to 340° C in the Salton Sea KGRA. Those resources above 150° C have potential for generation of electricity, while those below 150° C may be appropriate for space and process heating.

Four of the KGRAs in the Imperial Valley have resources above 150° C: Brawley, East Mesa, Heber, and Salton Sea. These are the largest KGRAs in the region and lie almost entirely within the area of irrigated agriculture. The three other KGRAs are considerably smaller in size and lie outside the area of agricultural production. Table 10 presents the acreage, estimated heat content, and electric energy potential for all seven KGRAs.

Heber KGRA is in the south-central part of the Imperial Valley, between El Centro and Calexico, along the Mexican border. It encompasses 58,568 acres and lies entirely within the region of irrigated agriculture, being criss-crossed with irrigation canals leading off the All American Canal. It is considered an excellent candidate for application of geothermal energy to food processing (see Harris et al., 1977). A wide variety of crops and livestock is produced within reasonable transport distance; these commodities include onions, tomatoes, and many other vegetables, as well as fruits,

Table 10

ESTIMATED ENERGY POTENTIAL, IMPERIAL VALLEY REGION KGRAs

Location/KGRA	Circular 726 Designation	Acres	Estimated Reservoir Temp., °C	Total Reservoir Heat Content, quads [†]	Electric Energy Potential, MWe for 30 Years
Brawley	Brawley	26,885	200	12	333
Dunes	Dunes	7,680	135	~2	**
East Mesa	East Mesa	38,365	180	22	487
	Border	5,050	160	~1	**
Ford Dry Lake	*	7,696	-	-	-
Glamis	Glamis (East)	25,505	135	~2	**
Heber	Heber	58,568	190	44	973
Salton Sea	Salton Sea	95,824	340	83	2786
	Pilger Estate H.S.	4,900	145	<u>~1</u>	<u>**</u>
				167	4579

*No data available

[†]One quad equals 10¹⁵ BTU.

**No estimate due to limited knowledge or insufficient temperature.

Source: Jet Propulsion Laboratory, 1976, p. 5-51.

cattle, sheep, hogs, and poultry (see Table 11). Hence, this site offers an extremely advantageous conjunction of agricultural production and geothermal resources.

Brawley KGRA is located in the central part of the Imperial Valley, south of the Salton Sea. This KGRA, too, is located well within the valley's irrigated region. The East Mesa KGRA is located in the southeastern part of the Imperial Valley, extending from the Mexican border north to the Holtville area. Only a small portion of this KGRA is actually within the area of irrigated agriculture, east of the East Highline Canal. A study of temperature gradient in this KGRA indicated a higher than normal temperature gradient in the locality (Jet Propulsion Laboratory, 1976). The geothermal fluids of this KGRA appear to be the least saline of the Imperial Valley resources. The total dissolved solids (TDS) average about 2,100 ppm (parts per million). The brine contains sodium, potassium, calcium, magnesium, chlorine, and other chemicals (see Table 12).

The Salton Sea KGRA dominates the Imperial Valley KGRAs both in size and in potential energy content; it contains about half of the total geothermal resources in the Valley. It covers about 95,824 acres, about half of which lies under the Salton Sea. Most of the remainder encompasses irrigated agricultural land. The flow rates for wells in the Salton Sea KGRA are quite high. The average flow rate for 10 wells in the field was 435,000 pounds/hour at average pressure of 215 psi. The fraction of steam ranged from 10 to 25 percent, with an average of 19 percent steam by weight. The average fluid enthalpy is 242 ± 26 calories/gram. The geothermal fluids are extremely saline. The salinity is lowest near the Colorado River — southeastern — side and increases northwestward toward the Salton Sea. In the KGRA as a whole the average TDS is about 210,000 ppm; by comparison the

Table 11

HEBER KGRA: AGRICULTURAL PRODUCTION WITHIN 50, 100, and 150 MILES

<u>Commodity</u>	<u>Unit</u>	<u>50 mi R</u> <u>Quant./% Total</u>	<u>100 mi R</u> <u>Quant./% Total</u>	<u>150 mi R</u> <u>Quant./%Total</u>
Onions (Dry & Dehydrated)	Ton	48,000/9.6	124,784/24.9	133,316/26.6
Tomatoes (Cannery)	Ton	74,300/1.1	94,245/1.6	175,286/3.0
Total Fresh Vegetables	Ton	1,505,120/11.5	2,006,543/15.3	2,159,646/16.5
Total Fresh Fruits	Ton	86,576/0.8	678,838/6.6	949,540/9.3
Cattle and Calves	Head	640,000/11.4	732,017/13.1	758,055/13.5
Sheep and Lambs	Head	163,000/10.2	204,940/12.8	209,600/13.1
Hogs and Pigs	Head	1,025/0.2	7,763/1.7	8,170/1.8
Poultry	Ton	1,100/0.4	7,082/2.4	7,747/2.6
Milk	CWT	760,700/0.6	2,895,751/2.4	3,140,979/2.6
Eggs	Dozen	28,000,000/3.7	243,196,500/32.1	274,167,000/36.2
Rabbits	Ton	229/17.6	942/72.5	945/72.7

Source: Harris et al., 1977, p. 82.

Note: "Total" refers to the total of agricultural production in California, Oregon, Nevada and Idaho.

Table 12

GEOTHERMAL BRINE COMPOSITION

East Mesa			
	$\bar{C},^a$		C^b
	ppm		
TDS	2,120	±	336
Na	701	±	68
K	41	±	17
Ca	39	±	36
Mg	1.2	±	0.8
HCO ₃	532	±	141
Cl	541	±	80
SO ₄	172	±	45
B	2.8	±	0.6

$\bar{C}^a$ = Average concentration of 4 wells

C^b = Standard deviation among wells (indicates variance among wells)

Source: Layton and Ermak, p. 102.

salinity in the East Mesa KGRA is 2,100 ppm. This salinity will cause serious problems of corrosion and scaling, which must be overcome before the Salton Sea resource can be effectively exploited. However, an intensive research effort is being directed to this goal.

C. PROCESS SUBSTITUTION: RETORTABLE POUCH

1. BRIEF PROCESS DESCRIPTION

The retortable pouch is a flexible food container that can withstand thermal processing temperatures of 250° F. It is a laminate consisting of three layers held together by a polyurethane adhesive: an inner layer of polyolefin as the heat seal and food contact material; a middle layer of aluminum foil as a moisture, light, and gas barrier; and an outer layer of polyester for strength. The retort pouch is "shelf-stable"; tests have shown that product quality can be maintained for periods up to

10 years under typical warehousing conditions (Mermelstein, 1978).

Processing of the retortable pouch closely resembles that of conventional cans: sealed containers are heated to an internal temperature sufficient for destruction of botulism-causing bacteria. The potential advantages of this new technology and some of its disadvantages are discussed below.

2. POTENTIAL ADVANTAGES

A wide variety of products can be processed in retortable pouches. The following list of food products tested for retort pouches is taken from Ludlow Corporation's Flexible Packaging Division: veal scallopini, meatballs with gravy, sausage rolls, liver and onions, and other beef products; sliced ham with raisin sauce, sweet and sour Cantonese pork, bacon, and other pork products; crabmeat, shrimp, tuna-noodle casserole, and other seafood dishes; sliced chicken and turkey with sauce, chicken stew, and other poultry dishes; lasagna, Hungarian goulash, macaroni and cheese, and other specialty dishes; peaches, prunes, pineapple, strawberries, and other fruits; and beets, potatoes, carrots, and asparagus for vegetable products. Sauces, soups, and bakery goods have also been processed in the retortable pouch.

The retortable pouch has many favorable attributes which may make it highly competitive with both canned and frozen foods. Advantages accrue throughout the marketing system, from the processor to the consumer.

- (1) Processing: The pouch has a thinner profile than cans or jars and thus takes up to 50 percent less time to achieve internal sterilizing temperatures than do cans or jars. Product quality is enhanced through reduced cooking time and considerable energy savings are obtained. Products such as fruits and vegetables

can be packed with less brine and sugar, with savings in production and hauling costs.

- (2) Storage: The pouched product is commercially sterile, does not require refrigeration, and is shelf-stable at room temperature for up to 10 years. Since storage space and costs are significant factors at the wholesale, retail, and consumer level, this feature is of paramount importance. The pouches, empty or full, take up to 85 percent less storage space than cans.
- (3) Hauling: Pouches, empty or full, weigh less than comparable cans and jars, thus reducing distribution costs: 1,000 empty 8-ounce pouches weigh 12.6 pounds, compared to 109 pounds for cans of the same capacity.
- (4) Marketing: Retortable pouches are well suited for military use and recreational camping due to shelf stability without refrigeration, resistance to handling abuse, light weight, and minimal space requirement. Pouches are desirable for the singles market and the hospital feeding market, since they can provide single-serving portions of foods. Their inherent ease of storage and preparation is convenient for elderly people.
- (5) Consumers: Reduced processing time enhances product quality. There is less waste of packing, heat transfer medium. The pouched food can be quickly prepared with virtually no mess; heating of a small retail pouch in boiling water takes approximately 3 to 5 minutes, in contrast to 30 minutes for frozen foods. This results in savings of both time and energy. At both the retail and the institutional levels, pouches take up much less disposal space than other forms of packaging. There may be lower costs for refuse removal and incineration (Lund, 1979).

- (6) Cost: Container costs for pouches are lower than for cans; according to one source (Steffe et al., 1980), the combined cost per 1,000 units for pouches and cartons is \$105, while the cost for number 303 cans is \$119 (1980 values). Container costs appear to be considerably higher for the pouch than for frozen foods, however. An industry source gave a price range of packaging materials for vegetables of \$36 to \$41 per 1,000 packages, based on 10-ounce packages (confidential industry source, 1980).
- (7) Energy: One of the most vaunted virtues of the pouch is its purported energy savings. In this area, the pouch is said to offer advantages over the can in the processing sector and over frozen foods in the storage, distribution, and retailing sectors.

Commercialization of the retort pouch is timely because of potential energy savings. Because of the narrow profile of the filled pouch, processing times can be reduced by approximately 30 to 50 percent. Energy requirements for moving the filled packages may be reduced by as much as 40 percent vs. canned foods. . . . When compared to frozen foods, retort pouch foods are projected to require 55 to 60 percent less total energy (Food Processing, 1979).

A study of the total energy required to produce food servings as a function of processing and marketing modes selected mashed potatoes as a model product because of its versatility across a wide range of processing and marketing modes (Olabode et al., 1977). Ten process/marketing models were considered; fresh, flaked, microwave-dried, granulated, spray-dried, freeze-dried, canned, retort-pouched, refrigerated, and frozen. Detailed energy accounting was performed for all components of the processing, marketing, consumption, and disposal systems (farm production not considered). The least energy-intensive mode was fresh potatoes, requiring 1,946 BTUs/4-oz. serving. The most energy-intensive modes were frozen, 6,951 BTUs/4-oz.

serving, and freeze-dried, 5,864 BTUs/4-oz. serving. Retort-pouched potatoes ranked fourth out of the 10 modes, using 3,001 BTUs/4-oz. serving. By comparison, cans required 3,381 BTUs.

3. POTENTIAL DISADVANTAGES

One of the principal disadvantages of the current pouch is slow line speed. Current common line speeds are 40 to 60 pouches/minute for forming, filling, and sealing, compared to 25 to 60 for No. 10 cans, 250 to 400 for smaller cans, and 80 to 200 for frozen foods (Mermelstein, 1978). Equipment manufacturers, however, expect filling and sealing equipment in the near future to operate at speeds in excess of 200 pouches per minute, thus significantly improving the economies of retort pouch packaging.

Another problem is that consumers tend to perceive the retort pouch incorrectly. Because of its resemblance to boil-in-bag frozen items many consumers, and even retail store managers, store retort pouches under refrigeration, thus eliminating its advantages in lower storage costs and speedy preparation.

4. OPERATING EXPERIENCE AND CURRENT STATUS

The prospects for commercialization of the retortable pouch are currently exciting a great deal of interest in the food processing industry. Attractive aspects of the pouch include possible space savings in storage and disposal, freight savings in distribution, and reduction in costs through elimination of much of the excess liquid in a product fill. Introduction to the U.S. market is of fairly recent origin, although over 20 years of development work has been performed in this country.

The U.S. military began work on the retortable pouch in 1959 at what is now the Natick Development Center, with the goal of fabricating an alternative to the metal can for combat rations that would be light, durable, convenient, stable without refrigeration, and of reasonable quality. At the same time Reynolds Aluminum and ITT Continental Baking began to explore the possibilities of producing a processable, flexible laminate. In 1962, Continental supplied the U.S. Army with 40,000 preformed pouches. Continental's licensees started the first commercial introduction of the retortable pouch in Europe in 1967 and in Japan in 1968 (Mermelstein, 1976).

Delays in attaining viable commercial status for the retortable pouch in the U.S. can be attributed to a number of factors, including difficulty in obtaining government approval of the adhesive components of the pouch. In mid-1974, the United States Department of Agriculture gave its approval for the marketing of meat and poultry products in the retort pouch, provided that the packaging materials met Food and Drug Administration Regulations. In early 1975, the FDS asked the USDA to withdraw its approval pending the results of a series of feeding studies, because of concern that components of the adhesive used to hold the three layers of the pouch together would migrate through the food-contact layer at retort temperatures. In 1977, USDA and FDA approvals were received for commercial use of retort pouches in the U.S., but by this time much marketing impetus had been lost (Belshaw, 1979). Nevertheless, this decision made possible the commercialization of the retortable pouch.

The retort pouch was first put into commercial usage in the United States in 1977, when ITT Continental Baking introduced a line of entree products into test markets. In 1978, George A. Hormel Company entered the market with a line of retort pouch products primarily for Boy Scouts

and the outdoor recreational market (Ludlow Corp., 1980).

In 1979, the first of a series of multi-million dollar contracts was awarded by the Department of Defense. The purpose of these contracts is to develop and employ a new army ration line to be called "Meals Ready to Eat" (MRE) to replace the current combat rations. The three prime contractors for the MRE program are American Pouch Foods Co., Inc., Southern Packaging and Storage Co., and Right Away Foods Corp. (Badenhop, 1980).

Also in 1979, ITT reintroduced its line of entree products in retortable pouches for the second phase of market testing; the first phase, initiated in 1977, was stoppped due to the inability of the pilot plant to keep up with demand (ibid.). Currently, food processors are developing production lines for large, institutional pouches.

Although the retortable pouch is still in the preliminary stages of market development in the U.S., it has enjoyed considerable commercial success in other parts of the world. In Japan, for example, processors have had over 10 years of experience with the pouch. Japan is the leading producer of retort pouches worldwide. In 1977, close to 350 million units of retort pouches were sold in that country. A wide diversity of products, some specifically developed for the pouch, are packaged and sold. In Europe, 50 million pouches were produced in Great Britain in 1977, and lesser quantities in Scandinavia and Germany (Belshaw, 1979). Among the reasons advanced to explain the retortable pouch's poor performance in Europe are poor product formulation, excessively high pricing, and lack of extensive advertising. In Canada, the firm Magic Pantry Ltd. is marketing dinners packaged in the retortable pouch (Leader-Post, 1979).

Proponents of the retortable pouch are optimistic about its future role in the food marketing system. Initially at least, retort pouches in

the retail market may compete with frozen rather than canned foods, and may perhaps expand the market for the boil-in-bag type of foods. For the institutional market, large retortable pouches will compete directly with the No. 10 cans now widely used, particularly for commodity-type foods such as plain vegetables and fruits. In the institutional market for formulated foods, the retortable pouch will compete with half-size steam table trays and frozen packs (Badenhop, 1980).

A consumer research survey conducted in 1977 by Ludlow Corporation (formerly Continental) concluded that the retortable pouch conveyed a strong convenience image over other forms of packaging based on the following attributes: speed of preparation, superior flavor, ease of preparation, speed of clean up, ease of storage, and ease of transport. According to this survey, consumers expressed a strong interest in using cooked vegetables packaged in retortable pouches and stated that cooked vegetables were the item they were most likely to buy (Ludlow Corporation, 1977).

Although no American companies currently market vegetables in retortable pouches, the concept is feasible. Indeed, a French company -- Lutuscru -- has been marketing a range of retort-pouched vegetables on a limited basis for over 3 years (Ebben, 1979). Lutuscru built a new processing plant specifically for retort pouch processing in late 1977. A local agricultural cooperative supplies the processing plant with potatoes, carrots, salsify, mushrooms, and brussels sprouts, among other vegetables (Food Processing Industry, 1979).

One obstacle to widespread market penetration by the retortable pouch is the slowness of existing processing lines. The line operated by Lutuscru in France, for example, operates at 50 pouches per minute and is capable of

100 pouches per minute. This rate of production falls far short of the rates of 250 to 400 units per minute that are standard for canning lines (Food Product Development, 1980). Proposed production speed lines for institutional-size pouches are generally between 20 and 25 units per minute. There are, however, reports that speeds of 40 to 48 units per minute for institutional packs can be reached on some available equipment, speeds which compare favorably with No. 10 can line speeds of 50 per minute (Badenhop, 1980).

The retortable pouch will probably not become economically viable until production rates are enhanced. FMC (Food Manufacturing Corporation) has proposals for retortable pouch processing lines operating at the rate of 180 to 210 pouches per minute (Mencacci, 1980). One of the primary causes of slow line speeds is the slowness of the filling lines; however, filler-sealers operating at 250 pouches per minute purportedly will be available in the early 1980s (Food Processing Industry, 1979).

The food processing industry views the retortable pouch as a technology whose time has come. In addition to the energy quality considerations discussed earlier, the industry views with optimism socio-demographic shifts in the U.S. population, apparent consumer preference for convenience foods, expanding markets in Japan and Europe, and possible introduction of the pouch to third-world countries. Thus, societal shifts toward more working women and smaller families are believed likely to increase the need for convenience foods and, therefore, enhance the role of the pouch. It is thought that with increasing energy costs the distribution and handling costs of frozen foods will rise, permitting the retortable pouch to make significant inroads into the market segment. In Third World countries, the lack of well-established frozen or refrigerated food distribution, and the antiquated nature of many existing can and glass processing plants, provide a high probability of success for the retortable pouch, both as a local industry and as

an import item (Peters, 1980). Another area in which the pouch will undoubtedly have an impact is the microwave market. The development of nonmetallic laminates would open up this expanding area of culinary technology.

CHAPTER III

STUDY METHODOLOGY

The purpose of this study is to examine in depth the economics and energy cost of frozen food processing, and to identify opportunities for improvement through substitutions in energy sources and modifications in food processing technology. The first step in the study, therefore, is to describe as completely as necessary the standard process. By describing the process chain from the farm to the checkout counter as a sequence of distinct unit processes or modules, a modification in production process or energy source can then be analyzed by replacing one or more of the standard modules with appropriate new ones. This general approach will be illustrated with the help of the standard process described in Section A. The procedures for analyzing the effects of an alternative energy source and an alternative food processing technology are described in Sections B and C.

A. THE STANDARD PROCESS

1. FLOW DIAGRAMS

We define our standard process as one that begins with soil preparation and planting at the farm and ends with frozen grade A broccoli spears at the retail checkout counter. We stop at the checkout counter because it is there that products of comparable quality first compete with each other. We specify that the standard process chain produces 1,000 "net nominal" pounds of product, and different process chains or modifications will be compared on the basis of this weight.³ The standard process chain will be broken into from eleven to thirteen steps, or unit processes, as shown in Figure 1. Three diagrams will be constructed: materials flow, energy flow, and value added. All three diagrams use the same modular process steps; they merely overlay different types of data on these steps. These diagrams will now be described in turn.⁴

2. MATERIALS FLOW

The materials flow diagram (MFD) is based on the concept of conservation of mass. The basic unit is 10^3 lb. For each unit process, the following accounting identity must hold

$$\text{main output} = \text{main input} + \text{other inputs} - \text{other outputs}.$$

An example of a MFD is given in Figure 2 below. The MFD starts with a single acre of farmland prepared and planted for broccoli production, and follows the product all the way from the farm to the retail market, keeping track of additions, losses and transformations. The input data come from analyses of farming operations carried out by State of California/U.C. Cooperative Extension specialists, from information obtained through contact with

processors, distributors and retailers, and from the general agricultural economics and food processing literature.⁵

The materials flow diagram is useful because it permits one to evaluate the efficiency of each unit process, and hence of the entire process chain, in converting input to output; it enables one to quantify material inputs at each unit process; and it allows one to identify the amount of waste in various forms generated at each step, and hence to evaluate waste treatment and reclamation methods and costs. Finally, the MFD is a key tool in converting the energy flow and value added diagrams to standard form.

3. ENERGY FLOW

Why have an energy flow diagram (EFD) at all? A major goal of this study is to analyze all the various energy inputs to production and to quantify the overall contribution of energy to product cost. Because we propose to examine energy flows in great detail, it is convenient to work with a separate EFD, rather than cluttering up the MFD. Energy and the other inputs to production are subsequently combined in the value added diagram. The ways in which the various forms of energy contribute to production may be summarized in the following diagram:

Firstly, energy is a direct input to production; for example, the mechanical harvesters in the field are powered by gasoline, the trucks which haul the produce from the farm to the processing plant run on diesel fuel, and at the plant natural gas is used for blanching the product and electricity for freezing it. But, in addition to this direct contribution, energy in various forms is also embodied in the other inputs to production — in the variable non-energy inputs such as fertilizer, chemicals, seed and water, and in the fixed capital.

In this study we aim to calculate and compare not only the direct energy input to broccoli processing but also the indirect input embodied in other variable and fixed input. This will permit us to assess the total energy input under various food processing technologies. This calculation involves a number of methodological issues:

- (a) In evaluating the direct energy input we have to allow for the different efficiencies of various energy sources. For example, the energy efficiency of diesel oil is about 0.8. That is, it takes the equivalent of about 1.25 gallons of crude oil to produce 1 gallon of diesel fuel, because of the energy consumed in the refining process and in transporting the petroleum product and the energy embodied in the capital for processing and marketing. The source of our information on the efficiency of this and other energy sources is Chapman et al. (1974). Different energy inputs will be compared and aggregated according to their BTU content of primary energy.
- (b) The energy content of other variable inputs will be estimated from various sources. Data on the energy content of fertilizers and chemicals is available in Cervinka (1974), FEA (1974), Wittmus (1975), and Pimentel (1979), although these data must usually be

corrected for the energy efficiency of the input fuel. The energy content of seeds will be derived from that for the vegetable crop itself, by comparing the yield of an acre of seed crop to the amount of seed required to grow an acre of vegetable crop, with some adjustment for the differences in cultural practice. The energy content of paper and other wrapping materials is estimated from data in Chapman (1975).

- (c) Our estimates of the energy embodied in the various capital inputs are based on the work of Bullard (1975), Chapman (1975) and Hannon (1978), who provide a detailed analysis of the energy content of the various materials from which capital items are constructed. In order to convert this energy input into an equivalent annual flow, the energy content of the capital items will be depreciated over their economic life using straight-line depreciation. In addition, an adjustment will be made to allow for the energy recovered by reclamation and recycling of the capital at the end of its life.

4. VALUE ADDED

With the help of the materials and energy flow diagrams one can construct a value added flow diagram. The basic unit in such a diagram is dollar cost. The aim of the diagram is to derive a hypothetical asking price P_j^A for unit output of process j , given the input asking price P_{j-1}^A , and the value added in the process.⁶ Inputs for the value added diagram (VAD) come from the MFD, from the EFD, and from price and cost information specific to the process in question. The MFD identifies how much principal input is required per unit output from process j . For example, chemical reactions or losses and inefficiencies may require more than one unit of input per unit of output. In addition, the MFD identifies secondary inputs which add to the value of P_j^A , and by-products which may be credited against it. The EFD specifies energy inputs purchased directly or embodied in variable and capital inputs. Finally, the amount of labor input to process j must be obtained from separate sources, together with the costs of energy inputs, secondary inputs, by-product outputs, labor and capital. All of these costs are added to P_{j-1}^A to derive P_j^A . With an adequately detailed flow diagram for the process chain, and sufficiently reliable information for the material and energy flows and costs for each process, one can derive a final product asking price that should come reasonably close to observed market prices for the final product.

We shall now address the question of capital costs and rates of return in some detail. Let

I = capital investment (\$),

n = tax life for depreciation (yr),

i = rate of return on equity (including variants i' , i''),

t = tax rate,

R = revenue (\$/yr),

Q = quantity produced (units/yr),

P^A = asking price (\$/unit),

N = operating cost (\$/yr) (excludes depreciation charges).

Then $R = P^A \cdot Q$. The annual rate of return on capital before taxes is given by

$$(1) \quad i_b = (R - N)/I.$$

Introducing taxes and straight-line depreciation, the after-tax rate of return is given by

$$(2) \quad i_a = \frac{(1-t)(P^A \cdot Q - N) + t I/n}{I}.$$

This formula can be used in two ways. If P^A is an observed market price and Q , N , I and n are known or can be estimated, the formula can be used to solve for the after-tax rate of return i_a as the unknown. Conversely, if i_a can be estimated, Eq. (2) can be rewritten in the form

$$(3) \quad P^A = \frac{1}{Q} \left[I \frac{i_a - t/n}{1-t} + N \right]$$

and solved for P^A as unknown. Note that i_a and i_b are related by the equation

$$(4) \quad i_a = (1-t)i_b + t/n.$$

Finally, the after-tax internal rate of return (IRR), i , is defined by the equation

$$(5) \quad I = \sum_{k=1}^n \left\{ (1-t) \left[\frac{Q_k P_k^A - N_k}{(1+i)^k} \right] + \frac{tI/n}{(1+i)^k} \right\}.$$

Here the index k stands for future years, and the annual quantities Q_k , P_k^A and N_k must be projected, including possible inflation effects. However, if Q , P^A and N are constant over time, (5) can be simplified to

$$I = [(1-t)(P^A Q - N) + tI/n] \left(\frac{(1+i)^n - 1}{i(1+i)^n} \right).$$

Hence (2) and (5) are exactly equivalent if we set

$$(6) \quad i_a = \frac{i(1+i)^n}{(1+i)^n - 1},$$

which defines the capital recovery factor, i_a , in terms of the internal rate of return, i . Note that if $i \gg 1/n$, i and i_a are almost equal.

Each of these rate of return concepts will be used below. In particular, we will use (3) to derive P^A in terms of i_a . If one wishes to ascertain the corresponding IRR, i , this can be obtained by solving (6).

B. PROCESS SUBSTITUTION

The retortable pouch process requires the same raw, machine-harvested vegetable input as frozen food processing. Moreover, the first processing step, which includes inspection, sorting, grading, cutting, washing, and blanching, is the same as for the frozen food process. The packing step is somewhat different, however, and the freezing step is entirely replaced by retorting or sterilization. The other changes are that pouched food requires some climate conditioning, but not refrigeration, in storage and retail display, and that, because of the addition of brine and different packaging materials, the volumes and weights for storage and shipping of the pouched product are different. Our analysis of the process substitution, therefore, consists of making the requisite changes in the materials flow and energy flow diagrams and then recomputing the value added diagram.

C. ENERGY SUBSTITUTION

In principle geothermal fluids can substitute for fossil fuels in food processing in at least three ways. They can provide heat for intensive cultivation of the crop in a greenhouse environment; they can provide heat for direct application in the processing stages; and they can be employed to generate electricity for use at various stages in the overall production chain. The feasibility of these applications depends on the temperature of the fluids and their geographical location. Although there is considerable evidence that geothermal fluids can be profitably employed for intensive crop cultivation we will not explore this possibility here.⁷ Similarly, we will not consider the possibility that the geothermal fluids are used for electricity generation. As was noted in the previous chapter, geothermal fluids in the Imperial Valley are currently being used for electricity generation. However, we shall make the conservative assumption that any geothermally generated electricity would be priced at its opportunity cost, i.e., at the same price as conventionally generated electricity, so that there would be no net savings in costs. Accordingly, we will assume that the geothermal fluids are dedicated exclusively for direct application in the processing stages of the production chain.

In the case of frozen foods, we assume that geothermal fluids can substitute for natural gas in blanching prior to freezing, and for electricity in the freezing and refrigerated storage of the product. In the case of the pouch process, geothermal fluids can substitute for natural gas and other fossil fuels in blanching, in steam displacement of air prior to pouch sealing, and in sterilization after sealing. In each case we will first make the appropriate modifications to the materials flow and energy flow diagrams and then recompute the value added diagram.

CHAPTER IV - ENERGY AND PROCESS SUBSTITUTION

In this chapter the methodology outlined in Chapter III is employed to evaluate the economics of the freezing process versus the pouch process, and conventional fossil energy versus geothermal energy. Section A deals with the standard process — frozen broccoli produced with conventional fossil fuels. We develop the materials and energy flow diagrams for this process and then compute the value added at each stage of the production chain. Section B deals with the substitution of geothermal energy in the frozen product, replacing electricity in freezing and cold storage, and natural gas in blanching. Section C presents the retortable pouch process using conventional fossil fuels; we modify the materials and energy flow diagrams and then recompute the value added. Finally, Section D considers the substitution of geothermal energy in the pouched product as a replacement for natural gas in blanching, sealing and sterilizing.

A. STANDARD PROCESS

Here we shall provide a process flow description for broccoli frozen using conventional fossil energy. Our basic item is broccoli grade A spears, packed by hand into 10-oz. cartons, and frozen by contact with plates or in air-blast tunnels. The description is carried all the way from the farm to the supermarket checkout counter. Three separate descriptions are developed: materials flow, energy flow, and cumulative value added.

1. MATERIALS FLOW

Figure 2 shows the materials flow of the main product, broccoli, through 11 processes from seed on the farm to sale at the checkout stand. These are the processes that were identified in Figure 1, except that two processes — 3, preprocessing at the farm site, and 9, repacking (applicable to IQF commodities) — are not relevant to the broccoli basic item and have been omitted.

Main inputs and outputs are shown along the central (horizontal) axis of the diagram; other inputs are shown as coming from above; other outputs are shown below the central axis. The accounting identity (conservation of mass) is used on our MFD to record secondary inputs such as fertilizer, ice, water, or cartons. These are either incorporated into the product or they are otherwise used in the unit process and become part of the "other output" stream. The latter includes solid and liquid wastes and any byproducts. For example, sorting and inspection of broccoli during the "receiving and preparation" stage results in discarded produce which ends up as either solid or "liquid" (water-carried) waste. Similarly, handling at the packing, loading and unloading stages may damage some cartons or cases, and add to the waste stream while diminishing the main product. Capital inputs, which do not

Figure 2

MATERIALS FLOW • BROCCOLI • IMPERIAL VALLEY

Conventional Methods
(per acre input)

contribute to or subtract from the main product flow, and are "used up" very slowly in the production process, are omitted from the MFD.

The diagram starts with an acre of land, and applies inputs of seed, water, fertilizer, and chemicals appropriate to this crop in the Imperial Valley. The yield is assumed to be 4.43 t/acre, which is a better-than-average yield. The diagram shows small losses at various stages; a larger loss (due to "dockage") occurs between Receiving and Preparation (5) and Pack, Wrap and Case (6), which is partly offset by the absorption of water.⁸ A large gain occurs following (6) due to the addition of cartons, overwraps and cases to the commodity. Inputs (such as fuels) that do not contribute directly to the materials balance are omitted at this stage. Following process 13 (retailing, store), the diagram shows 8,770 lb. of frozen 10-oz. cartons at the checkout counter resulting from the 8,860 lb. of broccoli harvested on the farm. Of the 8,770 lb., 1,017 is packaging material, the remainder frozen vegetable. Actual weight of the latter is 7,753 lb., but nominal weight (i.e., weight marked on packages, taking 1.67% overscaling into account) is 7,626 lb.

From Figure 2 it is now easy to derive a materials flow diagram based on sale of 1,000 lb. nominal product. This is shown as Figure 3, and serves as the basis for the energy flow and value-added diagrams that follow.

2. ENERGY FLOW

Figure 4 shows the direct and embodied energy inputs as raw data, in various units. Variable energy inputs — i.e., direct energy inputs and energy embodied in other variable inputs — are shown as flowing in from above the horizontal central axis of the diagram. Energy embodied in capital is shown as flowing into the unit processes from below the central axis. The

Figure 3

MATERIALS FLOW • BROCCOLI • IMPERIAL VALLEY

Conventional Methods*
(per 1,000-lb nominal output)

*thousands of pounds unless
otherwise indicated

Figure 4

ENERGY FLOW • BROCCOLI • IMPERIAL VALLEY

Conventional Methods (in various units)

LIFETIME	INDIRECT INPUT	DIRECT INPUT
	(1) Grow	(2) Harvest
11.24 yr	4.53 * 10 ⁶ BTU pumping sprinklers/ crop acre 1.45080 * 10 ⁶ BTU farm machinery/ crop acre	seed water 100.24 kwh/ crop/acre fertilizer 4.996 * 10 ⁶ BTU chemicals 0.66 * 10 ⁶ BTU gasoline 9.53 gal diesel 36.54 gal
11.24 yr	0.29152 * 10 ⁶ BTU harvest machinery/ crop acre	gasoline 5.75 gal/ crop/acre diesel 3.95 gal/ crop/acre
5 yr	0.024012 * 10 ⁶ BTU/10 ³ lb/yr truck	diesel 0.222 gal/mi, 1 gal/1,000 lb ice 25.98/1,000 lb
20 yr	0.0054 * 10 ⁶ BTU pump/10 ³ lb	natural gas 10.00 therm/1,000 lb
20 yr	1.6433 * 10 ⁶ BTU building capital equipment/10 ³ lb	electricity 14.961 kwh/1,000 lb
20 yr	0.3200 * 10 ⁶ BTU/10 ³ lb	electricity 1.559 kwh/1,000 lb paper 21.72 * 10 ⁶ BTU
20 yr	0.36313 * 10 ⁶ BTU plate	water 0.108 kwh/ 1,000 lb elec. plate 65.177 kwh/1,000 lb
20 yr	0.29963 * 10 ⁶ BTU tunnel/10 ³ lb	elec. tunnel 80.679 kwh/1,000 lb
20 yr	2.14567 * 10 ⁶ BTU/10 ³ lb	electricity 97.333 kwh/1,000 lb
5 yr	0.26101 * 10 ⁶ BTU/10 ³ lb /yr truck	diesel 11.25 gal
20 yr	2.14567 * 10 ⁶ BTU/10 ³ lb	electricity 43.710 kwh/1,000 lb
5 yr	0.01450 * 10 ⁶ BTU/10 ³ lb/yr truck	diesel 0.625 gal
20 yr	0.79188 * 10 ⁶ BTU	freezer box 40.880 kwh/10 ³ lb
20 yr	0.94482 * 10 ⁶ BTU/10 ³ lb	display case 62.120 kwh/10 ³ lb store, heat, light, etc. 47.854 kwh/ 10 ³ /week

assumptions underlying these calculations are summarized in Tables 13-16.

In particular, Table 13 shows our assumptions about the economic life of the capital inputs and Table 14 shows our assumptions about their embodied energy content. Next, using the unit materials flow diagram, Figure 3, these energy flows are normalized for the production of 1,000 lb. nominal broccoli at the checkout counter; this is shown in Figure 5.⁹

The energy flows in the unit processes are aggregated in Table 17. The first two columns of this table are based on Figure 5. The direct energy inputs of gasoline, diesel fuel, natural gas and electricity come directly from Figure 5.¹⁰ The energy embodied in other variable inputs is the aggregate of the other entries on the upper portion of Figure 5. The energy embodied in capital is based on the entries in the lower half of Figure 5, and is obtained by dividing the embodied energy statistics shown there by the economic life of the equipment in question; i.e., the embodied energy is prorated under the assumption that the production level is maintained throughout the life of the equipment. The fourth column of Table 17 shows the aggregate energy flows after adjusting for the efficiency of the various energy forms. The aggregate energy input to the production of 1,000 lb. of frozen broccoli is 9.6617×10^6 BTU before adjusting for energy efficiencies, and 14.6549×10^6 BTU after adjusting, which implies an aggregate energy efficiency of about 66%. The adjusted total amounts to 14,655 BTU/lb. of broccoli, or about 2,400 BTU per 2.62-oz. serving, which is about 28% higher than Rao's estimate for a similar serving of snap beans.¹¹ Rao estimates that the energy consumed in the household in preparing and serving the portion amounts to about 834 BTU/serving; if this figure can also be used for broccoli, it implies that the aggregate energy expenditure from farm to retail market, on which our study focuses, represents about 75% of the total energy expended from the farm to the family table.

Table 13

ASSUMPTIONS ON ECONOMIC LIFE

Item	Life, yr
Farm Machinery	11.24
Irrigation Equipment	10
Trucks	5
Buildings	20
All other machinery and equipment	20

} average: 11 years

Note: We do not distinguish between book life, economic life, and tax life. For long-lived capital (such as buildings), we choose the shortest of these--generally tax life.

Table 14

ASSUMPTIONS ON ENERGY EMBODIED IN MATERIALS

Material	Energy/lb, 10 ⁶ BTU	Specific Gravity
Steel	0.0232	7.80
Aluminum	0.1084	2.698
Concrete (cement/aggregate/sand)	0.000628	2.451
Wood	0.0040	1.00
Rubber	0.0633	
Paper & Paper Board	0.0200	
Polyester	0.0581	0.900
Polyolefin	0.0699	1.015
(NH ₄) ₂ SO ₄ fertilizer (per lb N ₂)	0.031	
P ₂ O ₅ fertilizer	0.006	
K ₂ O fertilizer	0.003	
Herbicides	0.045	
Insecticides & Fungicides	0.130	

SOURCE: Chapman et al. (1975).

Table 15

ASSUMPTIONS ON ENERGY CONTENT AND EFFICIENCY OF ENERGY FORMS

Energy Form	Density	Heat Content	Energy Efficiency	Energy Cost
Crude Oil	7.0 lb/gal	$0.1381 * 10^6$ BTU/gal	1.00	$0.1381 * 10^6$ BTU/gal
Gasoline (regular)	6.12 lb/gal	$0.1240 * 10^6$ BTU/gal	0.80	$0.1550 * 10^6$ BTU/gal
Diesel fuel	7.07 lb/gal	$0.1400 * 10^6$ BTU/gal	0.80	$0.1750 * 10^6$ BTU/gal
Natural gas	0.0446 lb/ft ³	10.675 therm/10 ³ ft ³	0.88	12.131 therm/10 ³ ft ³
Electricity	--	3,409.52 BTU/kwh	0.2544*	$0.01340 * 10^6$ BTU/kwh

*Based on a "higher heat rate" of 11,000 BTU/kwh, and an average energy efficiency for fuels used in California power plants of 0.82.

Table 16

A FEW USEFUL CONVERSION FACTORS

1 gallon of water weighs	8.345 lb
1 ft ³ of water contains	7.481 gal
1 acre-foot of water contains	3.259 * 10 ⁵ gal or 2.7194 * 10 ⁶ lb
1 HP is equivalent to	745.6 watts
1 lb is equivalent to	0.45359 kg
1 therm is equivalent to	10 ⁵ BTU
1 kwh is equivalent to	3,409.52 BTU
1 barrel (bbl) contains	42 gallons
1 BTU is equivalent to	252 calories

Figure 5

ENERGY FLOW • BROCCOLI • IMPERIAL VALLEY

Conventional Methods*
(per 1,000-lb nominal output)

*10⁶ BTU unless otherwise indicated

LIFETIME		INDIRECT INPUT		DIRECT INPUT		FARMING		PROCESSING				WHOLESALE		RETAIL	
(1) Grow	(2) Harvest	(4) Haul	(5) Receiving & Preparation	(6) Pack, Wrap, Case	(7) Freeze	(8) Store	(10) Haul	(11) Store	(12) Haul	(13) Store					
10.00 yr	11.24 yr	5.00 yr	20.00 yr	20.00 yr	20.00 yr	20.00 yr	5.00 yr	20.00 yr	5.00 yr	20.00 yr					
0.53167	0.03824	0.02790	0.00571	0.32850	0.37902	2.19829	0.30752	0.74542	0.01705	0.80806					
0.19024		0.00668	1.74336		0.31274					0.96413					

Table 17
ENERGY EXPENDED IN PRODUCING SALES OF
1,000 LB OF FROZEN BROCCOLI

Energy Form	Actual Quantity		Energy Efficiency*	Adjusted Quantity	
	Natural Units	10 ⁶ BTU		10 ⁶ BTU	%
Direct Energy Input					
Gasoline	2.0037 [#]	0.2485	0.80	0.3106	2.1
Diesel Fuel	20.4199 [#]	2.8588	0.80	3.5735	24.4
Natural Gas	10.596 ⁺	1.0596	0.88	1.2041	8.2
Electricity [†]	407.491 [∞]	1.3893	0.2544	5.4613	37.3
Indirect Energy Input					
Embodied in other variable inputs [§]		3.6026	1.0	3.6026	24.6
Embodied in capital		0.5029	1.0	0.5029	3.4
TOTAL		9.6617		14.6549	100.0

NOTES: *From Table 15

[#]In gallons

⁺In therms

[†]Assuming plate freezing rather than tunnel freezing

[∞]In kwh

[§]Seed, fertilizer, chemicals and paper

We can also compare the energy expenditure of 14,655 BTU/lb. with the caloric content of broccoli. Assuming that this content lies about halfway between that of spinach (468 BTU/lb.) and Brussels sprouts (810 BTU/lb.) (Pimentel, 1979), one can see that the energy output/input ratio is 0.044 ($= 640/14,655$), which is extremely small. Pimentel's estimates of caloric ratios include only the energy expended in growing and harvesting, and are an order of magnitude higher. An analysis of the components of the energy total in Table 17 is significant. Direct fossil fuel inputs, direct electricity inputs, and indirect (embodied) inputs each make up about a third of the total. Of the indirect inputs, only about 0.5×10^6 BTU, or 3.4%, is embodied in the capital. The rest is accounted for by seed, fertilizers, chemicals and, above all, packaging.

We can further break down the total raw material BTU's by activity, as shown in Table 18 and Figure 6. As might be expected, farming contributes only a relatively modest share (15%) to the overall energy expenditure.¹² Transportation is next with a share of 20%. Processing (over 35%) and storage and retailing (just under 30%) are the big spenders of energy. In fact, the largest single subcategory is that for packaging materials, which accounts for just over half of the processing energy and almost 20% of the total energy expenditure.

In conclusion, the frozen food processing and storage activities are the most energy intensive. If one could devise a less energy-intensive packaging material which was also an excellent thermal insulator, there would be considerable energy savings in packaging, storage and display. Such potential savings are part of our motivation for studying the retortable pouch in Section C.

Table 18

CONTRIBUTIONS TO ENERGY EXPENDED (10^6 BTU)
BY VARIOUS ACTIVITIES

Main activity and Sub-activity	Contribution	%
Farming	2.2439	15.31
Fertilizers & Chemicals	0.7417	5.06
Direct fuel inputs	1.2397	8.46
Other	0.2625	1.79
Hauling*	2.8509	19.45
Direct fuel inputs	2.6443	18.04
Other	0.2066	1.41
Processing	5.3258	36.34
Blanching (NG)	1.2041	8.22
Packaging materials	2.8480	19.43
Freezing**	0.9344	6.37
Other	0.3393	2.31
Cold Storage	4.2343	28.99
Processor	1.4464	9.87
Distributor	0.6362	4.34
Retail	2.1517	14.68
TOTAL	14.6549	100.00

*Does not include the hauling of supplies such as paper products, which makes a small contribution to energy consumption, or labor transportation, which varies by location.

**Plate freezing is assumed.

Figure 6

PIE CHART SHOWING CONTRIBUTIONS TO ENERGY EXPENDITURES
FROM ACTIVITIES AT PRESENT REQUIRED TO BRING FROZEN
VEGETABLES TO THE RETAIL SALES COUNTER

3. VALUE ADDED

Figure 7 shows the value added in the form of purchased inputs, labor and capital for each step along the process chain. Most of the entries are given in terms of dollars per output, where the output is in various units such as crop-acres, 1,000 lb., etc. Direct energy (electricity and fuel) inputs are an exception: they are kept in physical units (kwh, gallons, BTU or therms), since we wish to parametrize and vary their prices.¹³

Figure 8 presents the same information adjusted to correspond to the unitized diagrams in Figures 3 and 5. That is, at each process step the dollar values of the inputs have been set in accordance with the level of activity required to produce 1,000 lb. of frozen broccoli at the retail checkout counter.

There are two exceptions: direct energy inputs are kept in physical units, and capital costs (entered from below on the diagram) are adjusted to the right activity level but are yet to be converted to an equivalent annual charge by applying a rate of return factor, i_b . The format of Figure 8 permits us to parametrize both energy prices and the rate of return factor in order to investigate their impact on value added.

Before engaging in this parametric analysis we first present our baseline results. Actually we will consider two baseline cases. Both involve the same assumptions about energy prices, which are exhibited in Table 19. These prices are typical of conditions in California in the latter half of 1979, when this study was initiated. The two baselines differ with respect to assumptions about the rate of return factors used to compute the capital charges at each stage of the production chain. Our first set of assumptions is exhibited in Table 20. The first column shows the values of i_a that are assumed for each of the four main groups of production stages; the third and fourth columns show the corresponding values of i_b and i ,

Figure 7

VALUE ADDED • BROCCOLI • IMPERIAL VALLEY

Conventional Methods
(in various units)

FARMING		PROCESSING						WHOLESALE		RETAILING	
(1) Grow	(2) Harvest	(4) Haul	(5) Receiving & Preparation	(6) Pack, Wrap, Case	(7) Freeze	(8) Store	(10) Haul	(11) Store	(12) Haul	(13) Store	
<div><div>INDIRECT INPUT</div><div><div>\$350.050</div><div><div>seed \$90/crop acre</div><div>chemicals \$75/crop acre</div><div>fertilizer \$61.20/crop acre</div><div>water \$26.25 crop/acre</div><div>diesel 9.53g/crop acre</div><div>gasoline 36.54g/crop acre</div><div>labor \$242.9 + 30% (30% of labor cost added for operating capital)</div><div>land rent \$300/crop acre/year</div></div></div></div>	<div><div>labor \$305.48/crop acre</div><div>diesel \$3.95g/crop acre</div><div>gasoline 5.75g/crop acre</div></div>	<div><div>\$126/load/yr truck</div><div>elec. 26.152 kwh/10³</div><div>diesel 222g/track mile (40 g/loads/8hrs)</div><div>labor \$106.624/load</div><div>other costs \$41.94/load + \$110/load (field term. cost)</div></div>	<div><div>\$86.733/10³ lb building & equipment</div><div>\$4.80/10³ lb pump & well</div><div>electricity 14.961 kwh</div><div>natural gas 10.00 therms/10³ lb</div><div>water \$0.02874/10³ lb (1978)</div><div>labor \$34.30 + 7% general service/10³ lb</div></div>	<div><div>\$41.70 building & equipment</div><div>electricity 1.559 kwh</div><div>materials \$60.568/10³ lb</div><div>labor \$55.33/10³ lb + 7% for general service labor</div></div>	<div><div>\$55.68/10³ lb plate</div><div>\$109.56/10³ lb tunnel</div><div>labor \$7.27/10³ lb + 7% for general service labor</div><div>water 0.108 kwh</div><div>elec. Plate 65.177kwh/10³ lb</div><div>lights 0.267 kwh/10³ lb for plate freezer</div></div>	<div><div>\$144.71/10³ lb building & equipment</div><div>electricity 97.333 kwh/10³ lb/.333yr</div></div>	<div><div>\$1,162/load/yr truck</div><div>brokerage fee 5% of processor's price</div><div>diesel 11.25g/10³ lb</div><div>labor \$619.20/load</div><div>variable truck costs \$419.40/load (\$0.344/mile)</div><div>fixed terminal cost \$220/load (\$0.233/mile)</div></div>	<div><div>\$48.279/10³ lb building & equipment</div><div>electricity 43.710 kwh/10³ lb for .06 years</div><div>labor \$9/10³ lb</div></div>	<div><div>\$64.56/load/yr truck</div><div>diesel 0.625g/10³ lb</div><div>labor \$34.30/load</div><div>variable truck costs \$23.30/load</div><div>fixed terminal cost \$220</div></div>	<div><div>\$89.14/10³ lb /yr freezer box</div><div>\$157.38/10³ lb/yr display case</div><div>electricity 103.00 kwh/10³ lb</div><div>freezer box & display case</div><div>labor (0.1615 of cumulative value)</div><div>store heat, light, etc.</div><div>47.854 kwh/10³ lb/week</div></div>	

Figure 8

VALUE ADDED • BROCCOLI • IMPERIAL VALLEY

Conventional Methods

(\$unless indicated, per 1,000-lb nominal output)

[illegible]

Table 19

ASSUMED INITIAL (1979) PRICES FOR VARIOUS ENERGY FORMS

Energy Form	Price per unit, \$
Gasoline	1.22 /gal
Diesel fuel	1.12 /gal
Natural gas	0.40 /therm
Electricity	0.040/kwh
Crude oil	28.00 /bbl

Table 20

ASSUMED RATES OF RETURN

Activity	Assumed Annual CRF, i_a^*	Economic Life (yr), n	Corresponding Return before Taxes, i_b	Corresponding Internal Rate of Return, i
Farming	0.2000**	11	0.3091	0.1615
Processing	0.1600	20	0.2700	0.1503
Hauling	0.3333	5	0.4667	0.1981
Storage and retailing	0.1600	20	0.2700	0.1503

*Assuming a tax rate of $t = 0.5$.

**Land cost is taken into account by an annual rent, so is not included in the capital base on which a return has to be earned in this calculation.

obtained by reference to equations (4) and (6) in Chapter III. All of these rates of return are significantly higher than the average rates of return currently experienced in these industries. They were selected to represent more efficient than average farms and more modern than average processing, hauling and retailing facilities, based on our field research and informal industry contacts.

Using the values of i_b in Table 20, the value added can be calculated for each stage in the chain from farm to checkout counter. The results are shown in Table 21. At each stage, j , value added at that stage satisfies the relationship

$$(7) \quad VA_j = P_j^A - P_{j-1}^A,$$

where the asking prices P_j^A and P_{j-1}^A are calculated from the formula in equation (3). Several features of these results are worth commenting on:

- (1) The total value of \$903 for 1,000 lb. of net product is of the right magnitude — the actual market value in that period is estimated at between \$900 and \$1,000.
- (2) Labor cost (53%) dominates capital charges (23%). Thus, a modest increase in labor expenses could drown out a much smaller decrease in capital charges. Since the latter are made up of depreciation, taxes and profit, such an increase could easily wipe out profits altogether.
- (3) Energy costs seem to account for only 5% of the total value added (see the second column of the table). This is somewhat misleading, because the energy column contains only direct energy inputs, such as purchased fuels and electricity. The columns for other inputs and capital charges also contain some energy costs, namely the indirect energy costs embodied in these inputs.

Table 21

VALUE ADDED IN FROZEN FOOD PROCESSING CHAIN

Value added (\$) by each unit process in the production of frozen broccoli for retail sale. Energy prices used are given in Table 19, and capital charges are based on Table 20.

Process step description	Labor and G & A*	Direct Energy	Other purchased inputs	Capital charges	Total V.A.	Cumul. V.A.
(1) Grow	41.407	7.417	72.443	14.189	135.456	135.456
(2) Harvest	40.058	1.500	--	2.852	44.410	179.866
(4) Haul to processor	8.762	1.707	--	2.122	12.591	192.457
(5) Receiving and preparation	65.332	4.873	1.858	26.187	98.250	290.707
(6) Pack, wrap & case	102.102	0.064	64.664	11.558	178.388	469.095
(7) Freeze	13.640	2.737	--	15.691	32.068	501.163
(8) Store (processor)	--	3.989	27.259 ¹	40.030	71.278	572.441
(10) Haul to distributor	37.072	14.845	--	15.974	67.891	640.332
(11) Store (distributor)	11.042	1.788	--	13.328	26.158	666.490
(12) Haul to retailer	9.796	0.777	--	0.886	11.459	677.949
(13) Store & display (retailer)	150.550 ²	6.157	--	67.921	224.623	902.577
TOTALS \$ values	479.761	45.854	166.224	210.738	902.577	--
% values	53.15	5.08	18.42	23.35	100.00	--

*G & A = general & administrative labor, sales labor, repair & maintenance labor

¹ This entry represents a 5% brokerage fee on the value of products sold to the distributor.

² This figure is based on direct labor costs in retailing being about 13.9% of the value of product sold. This amounts to 16.68% of the value excluding labor and overhead expenses. The latter are taken at 20% of direct labor.

- (4) The value of the produce at the farm gate (\$180) makes up only 20% of the retail value.
- (5) Processing adds about \$310 to the value, all transportation about \$90, all cold storage prior to retail about \$100, and retailing (including storage and display) about \$220.

Our second set of baseline figures is based on somewhat lower values of i_b , which are exhibited in Table 22 together with the corresponding values of i_a and i . These lower rates of return are more typical of average farms and older processing, hauling and retailing capital facilities. The results of a value-added calculation based on these rates of return are summarized in Figure 9, along with the preceding results. A comparison shows that hauling, farming and food processing are insensitive to capital charges; as Table 21 bears out, these activities are labor-intensive. By contrast, cold storage and, to a lesser degree, retailing are capital-intensive.

4. SENSITIVITY ANALYSIS

The final step is to perform a parametric sensitivity analysis on value added, allowing for variations in the rate of return factor and in energy prices. The object of this analysis is to show how the estimated 1979 asking price for frozen broccoli of \$903/1,000 lb. net product might change as a function of different rates of return and different levels of energy prices. In performing this calculation we take note not only of the direct energy inputs, which accounted for about \$45 out of the \$903, but also of the indirect energy inputs embodied in other variable inputs and in capital. As was pointed out above, several different forms of energy are involved in the production of broccoli; in order to forecast future trends in the price of the standard product, it is convenient to work with a single price of energy.

Table 22

LOWER ASSUMED RATES OF RETURN

Activity	Assumed Annual CRF, i_a	Corresponding Return Before Taxes, i_b	Corresponding Internal Rate of Return, i
Farming	0.1400	0.1891	0.0799
Processing	0.1000	0.1500	0.0775
Hauling	0.2700	0.3400	0.1092
Storage and retailing	0.1000	0.1500	0.0775

NOTE: The tax rate and equipment life are the same as in Table 20.

Figure 9

COMPARISON OF VALUE ADDED ALONG THE PROCESS CHAIN
FOR LOW RETURNS ON INVESTMENT AND NORMAL RETURNS
ON INVESTMENT IN 1979

For this purpose we will relate the prices of all energy sources to the price of a barrel of crude oil, henceforth denoted P . Thus $P^{79} = \$28/\text{bbl}$. Equivalently, since a barrel of crude oil contains $5.8 * 10^6$ BTU, we shall reckon the cost of energy at $P/5.8$ per 10^6 BTU. Our justification for taking the price of a barrel of crude oil as the surrogate price of energy in general is both analytical convenience and the empirical fact that in today's markets most energy prices are pegged to the price of crude oil; this certainly has been the driving force behind energy prices in recent years.¹⁴

In preparing for the sensitivity analysis we will consider in turn energy embodied in other variable inputs, energy embodied in capital, and direct energy inputs. Using 1979 prices, other variable inputs account for \$166.224 of total value added (see Table 21). Of this amount, \$3.442 is water input, \$1.858 is water treatment, \$39.339 is land rent, and \$27.259 is brokerage fees; we have not attempted to measure the energy embodied in these inputs. The remainder (\$94.326) represents the inputs of seeds, chemicals, fertilizers and paper packaging; the energy embodied in these inputs is $3.6026 * 10^6$ BTU (see Table 17). Rather than breaking it up into its component energy forms, we will treat this embodied energy input as equivalent to 0.62114 ($\approx 3.6026/5.8$) barrels of crude oil. Since the 1979 price of crude was $P^{79} = \$28/\text{bbl}$, we will cost this embodied energy input at \$17.392 ($\approx 0.62114 * 28$); hence we estimate the total cost of all the non-energy elements of these variable inputs as \$148.848 ($= \$166.24 - \17.392) in 1979 prices. In addition, the 1979 value added included a component of \$479.761 for labor and G&A expenses (see Table 21), which for our purposes has no embodied energy input. Thus the total cost of all non-energy variable inputs, net of any embodied energy, is estimated in 1979 prices at \$628.609 ($= \$148.848 + \479.761).

Accordingly, our final formula for the non-energy variable input component of value added is

$$(8) \quad VA_{NE} = 628.609 + 0.62114P$$

The formula will be used to forecast the effect on this component of value added of changes in the generalized price of energy, P , conditional on the assumption of no change in any other input price (e.g., labor costs). This assumption permits us to focus exclusively on the role of energy costs in the price of the standard broccoli product and to compare alternative energy sources while abstracting from general price inflation, which we do not attempt to model in this study.

We now perform a similar analysis for capital charges, which amounted to \$210.738 in 1979 prices (Table 21). However, here we parametrize the portion of total value added attributable to these charges (denoted VA_C) not only on the generalized price of energy, P , but also on the rate of return factor (i_p) used to convert lifetime capital costs to an equivalent annual capital charge. Table 23 shows the cost and embodied energy component of all capital equipment in the production chain grouped into three categories according to economic life.¹⁵ The second column of the table shows the aggregate cost of all capital equipment having the given economic life per 1,000 lb. of product at the checkout counter, before conversion to an equivalent annual charge (this is taken from Figure 8). The third column shows the energy embodied in this capital, in 10^6 BTU (this is taken from Figure 5). Using the conversion factor of $5.8 * 10^6$ BTU per barrel of crude oil, these embodied energy inputs are equivalent to 0.1303 barrels of crude for capital with an 11-year economic life, 0.06077 barrels of crude for capital with a 5-year economic life, and 1.23779 barrels of crude for capital with a 20-year economic life. In the fourth column of the table these embodied energy inputs are priced at the 1979 price of \$28 per barrel of crude and the resulting imputed cost of

Table 23
COST AND EMBODIED ENERGY COMPONENT OF CAPITAL EQUIPMENT,
BY ECONOMIC LIFE

(1) Years of Economic Life (n)	(2) Total Capital Cost (\$)	(3) Embodied Energy (10 ⁶ BTU)	(4) Non-Energy Component of Capital Cost (\$)*	(5) Embodied Energy Component of Capital Cost (\$)
11	55.130	0.75995	51.461	0.13103 P
5	40.395	0.35247	38.693	0.06077 P
20	647.565	7.17917	612.907	1.23779 P

*Assuming energy cost of P⁷⁹ = \$28/bbl.

embodied energy is subtracted from the total capital cost (i.e., the second column) in order to obtain the non-energy component of total capital cost. For example, the imputed cost in 1979 prices of the energy embodied in all the capital equipment with an 11-year economic life is \$3.669 ($= 0.13103 \times 28$) and, since the total cost of this capital in 1979 prices is \$55.130, the imputed cost of the non-energy component in 1979 prices is \$51.461 ($= 55.130 - 3.669$). Accordingly, the total cost of this capital may be expressed for forecasting purposes as $51.461 + 0.13103 P$. Lastly, this cost must be multiplied by i_b (11), obtained from equation (4), in order to convert it to an equivalent annual charge, which is the form in which it enters the final product price. A similar procedure is followed with the two other types of capital equipment. The final expression for the capital component of value added is

$$(9) \quad VA_C = i_b (11) \cdot [51.461 + 0.13103 P] + i_b (5) [38.693 + 0.06077 P] + i_b (20) [612.907 + 1.23779 P]$$

Lastly, there is the component of value added which is attributable to the direct energy inputs of gasoline, diesel fuel, natural gas, and electricity. The quantities of these inputs are given in the first column of Table 17. Using these data, the direct energy component of value added can be written as

$$(10) \quad VA_E = 2.0037P_{gs} + 20.4199P_{df} + 10.596P_{ng} + 407.491P_e$$

where P_{gs} is the price of gasoline (\$/gal), P_{df} is the price of diesel fuel (\$/gal), P_{ng} is the price of natural gas (\$/therm), and P_e is the price of electricity (\$/kwh). For the purposes of our sensitivity analysis it is necessary to relate each of these prices to the basic energy price variable P , the cost of a barrel of crude oil. In making this calculation we will explicitly allow for the differing energy efficiencies of these various fuels, as given in Table 15.

Since there are 42 gallons in a barrel and the fuel energy efficiency of gasoline is 0.8, the price of gasoline can be written in the form

$$(11) \quad P_{gs} = \frac{P}{42(0.8)} + R_{gs}$$

The first term represents the cost of the fuel (in crude oil equivalents) required directly and indirectly to produce one gallon of gasoline, and the second term, R_{gs} , represents the cost of all the nonfuel inputs to the production of gasoline, stripped of their embodied energy content. Similarly, for diesel fuel

$$(12) \quad P_{df} = \frac{P}{42(0.8)} + R_{df}.$$

Using the 1979 prices, $P_{gs}^{79} = \$1.22$, $P_{df}^{79} = \$1.12$ and $P^{79} = \$28$, we obtain $R_{gs} = 0.387$ and $R_{df} = 0.287$. Hence

$$(11') \quad P_{gs} = \frac{P}{42(0.8)} + 0.387$$

$$(12') \quad P_{df} = \frac{P}{42(0.8)} + 0.287.$$

For electricity we use a similar formulation, and write

$$(13) \quad P_e = \frac{P_f}{0.310} + R_e$$

where P_f is the cost, per kwh of electricity, of the fossil fuel used to generate the electricity, 0.31 is the fuel's energy efficiency in electricity generation, and R_e is the cost of all the other non-energy inputs to the generation process. In California in 1979 the boiler fuel for electricity generation would be a mixture of natural gas and distillate, but primarily the latter. Moreover, its cost would depend not on the 1979 price of oil but on prices lagged by, say, two years because of long-term fuel supply contracts and delays in the fuel price adjustment; we denote the lagged price of oil by P^+ . We postulate that

$$(13') \quad P_f = \left(\frac{P^+}{42(0.82)} + 0.046 \right) \left(\frac{3,409.5}{140,000} \right).$$

Here we have set the average energy efficiency of the fuel used in California powerplants at 0.82 and we have included a constant of \$0.046/gallon to reflect the small refinery and marketing charges for large utility customers. The second term in brackets in (13') is a conversion factor from gallons to kwh, and is based on the assumption that a gallon of distillate contains about 140,000 BTU of heat value while the thermal equivalent of a kwh is 3,409.52 BTU. Combining (13) and (13') yields

$$(13'') \quad P_e = 2.281 * 10^{-3} P^+ + 3.614 * 10^{-3} + R_e.$$

Finally, we estimate R_e at $9.00 * 10^{-3}$, so that

$$(13''') \quad P_e = 2.281 * 10^{-3} P^+ + 12.614 * 10^{-3}.$$

This formula for electricity prices is intended only as a rough approximation. In 1972, at $P^+ \approx \$3/\text{bbl}$, P_e would have been about 19 mills per kwh. In 1979, with fuels at an average lagged supply price of $P^+ \approx \$12/\text{bbl}$, P_e was roughly 40 mills/kwh. Currently, a more accurate estimate of P^+ would be \$22/bbl, which would imply a value for P_e of about 63 mills/kwh. Finally, should utility fuel prices rise to the current crude market price of about \$35/bbl, we would expect an electricity price of about 92 mills/kwh.

We shall also employ this electricity price formula to model the price of natural gas. Because of the complex and changing structure of natural gas price regulation, it would be extremely difficult to develop a satisfactory formula for forecasting natural gas prices. Accordingly, we shall adopt the simple formula

$$(14) \quad \begin{aligned} P_{ng} &= 10P_e \\ &= 2.281 * 10^{-2} P^+ + 12.614 * 10^{-2} \end{aligned}$$

which is based on the observation that over the last few years the price (per therm) of natural gas has been approximately ten times the price per kwh of electricity. We now substitute (11'), (12'), (13'') and (14) into (10) to obtain the final equation for the component of value added which is attributable to direct energy inputs,

$$(15) \quad VA_E = 0.66737P + 1.17118P^+ + 13.11261.$$

Combining (8), (9) and (15) we obtain the overall formula relating value added in the production of 1,000 lb net product of frozen broccoli to the current and lagged price of crude oil, used as a surrogate price for energy in general:

$$(16) \quad \begin{aligned} VA &= VA_{NE} + VA_C + VA_E \\ &= 641.722 + 38.693 i_b(5) + 51.461 i_b(11) + 612.907 i_b(20) \\ &\quad + 1.17118P^+ + P[1.28851 + 0.06077 i_b(5) + 0.13103 i_b(11) \\ &\quad + 1.23779 i_b(20)]. \end{aligned}$$

This formula allows us to vary parametrically the discount rates used to amortize the capital inputs, as well as the price of energy, and predict the resulting price of frozen broccoli product (in 1979 dollars). Suppose, however, that we use the discount rates given in Table 20, namely $i_b(5) = 0.4667$, $i_b(11) = 0.3091$, and $i_b(20) = 0.27$. The value added formula simplifies to

$$(16') \quad VA = 841.172 + 1.69158P + 1.17118P^+.$$

Substituting the prices $P = \$28$ and $P^+ = \$12$ into (16') yields the 1979 value added of \$902.60. Suppose, however, that $P = \$35$ and $P^+ = \$22$, roughly the current price levels; then the final product price, computed from (16'), rises to \$926.14.

The first term in (16') represents the entire non-energy component of

the product price; the other two terms represent the energy component of the price. Using 1979 prices, this energy component amounts to \$61.418, or 6.8% of the product price. The figure of \$61.418 must be interpreted with some care. It differs from the cost of the direct energy inputs (\$48.854, as given in Table 21) in two ways. First, it excludes the non-energy component of the cost of these direct energy inputs. For example, only part of the cost of the diesel fuel used directly in the production of broccoli is attributable to the cost of the crude oil and other fossil fuels used in the production of the gasoline — the rest is the cost of the labor and other nonfuel inputs used in the production of the gasoline and, presumably, would not change if the cost of crude oil rose. Setting $P = \$28$ and $P^+ = \$12$ in (15), we find that the energy component of the cost of the direct energy inputs amounts to \$32.741. Secondly, the figure of \$61.418 includes the cost of all of the indirect energy input to the broccoli product embodied in the fixed capital and in the non-energy variable inputs. With $P = \$28$ and the i_p factors given above, the cost of the energy embodied in the other variable inputs is \$17.392, from (8), and the cost of the energy embodied in the capital is \$11.285, from (9). Together, the three costs sum to \$61.418. Thus, the figure of \$61.418 represents a "purified" energy cost, net of all non-energy components. Its purpose — and the purpose of equations (16) and (16') — is to enable us to forecast how the final product price might change as a function of changes in the price of energy, P .

As P varies, not only will the product price vary, but also the proportion of this price attributable to energy. Figure 10 shows graphically how this proportion changes; it is based on (16') and assumes that $P^+ = P$, and that the non-energy cost (\$841.172) stays constant.

Figure 10

CONTRIBUTION OF ENERGY COST TO VALUE ADDED
IN ¢/LB (SOLID LINE) AND AS A PERCENTAGE
OF VA (DOTTED LINE), AS A FUNCTION OF THE
PRICE P OF A BARREL OF CRUDE OIL (\$/BBL),
ALL IN CONSTANT (1979) DOLLARS

B. ENERGY SUBSTITUTION

1. GENERAL FRAMEWORK

The substitution of geothermal energy for fossil fuels and electricity entails some additional capital expenses as well as some savings for the frozen food processor. Additional capital expenses arise because the absorption chilling units required to extract work from hot geothermal water are, ton for ton, more expensive than the units based on a vapor compression cycle.¹⁶ Savings can come about because geothermal energy can substitute for electricity in operating the refrigeration units used to freeze and store the product, and for fossil fuel in blanching the product prior to freezing.

Whether any net savings result from the geothermal substitution depends, of course, on the price charged for geothermal fluids. We assume that the geothermal fluids are dedicated exclusively to food processing, and that any electricity produced on-site from the geothermal fluids is priced at its opportunity cost (i.e., at that of conventionally generated electricity); hence there are no net savings from any substitution of geothermal for conventional electricity. These are very conservative assumptions, and they may cause us to understate the actual savings from switching to geothermal energy.

Following Harris et al. we shall analyze the potential savings from geothermal fluids in two steps. For the food processor there is a bid price P_G^B for geothermal fluids above which the energy substitution is uneconomical. For the utility supplying the geothermal resource there is an asking price P_G^A below which its production is uneconomical. Only if $P_G^B \geq P_G^A$ is there a net gain that makes the substitution economical.

A preliminary analysis revealed that any potential gain is considerably enhanced if geothermal water is used not only for freezing the produce and

keeping it in cold storage but also used for blanching. This is because the spent fluid from the refrigeration plants is hot enough to serve as heat exchange medium for the blancher and is available in sufficient quantity that no additional geothermal water is needed for blanching. In what follows, therefore, it is assumed that geothermal water is used for blanching, freezing and cold storage.

2. ASSUMPTIONS REGARDING WATER

We assume a processing plant with a maximum capacity of 16,670 lb/hour for processing vegetables such as broccoli. Broccoli might be processed at the maximum hourly rate for 10 hours per day in one or two crops over four months; thus the total annual output of $(16.67 * 10^3 \text{ lb/hr}) * (10 \text{ hr/day}) * (25 \text{ d/mo}) * 40 \text{ mo} = 16.67 * 10^6 \text{ lb/yr}$. Two other vegetables might round out the annual load and result in a total plant output of $40 * 10^6 \text{ lb/yr}$ of frozen pack or bulk. The freezing capacity must be sufficient to remove from the produce an amount of heat equal to $200 \text{ BTU/lb} * 16,670 \text{ lb/hr} = 3.333 * 10^6 \text{ BTU/hr}$. For plate freezing at 70% efficiency of heat extraction, this entails a freezing capacity of 400 t ($400 * 12,000 \text{ BTU/t-hr} \approx 4.8 * 10^6 \text{ BTU/hr}$, and $3.333 * 10^6 \text{ BTU/hr} * 100 / (4.8 * 10^6 \text{ BTU/hr})$ yields 69.4% efficiency. For IQ freezing at 50% efficiency, the needed capacity is 556 t; for tunnel freezing at 30% efficiency, it is 926 t. Our results are almost independent of the freezing method chosen; to fix the analysis we shall focus on plate freezing.

At an average residence time of half a year, the cold-storage facility needs to have $100,000 \text{ ft}^2$ of floor space and 300 t maximum refrigeration capacity. The average yearly utilization factor for the refrigeration plant of such a facility would be about 0.5.

According to Harris et al., an optimally designed absorption refrigeration

system powered by 300° F geothermal water, whether operating at $T_E = -4^\circ \text{ F}$ or $T_E = -40^\circ \text{ F}$ evaporator temperature with an ammonia working fluid, extracts about 75° F from the water. Once a temperature drop of 75° is given, how much water is needed then depends on 1) the maximum refrigeration capacity; 2) the average utilization factors of the refrigeration plants; and 3) the effective coefficients of performance, COP^* , given by $\text{COP}^* = \text{COP} \cdot \eta$, where COP is the theoretical coefficient of performance, defined as

$$(17) \quad \text{COP} = \frac{T_E}{T_O - T_E} * \frac{T_G - T_O}{T_G} .$$

Here T_E is the evaporator temperature (-4° or -40° F), T_G the inlet temperature of the geothermal water (300° F), T_O the condenser temperature (80° F), all expressed in °R; °R = °F + 459.67°. Finally, η is the refrigeration efficiency, which depends on irreversibilities and heat transfer limitations. According to Harris et al., this efficiency is about 25% at -4° F , and 20% at -40° F . These technical assumptions are summarized in Table 24.

Given $\Delta T_G = 75^\circ \text{ F}$, and the utilization factors, U_S (≈ 0.50) and U_F , one can easily determine the water flow required for cold storage and freezing. The average water flows, W_S and W_F , are

$$(18) \quad W_S = \frac{T_S * 0.012 * U_S}{\Delta T_G * \text{COP}_S^*} = \frac{300 * 0.012 * U_S}{75 * 0.40} = 0.120 * 10^6 U_S \text{ lb/hr}$$

$$(19) \quad W_F = \frac{T_F * 0.012 * U_F}{\Delta T_G * \text{COP}_F^*} = \frac{400 * 0.012 * U_F}{75 * 0.20} = 0.320 * 10^6 U_F \text{ lb/hr} .$$

T_S and T_F are the refrigeration capacities (tons), and the factor 0.012 converts tons of refrigeration into millions of BTU.

Blanching, which typically takes the produce from about 80° F to 205° F and holds it there for approximately three minutes, is generally only about

Table 24

PERFORMANCE CHARACTERISTICS FOR ABSORPTION COOLING

Activity	T_E , °F	Type of Unit	COP	η	COP*
Cold Storage	-4	NH ₃ /H ₂ O, single-stage	1.571	0.25	0.40
Food Freezing	-40	NH ₃ /H ₂ O, two-stage	1.013	0.20	0.20

30% efficient in modern equipment (Chinnan et al.). Thus, at 16,670 lb/hr, we require $U_B * (125 * 16,670)/0.3 = 6.945 * 10^6 U_B$ BTU/hr of heat input, where $U_B = U_F$ is the utilization factor for blanching. Dividing the heat requirement of $6.945 * 10^6 U_B$ BTU/hr by the water throughput for freezing, W_F , yields a BTU extraction from the still-hot (225° F) geothermal outlet water of 21.71 BTU, or a temperature drop from 225° F down to 203.29° F.

The appropriate flow diagram is shown in Figure 11. This is derived from the following considerations. The gpm (gallons per minute) flows are derived from lb/hr flows by dividing the latter by 60 min/hr and 8.345 lb/gal. Clean process water at 205° F is required for blanching the produce, since the geothermal water is probably too contaminated with dissolved salts for direct contact. The cost of the heat exchanger is ignored; it is assumed to be offset by the saving of a conventional boiler. The required amount of process water, W_B , is obtained by dividing the heat to be transferred by the temperature rise in the process water:

$$W_B = \frac{6.945 * 10^6 U_B \text{ BTU/hr}}{125 \text{ BTU/hr}} = 0.05556 U_B * 10^6 \text{ lb/hr.}$$

This corresponds to $100.96 U_B$ gpm.

The refrigeration plant condensers, working between, say, 80° and 100° F, also require cool water of adequate quality. The condensers must remove the heat transferred out of the geothermal water, as well as the heat transferred from the freezing operation or from cold storage. The heat from cold storage is

$$\frac{239.66 * 75 + 300 * 200/8.345}{20} U_S = 1258.22 U_S \text{ gpm,}$$

and the heat from freezing is

$$\frac{239.11 * 75 + 400 * 200/8.345}{20} U_F = 2875.99 U_F \text{ gpm.}$$

The total fresh water requirement is $110.96 U_B + 1258.22 U_S + 2875.99 U_F$
 $= 1258.22 U_S + 2986.95 U_F$ gpm. This is a considerable amount of water —

Figure 11

GEOTHERMAL WATER UTILIZATION (gpm)

on average it comes to 1,500 gpm, or five times the amount of geothermal water used. A wet cooling tower therefore seems indicated; this would reduce the fresh water makeup requirements by a factor of about 10.

As mentioned above, we assume a cold storage refrigeration plant utilization, U_S , of about 0.50. The freezing or blanching plant utilizations U_F and U_B can be derived by comparing the annual assumed output ($40 * 10^6$ lb) with that achievable if processing occurred at the maximum capacity and around the clock:

$$U_F \equiv U_B = 40 * 10^6 / (16,670 * 8,760) = 0.2740.$$

The required geothermal water flow can be calculated from Figure 11, and is presented in Table 25.

If 500,000 lb/hr or 1,000 gpm is a good working figure for a 300° F geothermal well (Harris et al.), it is clear that, given adequate pump size, a single typical well would be adequate to provide an average flow of 295 gpm, with a peak flow three times as high for short periods and a steady flow of 639 gpm for longer ones.

There remains the question of the disposal of the used geothermal fluids (295.0 gpm on the average) and the salt-enriched fresh condenser water (about 10% of $1258.22 * 0.5 + 2986.95 * 0.2740$, or 144.8 gpm with wet cooling). These waters could be treated and disposed, or reclaimed for other (e.g., agricultural) uses, or reinjected into the well. The cost of the fresh water and the cost of spent processing water are both ignored in the analysis that follows.

3. ASSUMPTIONS REGARDING COSTS

a. Well Capital Costs

Harris et al. project 1980 costs for a typical geothermal well yielding

Table 25

GEOHERMAL WATER FLOW REQUIREMENTS (gpm)

Water Usage	Maximum	Average	Utilization
Cold storage	239.66	119.83	0.5000
Freezing and blanching	639.11	175.12	0.2740
Total	878.77	294.95	0.3356

300° F fluids at no more than \$500,000. These costs include drilling to 5,500 feet, casing, pumping suitable for conveying a flow of 1,000 gpm a distance of 2,000 feet, valving, instrumentation, metering, engineering and administration, and contingency. The economic life of the well is taken to be 20 years.

With a greater cost inflation than was foreseen in 1977, but a 10% smaller maximum water flow, we conservatively assume a total capital cost of M\$0.667. It will be easy to test the sensitivity of the asking price to this figure. Tax life will be taken as 20 years.

b. Absorption Refrigeration Plant Capital Costs

According to Harris et al., the cost per t capacity for compression plants with evaporator temperature of -4° F is about 42% lower than that for freezing plants (-40° F). For absorption plants the difference is somewhat greater (46%). Of course, it is the difference between the two types of plant that counts. In both cases absorption plants are the more expensive. For cold storage plants (-4° F), the difference is about \$100/t; for freezing plants (-40° F), it is about \$300/t.

We shall adopt these estimates without change. Although our compression plant estimates are about 25% higher (partly because of inflation), we believe that absorption plant costs have increased less rapidly, since they constitute an emerging technology and will benefit from economies of scale and learning experience. The tax life will be taken as 20 years.

c. Energy Savings

Harris et al. estimate electricity savings of 1.60 kw/t for geothermally powered absorption plants operating at -4° F evaporator temperature, compared

to more conventional electrically powered compression plants, and savings of 2.04 kw/t for geothermally powered absorption plants operating at -40° F. This takes into account the relatively small amount of electric power (0.08 kw/t and 0.16 kw/t, respectively) used in absorption systems for various auxiliary pumps. Although the COP* figures adopted for the compression systems in our study are somewhat lower than those of Harris et al. we feel that their estimates of the electricity savings are conservative and should be retained. For blanching, the potential natural gas savings were estimated above at 69.45 therms per hour of blancher operation.

The costs of electricity P_e and natural gas P_{ng} will be taken as variables in the sensitivity analysis. Their 1979 values are taken as 4¢/kwh and 40¢/therm, respectively.

d. Operating Costs

It will be assumed that the operating costs of the absorption and compression refrigeration systems, apart from energy costs, are small and sufficiently similar in magnitude that they can be omitted from the comparison.

Following Harris et al. the operating costs for a geothermal well, N_G , will be taken as

$$(20) \quad N_G = 16.67 * P_e * U_G * 8760 + 0.05 I_G \text{ (\$/yr)},$$

where P_e is the assumed price of electricity (\$/kwh), U_G the effective yearly utilization of geothermal water at maximum flow, and I_G the capital cost of the geothermal well. The term $0.05 I_G$ is an estimate of yearly O and M costs (labor and materials); the factor 16.67 (units kw) is the estimated power needed to lift 878.8 gpm by 60 ft at 60% pump efficiency, to make up for pressure losses between the well and the processing plant.

It is assumed that both conventional and geothermally powered refrigeration plants require wet cooling towers and makeup water, and that the cost difference for the two systems can be neglected. All investment costs are assumed to be made with equity funds requiring an appropriate return, so debt service costs will be taken as zero.

4. BID PRICE

Our point of departure is the basic equation (3), rewritten in the form

$$(21) \quad P_G^B = \frac{1}{Q_G} \left[\Delta I * \frac{i_a^B - t/n}{1 - t} + \Delta N \right],$$

where P_G^B = break-even (bid) price offered by a processor for geothermal water (\$/1,000 gal),

Q_G = quantity of geothermal water used annually in processing (000 gal/yr),

ΔI = capital investment savings (\$) of geothermally-powered absorption refrigeration systems over conventional compression systems (negative in our case),

i_a^B = processor's after-tax rate of return factor

t = tax rate,

n = investment tax life (yr),

ΔN = operating cost savings (\$/yr).

By virtue of the assumptions described above, we have

$$(22) \quad Q_G = 60 * 8760 * (239.66 U_S + 639.11 U_F) * 10^{-3},$$

$$(23) \quad \Delta I = -100 T_S - 300 T_F,$$

$$(24) \quad \Delta N = (T_S * 1.60 * U_S + T_F * 2.04 * U_F) * 8760 P_e + 69.45 * U_F * 8760 P_{ng}$$

with $T_S = 300$, $T_F = 400$.

As an example, we can evaluate equation (21) for the following set of

parameter values: $U_S = 0.500$

$U_F = 0.274$

$$P_e = 0.04$$

$$P_{ng} = 0.40$$

$$i_a^B = 0.10$$

$$t = 0.50$$

$$n = 20.$$

Hence, equations (22), (23) and (24) become

$$Q_G = 1.5502 * 10^5$$

$$\Delta I = -1.5000 * 10^5$$

$$\Delta N = 2.2912 * 10^5$$

Substituting into (21) we obtain the estimated bid price:

$$P_G^B = \$1.3329/1,000 \text{ gal.}$$

The bid price derived above applies to plate freezing. How is it affected if we compare geothermal and conventional power with the individual quick freezing (IQF) or tunnel freezing methods? It is not difficult to show that for both methods the bid price P_G^B will be somewhat lower. The effect is on the order of 10% to 25%. The argument goes as follows.

For IQF greater freezing capacity (about 556 t) is needed, because the heat transfer efficiency is less (~50%, instead of ~70% for plate freezing). This means that one requires proportionately more geothermal water for freezing [Eq. (19)]. Thus Q_G in Eq. (21) increases. ΔI also increases [see Eq. (23)], as does the freezing term of ΔN [Eq. (24)], since the savings per ton-hour (2.04 kWh) remain unchanged. However, ΔN increases more slowly than Q_G , because the natural gas savings are unaffected. In other words, the BTU/lb extracted from geothermal water for blanching is less than with

plate freezing, because more water is used for freezing. Thus P_G^B will decrease slightly.

In the case of tunnel freezing, even more refrigeration capacity (926 t) is needed for freezing. But here the impact is more complicated, because the heat removal capacity not effective in freezing food is fully utilized, albeit at a lower and less efficiently produced temperature, in cooling the cold storage space where the tunnels are located. Thus the tonnage and/or utilization of the refrigeration plant for the warehouse can be considerably reduced. The net effect is to decrease P_G^B by somewhat more than for IQF.

5. ASKING PRICE

For the asking price P_G^A , equation (3) may be applied in its original form. Q_F is the same as for the bid price; the geothermal investment I_G is taken at \$667,000; and the geothermal operating cost, N_G , is given by equation (20) with

$$U_G = (239.66 U_S + 639.11 U_F) / 878.77.$$

As an example, we can evaluate equation (3) for the following set of parameter values: $U_S = 0.500$

$$U_F = 0.274$$

$$U_G = 0.3356$$

$$P_e = 0.04$$

$$i_a^A = 0.100 - \text{resource supplier's after-tax rate-of-return factor}$$

$$t = 0.50$$

$$n = 20.$$

Hence (22), (23) and (24) become

$$Q_G = 1.5502 * 10^5$$

$$I_G = 0.667 * 10^6$$

$$N_G = 35,310.$$

Substituting into (3), we obtain the estimated asking price

$$P_G^A = \$0.8727/1,000 \text{ gal.}$$

In summary, we have shown that a food processor would be willing to pay up to \$1.3329 per thousand gallons for geothermal fluids as a substitute for natural gas in blanching and for electricity in freezing and cold storage. We have also shown that a geothermal resource developer would need to charge at least \$0.8727 in order to supply these fluids. Both figures depend on a series of technical and economic assumptions, which have been described above; these assumptions will be varied and a sensitivity analysis will be performed in Chapter V. Given the above assumptions, it is clear that the substitution of geothermal fluids for natural gas and electricity is economically viable. Suppose that the fluids were supplied to the food processor at the minimum asking price of \$0.8727/1,000 gal, so that the processor captures all of the cost savings from the substitution of geothermal energy. This would reduce the cost of processing by:

$$\frac{(P_G^B - P_G^A) * Q_G}{\text{annual production}} = \$1.784/1,000 \text{ lb product.}$$

This cost reduction may be compared with the final product price of \$903, and the processor's price to the wholesaler (net of haulage costs) of about \$572.¹⁷ It may also be compared with the processor's before tax profits of \$76.16¹⁸ — it represents about 2.3% of these profits.

C. PROCESS SUBSTITUTION

In this section we shall consider the packaging and processing of broccoli in a retortable pouch as a substitute for freezing it. We shall focus on the same basic item as in the standard process (grade A spears in nominal 10-oz. packages), although we realize that this may not be the item most suitable for pouching. Broccoli is used here as a surrogate for a suitable vegetable. With this caveat we shall assume that one-seventh of the nominal weight is brine (a slightly higher proportion than that assumed by Steffe, 1980) and that, as in the standard process, the net content of broccoli in pouches is overscaled by 1.67%. We first assume that pouches have to be overwrapped for handling and labeling in a carton of weight similar to that for a 10-oz. frozen package; we shall later examine the effect of dropping this requirement.

To describe the impact of this process substitution on energy consumption and final product price, we shall follow the same procedure as for the standard process. That is, we shall develop materials flow, energy flow and value-added diagrams incorporating the new process. In particular, we shall make two formal changes in the flow diagram. Virtually nothing changes, up to and including step 5, "Receiving and preparation." Step 6, "Pack, wrap, case," will be replaced by "Fill, seal, dry, wrap, case"; i.e., this step also includes pouch drying and casing of cartons. Step 7, "Freezing," is replaced by "Sterilization," which includes retort loading, heating for the appropriate time, and unloading. As before, in real time part of step 6 occurs before step 7 and part after.

Following step 7, the steps in the production chain are the same as before. But the mass flows, energy inputs and values added are different, because of the change in the nature of the product. There are two main

differences. Firstly, because of the addition of brine, overwrap and pouch material, the quantity to be hauled and stored is heavier and bulkier per 1,000 lb net nominal output. This increases storage space requirements and diesel fuel consumption for transport, and retail space conditioning needs for storage and display. Secondly, there is some need for space conditioning in storage, but none for refrigeration in warehouses, on the road, and in display cases. This greatly reduces electricity consumption, as well as capital and variable costs of hauling. However, we assume the same residence times in the various storage facilities as for the frozen product, and also the same losses in processing, hauling and retail handling.

One last preliminary: in order to construct the energy flow and value-added diagrams, one needs a concept of the pouch processing line, how much energy it uses, how much space it takes up, and what operating staff it requires. The weight of the machinery must also be known, although our analysis of the conventional process showed that, of the energy embodied in capital, the overwhelming amount came from building materials and very little from machinery. Our assumptions are presented in Table 26. All this equipment is assigned an economic life of twenty years.

The capital costs in this table should be treated with considerable caution. They may be too low because they assume (perhaps unrealistically) that the equipment specified for one type of product and one size of package will suffice for the whole annual production. They may be high because it might turn out to be possible to replace the eight parallel lines with a smaller number — say, two or three — each having a higher capacity. With time, technological improvements should greatly increase the number of pouches per minute that can be formed, filled, air-purged and sealed; this should significantly lower the capital costs.

Table 26

POUCH MATERIALS, CAPITAL AND LABOR REQUIREMENTS

Equipment for pouch-packing 16,670 lbs/hr of broccoli, 19,448 lbs/hr including brine, in 10-oz pouches at the rate of 518.6 pouches/minute

Item No.	Equipment	Quantity	Unit Price, 000 \$	Number of Persons	Unit Weight, Short Tons	Price 000 \$	Weight, Short Tons
1	Filler-sealer	8	200	32	1.6	1,600	12.8
2	Lane divider	8	10	8	0.5	80	4.0
3	Sterilization car loader	8	30	10	1.0	240	8.0
4	Fork lift	6	7	6	1.5	42	9.0
5	Sterilizer	8	190	8	7.0	1,520	56.0
6	Sterilization car unloader	8	30	10	1.0	240	8.0
7	Dryer	3	35	1	1.5	105	4.5
8	Checkweigher	6	6	3	0.5	36	3.0
9	Cartoner	2	120	3	1.0	240	2.0
10	Case packer	3	24	3	2.0	72	6.0
11	Case gluer	2	17	2	0.5	34	1.0
12	Conveyors	-	-	4	-	80	10.0
13	Ancillary	-	-	34	-	429	12.4
	TOTAL			124		4,718	136.7

Ancillary labor, consisting of 10 foremen and supervisory, and 24 inspectors, is taken at 34 persons, ancillary cost and weight at 10% of total.

1. MATERIALS FLOW

Figure 12 shows the major changes in the materials flow diagram required for the pouch process (compare Figure 3). The paper input is taken from Figure 3, but must of course be increased to reflect the addition of brine, which makes the net nominal content of each pouch 60/7 oz., thus requiring more pouches for 1,000 lb of final product. Water needs in step (6) have been increased to take the brine filler into account. Water in step (7) is dominated by that for filling the retort. It has been assumed that most of this water is recirculated, but that each new load requires twice its weight in make-up water. With an 0.2% loss for each of the two hauls, and a 2% loss in retail handling, the final output on the retail counter is 1,367.8 lb. Of this, 1,016.7 lb is broccoli, 166.7 lb is brine, 155.2 lb is paper, and 29.2 lb is pouch laminate.

2. ENERGY FLOW

Alterations in energy flow for the pouch are shown in Figure 13. A comparison with Figure 5 shows greatly reduced electricity requirements for storage and retail, and slightly increased diesel fuel for hauling. Energy for step (6) is doubled. Not only has the amount of paper for the overwrap increased, but the energy embodied in the pouch laminate is substantial, even though the pouch is light in weight.

The energy flows in the unit processes are aggregated in Table 27. This table may be compared with Table 17 for the frozen product. If one compares the second column in each table, it can be seen that the quantity of energy actually expended in the pouch process is some 36% higher than for frozen food processing. There is a decline in electricity consumption, but this is more than offset by the large increases in natural gas consumption and in embodied energy input. The decrease in electricity consumption is due to the absence

Figure 12

MAJOR MODIFICATIONS IN MATERIALS FLOW FOR POUCH

Labor is in number of persons required.

Other figures without units are in 000 lb.

of any need for freezing or refrigerated storage throughout the production chain. The increase in natural gas consumption arises from the need for steam exhausting prior to sealing as well as for sterilizing. The considerable increase in embodied energy input is due partly to the increased input of paper packaging, but largely to the dual requirement for a laminated pouch and a cellulose-based overwrap. Whether any overwrap is really needed, and how heavy it should be, are really open questions.

The figures used here are our own estimates, and they differ greatly from the latest estimates available (Steffe, 1980). The latter are over an order of magnitude lower, and seem unrealistic to us. Nevertheless, there can be little doubt that more carefully designed blanchers, sealers and retorts could bring considerable economies in natural gas consumption. Also, if one could dispense with a heavy carton this would dramatically reduce the energy requirements.

It should be noted that, if one compares the last columns of Tables 17 and 27, the overall energy expenditure for the pouch process is only about 6.4% higher than for frozen processing. This is because of the reduction in electricity consumption, which is very highly leveraged by its low conversion efficiency. We should also point out that our analysis excludes the final stage of food preparation and cooking in the home, where the pouched product is likely to offer a considerable saving in energy use because of its much lower storage and cooking requirements.

We can break down the total raw material BTU's by activity, as shown in Table 28, which should be compared with Table 18. Figure 14, showing the same data in graphic form, should be compared with Figure 6. For both the pouched and the frozen product, farming and transport each account for about 1/6 of the raw-material resource energy. But, whereas processing, storage and retailing for the frozen product share the remaining 2/3 about equally,

Figure 13

ENERGY FLOW MODIFICATIONS FOR POUCH PROCESSING

TOTAL WEIGHTS PER 1000 LB NOMINAL OUTPUT AT RETAIL END ARE GIVEN ABOVE THE ARROWS
CONNECTING THE UNIT PROCESSES, ACTUAL WEIGHTS OF THE COMMODITY BELOW THE ARROWS, BOTH IN 000 LB

Table 27
ENERGY EXPENDED IN PRODUCING SALES OF
1,000 LB OF POUCHED OVERWRAPPED BROCCOLI

ENERGY FORM	ACTUAL QUANTITY		ENERGY EFFICIENCY*	ADJUSTED QUANTITY	
	Natural Units	10 ⁶ BTU		10 ⁶ BTU	%
Direct Energy Input					
Gasoline	2.0037 [†]	0.2485	0.8	0.3106	2.0
Diesel Fuel	21.2614 [†]	2.9766	0.8	3.7207	23.9
Natural Gas	26.693 [#]	2.6693	0.88	3.0333	19.5
Electricity	124.911 ^{\$}	0.4259	0.2544	1.6741	10.7
Indirect Energy Input					
Embodied in other variable inputs [∞]		6.4583	1.0	6.4583	41.4
Embodied in capital		0.3921	1.0	0.3921	2.5
TOTAL		13.1707		15.5891	100.0

NOTES: *From Table 15

[†]In gallons

[#]In therms

^{\$}In kwh

[∞]Seed, fertilizer, chemicals, paper and laminate

Table 28

CONTRIBUTIONS TO ENERGY EXPENDED (10^6 BTU)
BY VARIOUS ACTIVITIES

Main Activity and Sub-Activities	Contributions	%
Farming	2.2439	14.39
Fertilizer and Chemicals	0.7417	4.76
Direct fuel inputs	1.2397	7.95
Other	0.2625	1.68
Hauling	3.0104	19.31
Direct fuel inputs	2.7916	17.91
Other	0.2189	1.40
Processing	9.2527	59.35
Blanching (NG)	1.2041	7.72
Packaging materials	5.7037	36.59
NG for sealing & retorting	1.8292	11.73
Other	0.5157	3.31
Storage	1.0820	6.94
Processor and Distributor	0.1382	0.89
Retail	0.9438	6.05
TOTAL	15.5891	99.99

Figure 14

ESTIMATED CONTRIBUTIONS TO ENERGY EXPENDITURES REQUIRED
TO BRING POUCHED VEGETABLES TO THE RETAIL SALES COUNTER

for the pouched product processing accounts for almost 90% of the remaining energy consumption. The increased natural gas and packaging materials inputs at the processing stages are responsible for this shift.

3. VALUE ADDED

The value added diagram for pouch processing is shown in Figure 15. From it, using the prices shown in Table 19 and the i_b values in Table 20, we can at once derive the equivalent of Table 21, which gives the value added by each unit process in the production of pouched broccoli. This is shown as Table 29. It will be seen that the final product price amounts to about \$1,026 per 1,000 lb of broccoli, which is about 13% more expensive than the cost of the frozen product. A comparison with Table 21 shows that this higher cost comes partly from somewhat higher labor costs at the retail stage, but mainly from the much higher cost of non-energy variable inputs. The main culprit here is the pouch itself, which has a very high unit cost. These extra costs outweigh the reduction in capital costs in storage and retailing. We should emphasize that a considerable degree of uncertainty is associated with the cost figures in Table 29, because of the novelty of the pouch process. This is particularly true of our estimates of the labor charges for filling the pouches and handling them at the retail stage.

The final step is the development of a value added forecasting equation analogous to equations (16) and (16') for the frozen product. We start with the non-energy variable inputs. From Table 29, the total cost of these inputs is \$342.228. From Table 27 the energy embodied in these inputs is equivalent to 6.4583×10^6 BTU; this, in turn, is equivalent to 1.1135 ($= 6.4583/5.8$) barrels of crude oil. Allowing for the labor charge of \$495.145 we obtain

$$(25) \quad VA_{NE} = 806.195 + 1.1135P.$$

122-

Retortable Pouch Process
(\$ unless indicated, per 1,000-lb nominal output)

LIFETIME	INDIRECT INPUT		DIRECT INPUT	
11 yr	farm machinery	45.903	seed chemicals fertilizer water diesel gasoline labor land rent water pumping	11.802 9.835 8.025 3.462 4.7915 gal 1.2497 gal 41.407 39.339 13.145 kwh
11 yr	harvesting machinery	9.227	labor diesel gasoline	40.058 0.5180 gal 0.7540 gal
5 yr	truck	4.270	elec. for ice diesel labor other var. costs fixed terminal costs	10.129 kwh 1.1619 gal 3.613 1.421 3.728
20 yr	ice	0.477		
20 yr	building & equipment	91.902	electricity natural gas water treatm.	15.853 kwh 10.596 therm 1.948
20 yr	pump & well	5.086	labor	38.888 X 1.4 X 1.2
20 yr	building & equipment	79.640	electricity materials labor natural gas	13.095 kwh 159.047 pouch 75.244 overwrap 44.917 X 1.2 G&A 3.179 therm
20 yr	building & equipment	65.576	labor natural gas electricity	19.107 X 1.2 G&A 12.918 1.423 kwh
20 yr, 0.133 yr resid. time	building & equipment	83.866	electricity brokerage	3.031 kwh 5%
5 yr	truck	31.700	diesel labor other variable truck costs fixed terminal cost	14.0130 gal 21.693 14.692 7.707
20 yr 0.06 yr resid. time	building & equipment	26.839	electricity labor	0.544 kwh 10.736 X 1.2 G&A
5 yr	truck	1.756	diesel labor other variable truck costs fixed terminal cost	0.7769 gal 1.202 X 1.2 0.815 X 1.2 7.692 X 1.2
20 yr 0.06 yr resid. time	building & equipment	59.831	elec. for space cond., lights labor add	67.691 kwh 23.350% of value

Table 29

VALUE ADDED IN POUCH PROCESSING CHAIN

Value added (\$) by each unit process in the production of pouch-packed broccoli for retail sale. Energy prices and capital charges are based on Tables 19 and 20.

Process step description	Labor and G&A	Direct Energy	Other purchased inputs	Capital Charges	Total V.A.	Cumulative V.A.
(1) Grow	41.407	7.417	72.443	14.189	135.456	135.456
(2) Harvest	40.058	1.500	--	2.852	44.410	179.866
(4) Haul to Processor	8.762	1.707	--	2.122	12.591	192.457
(5) Receiving & Preparation	65.332	4.873	1.948	26.187	98.340	290.797
(6) Fill, seal, dry, wrap, & case	53.901	1.795	234.291	21.503	311.490	602.287
(7) Sterilize	22.929	5.224	--	17.706	45.859	648.146
(8) Store (processor)	--	0.121	33.546 ¹	22.644	56.311	704.457
(10) Haul to distributor	44.092	15.695	--	14.794	74.581	779.038
(11) Store (distributor)	12.883	0.022	--	7.247	20.152	799.190
(12) Haul to retailer	11.651	0.870	--	0.820	13.341	812.531
(13) Store & display (retailer)	194.130 ²	2.708	--	16.154	212.992	1,025.523
TOTALS:						
\$ values	495.145	41.932	342.228	146.218	1,025.523	--
% values	48.28	4.09	33.37	14.26	100.00	

¹This entry represents a 5% brokerage fee levied on the value of the product after storage (8) sold by the processor to the distributor or wholesaler.

²This figure is based on direct labor costs + G & A in retailing being 7/6 of 20.0192% or 23.356% of the product's retail value, where 20.0192% was the percentage applied for frozen food.

Next we consider the capital component of value added, which amounts to \$146.218 in 1979 prices. The data for this analysis are provided in Table 30, which may be compared with Table 23. The resulting decomposition of value added is

$$(26) \quad VA_C = i_b(11)[51.461 + 0.13103P] + i_b(5)[35.728 + 0.07137P] \\ + i_b(20)[390.441 + 0.81342P].$$

Lastly, we consider the direct energy inputs. From Table 27, this component of value added can be written as

$$(27) \quad VA_E = 2.0037P_{gs} + 21.2614P_{df} + 26.693P_{ng} + 124.911P_e$$

Substituting (11'), (12'), (13'') and (14) into this equation yields

$$(28) \quad VA_E = 0.69241P + 0.89379P^+ + 11.82014.$$

Combining (25), (26) and (28) we obtain

$$(29) \quad VA = 818.015 + 35.728 i_b(5) + 51.461 i_b(11) + 390.441 i_b(20) \\ + 0.89379P^+ + P[1.80591 + 0.07137 i_b(5) + 0.13103 i_b(11) \\ + 0.81342 i_b(20)].$$

Setting $i_b(5) = 0.4667$, $i_b(11) = 0.3901$, and $i_b(20) = 0.27$, we obtain

$$(29') \quad VA = 956.015 + 2.09934P + 0.89379P^+.$$

If $P = \$28$ and $P^+ = \$12$, we obtain our previous estimate of $VA = \$1025.52$.

Suppose, however, that $P = \$35$ and $P^+ = \$22$; then the final product price rises to \$1049.16, an increase similar to that which we predicted for the frozen product.

Table 30

**COST AND EMBODIED ENERGY COMPONENT OF CAPITAL EQUIPMENT,
BY ECONOMIC LIFE**

(1) Years of Economic Life (n)	(2) Total Capital Cost, (\$)	(3) Embodied energy (10^6 BTU)	(4) Non-Energy Component of Capital Cost (\$)*	(5) Embodied Energy Component of Capital Cost (\$)
11	55.130	0.75995	51.461	0.13103 P
5	37.726	0.41393	35.728	0.07137 P
20	413.217	4.71781	390.441	0.81342 P

*Assuming energy cost of P^{79} = \$28/bbl.

D. COMBINATION OF ENERGY AND PROCESS SUBSTITUTION

The substitution of geothermal for fossil energy in pouch processing will be treated in the same way as for frozen food processing. We shall develop a bid price for geothermal fluids, P_G^B , to be compared with an asking price, P_G^A . The situation is actually somewhat simpler in this case, in that we do not need to deal with the savings of refrigeration costs, but only with savings derived from using 300° F geothermal water instead of natural gas in blanching, sealing and sterilizing. We shall simplify further by ignoring differences in the capital costs for the equipment needed for the two forms of energy. That is, we assume that the costs of a boiler (used with natural gas) are comparable to those for a well-designed heat exchanger (used with geothermal water at least in blanching and sealing).

As with frozen food, we shall assume an annual output of 40 million pounds net of product, and a maximum hourly output of 16,670 lb, for a utilization factor $U = 0.2740$, which applies to blanching, sealing and sterilization alike. For a thorough optimization analysis we would have to make a preliminary design of a system; this would go beyond the scope of this study. We therefore make the simple assumption that the steam for sealing and sensible heat for sterilization require the hottest geothermal fluids, and can usefully extract its heat down to 250° F. This latter water is of sufficient temperature and quantity to serve for blanching.

We thus require enough 300° F water to supply 16.097 therms (from Figure 13) for sealing and sterilizing 1,000 lb of net product, or $16.670 * 16.097/10 = 26.834 * 10^6$ BTU/hr, or, dividing by a temperature drop of 50° F, $536.67 * 10^3$ lb/hr of water at peak production capacity (1,071.85 gpm). This maximum flow is only slightly higher than that for frozen food processing (see Table 25). The utilization at that flow is somewhat lower (0.2740 instead of

0.3356). Accordingly, well capital costs will be assumed to be the same as before (M\$0.667). Well operating cost will be chosen as in Equation (20) except that the coefficient of P_e in Equation (20) will be taken as 20.33 instead of 16.67, in order to allow for the slightly higher flow. Thus, the formula for well operating cost becomes

$$(20') \quad N_G = 20.33 * P_e * U * 8760 + 0.05 I_G,$$

where we set $U = 0.274$. Note that fresh water requirements can be considerably reduced over those in frozen food processing. Condenser cooling is no longer needed. Cooling towers can be dispensed with, evaporative cooling losses held to a minimum, and at least the blanching and sterilizing water can be recycled repeatedly before being discarded.

Bid Price

We go back to Equation (21) of Section C, where

$$Q_G = 60 * 8760 * 1071.85 * 10^{-3} * 0.274 = 1.5436 * 10^5,$$

$$\Delta I = 0,$$

$$\Delta N = 268.3 * P_{ng} * 8760 * 0.274 = 643,984 P_{ng}.$$

Values of i_a^B , t and n are now irrelevant, since we assumed no incremental processing investment. Thus

$$(30) \quad P_G^B = \frac{\Delta N}{Q_G} = 4.172 P_{ng}.$$

Asking Price

We use Equation (3) and put

$$Q_G = 1.5436 * 10^5,$$

$$I_G = 0.667 * 10^6,$$

$$N_G = 33,350 + 48,797 P_e.$$

Selecting $i_a^A = 0.100$, $t = 0.50$, $n = 20$, we obtain

$$(31) \quad P_G^A = 0.864 + 0.316 P_e.$$

Substituting the 1979 prices of $P_{ng} = \$0.40/\text{therm}$ and $P_e = \$0.04/\text{kwh}$ into (30) and (31), we obtain the following asking and bid prices per thousand gallons of geothermal fluids:

$$P_G^A = \$0.8768$$

$$P_G^B = \$1.6688.$$

The asking price is virtually the same as that derived in our analysis of frozen food processing in Section B. The bid price, the maximum amount that a food processor using the pouch process would be willing to pay for geothermal fluids, is about 22% higher than for the frozen food case (\$1.6688 versus \$1.3716). Thus, geothermal fluids are definitely a viable economic option for the pouch process. Assuming that all of the cost savings are captured by the food processor, the potential reduction in production costs from using geothermal fluids amounts to

$$\frac{(1.6688 - 0.8768) * 154,360}{40,000} = \$3.06/1,000 \text{ lb product}.$$

This cost reduction may be compared with the final product price of \$1025, and the processor's price to the wholesaler (net of haulage cost) of about \$704.¹⁹ It may also be compared with the processor's before tax profit of \$71.74 — it represents about 4.3% of this profit.²⁰ By comparison, the cost reduction from the use of geothermal fluids in frozen food processing was \$1.78/1,000 lb product, which amounted to only about 2.3% of the food processor's gross profit.

CHAPTER V

SENSITIVITY ANALYSIS FOR ENERGY SUBSTITUTION

In this chapter we will perform a sensitivity analysis on the results of the previous chapter concerning the substitution of geothermal fluids for electricity and natural gas in both frozen food processing and the pouch process. In the frozen product, geothermal energy substitutes for natural gas in blanching and for electricity in freezing and cold storage. In the pouched product, geothermal energy substitutes for natural gas in blanching, sealing and sterilizing.

A. FROZEN PRODUCT

Here we reconsider the estimates presented in section IV.B. of the geothermal resource supplier's asking price for geothermal fluids, P_G^A , and the frozen food processor's bid price (maximum willingness to pay) for the fluids, P_G^B , and examine their sensitivity to the following variables: P_e , the price of electricity; U_F , the freezing plant utilization factor; I_G , the capital cost of the geothermal well; and i_a^A and i_a^B , the capital recovery factors, which apply respectively to the resource supplier's and the food processor's investments. Another variable which enters into the sensitivity analysis is the price of natural gas, P_{ng} . However, we assume that $P_{ng} = 10P_e$, so that P_e is the only fossil fuel price that explicitly appears in the sensitivity analysis. All of the other parameters will be kept at the values given in section IV.B.

From equations (21) - (24) the food processor's bid price (in \$/1,000 gal) may be written in the form

$$(32) \quad P_G^B = \frac{P_e (2,102,400 + 13,231,980 U_F) - 300,000 i_a^B + 7,500}{62,982.65 + 335,916.22 U_F}.$$

When $P_e = 0.04$, $U_F = 0.274$ and $i_a^B = 0.1$, one obtains the value $P_G^B = 1.3329$ which was given in Chapter IV. Similarly, the geothermal resource supplier's asking price (in \$/1,000 gal) may be written in the form

$$(33) \quad P_G^A = \frac{2I_G i_a^A + P_e (19,912.7 + 106,203.8 U_F)}{62,982.65 + 335,916.22 U_F}.$$

In particular, under the assumption that the geothermal well capital cost is $I_G = 667,000$, this becomes

$$(33') \quad P_G^A = \frac{1,334,000 i_a^A + P_e (19,912.7 + 106,203.8 U_F)}{62,982.65 + 335,916.22 U_F}.$$

When $i_a^A = 0.1$, $P_e = 0.04$, and $U_F = 0.274$, this yields the value $P_G^A = 0.8727$ given above. Combining (32) and (33'), the formula for the maximum cost saving to the food processor from the substitution of the geothermal fluids is

$$(34) \quad \begin{array}{l} \text{Cost} \\ \text{Saving} = \frac{P_e (2,082,487.3 + 13,125,776.2 U_F) + 7,500 - 300,000 i_a^B - 1,334,000 i_a^A}{40,000} \\ (\$/1,000 \\ \text{lb product}) \end{array}.$$

Equations (32)-(34) can be used to perform a sensitivity analysis on the results presented in section IV.B. This is perhaps best done graphically. Figure 16 shows how P_G^A and P_G^B vary with P_e and U_F , when $i_a^A = 0.1$ and $i_a^B = 0.1$; Figure 17 shows how P_G^A and P_G^B vary with P_e , i_a^A , and i_a^B , when $U_F = 0.274$. These figures suggest a number of conclusions. The food processor's bid price for geothermal fluids, P_G^B , is relatively insensitive to both U_F and i_a^B . Intuitively, this is because the substitution of geothermal fluids for electricity and natural gas requires a small capital investment by the food processor in relation to the value of the energy savings. Hence a large change in the rate at which this investment is amortized has little effect on the bid price. An implication is that the substitution of geothermal fluids is an attractive

Figure 16

APPLICATION OF GEOTHERMAL ENERGY IN FROZEN FOOD PROCESSING (I)

Bid price P_G^B (solid lines) and asking price P_G^A \$ (dashed lines) as a function of P_e for varying values of U_F , with $i_a^B = 0.08$, $i_a^A = 0.10$.

Figure 17

APPLICATION OF GEOTHERMAL ENERGY IN FROZEN FOOD PROCESSING (II)

Bid price P_G^B (solid lines) and asking price P_G^A (dashed lines) as a function of P_e for varying values of i_a^B and i_a^A , with $U_F = 0.274$.

investment for the food processor. Another implication is that even if our choice of i_a^B in the previous chapter were unrealistic, it would not seriously invalidate our conclusions. The diagrams also show that P_G^B is very sensitive to the price of conventional fossil fuels, as one might expect. From (32), assuming that $U_F = 0.274$, each one cent increase in P_e raises the processor's bid price for geothermal fluids by about 37 cents.

By contrast, the geothermal resource supplier's asking price, P_G^A , is quite sensitive to the utilization factor, U_F , and the capital recovery factor, i_a^A , but it is relatively insensitive to P_e , since the electricity needs for well operation are minimal. The sensitivity of P_G^A to i_a^A means that this parameter must be chosen with some care. We noted earlier that Harris et al assumed a value of $i_a^A = 0.2$ in their study of geothermal supply economics. This implies a before-tax return of about 35%, which seems too high. Our assumption of $i_a^A = 0.1$ implies a before-tax return of 15%. In this context, it might be noted that under current California law public utilities are constrained to an average return on their rate base of under 10.59% before taxes. The sensitivity of P_G^A to U_F bears further investigation. The lowest value plotted in Figure 16, $U_F = 0.114$, corresponds to an annual production of only 16.67×10^6 lb, e.g., only one or two crops of broccoli over a period of four months. This might correspond to the load factor during an initial trial period. The value of $U_F = 0.274$ used in the previous chapter corresponds to an annual production of 40×10^6 lb, which would be characteristic of modern medium-sized frozen food processing operations. In most locations in the Imperial Valley it would probably be difficult to raise this load factor significantly through further product diversification. However, it might be possible to raise it by employing multiple labor shifts. This is a possibility which merits further research.

It is clear from (33) that the geothermal fluids supply price, P_G^A , is also

very sensitive to the well capital costs, I_G . If two wells were required rather than one, P_G^A would just about double. On the other hand, it might be possible to exploit the well more intensively, since the average yearly flow which we have assumed is only 34% of peak flow. Suppose, for example, that the processing production level could be pushed to $60 * 10^6$ lb/yr with utilization unchanged. In that case the maximum flow (occurring when both freezing and cold storage plants are running full tilt) would be about 1,318 gpm. Perhaps this could be tolerated for short periods of time, since the well region may act like a reservoir. A flow of 959 gpm would have to be provided for longer (10-hr) periods. If all this could be done, P_G^A would be reduced by about 30%.

Finally, since the cost of conventional fossil fuels influences the food processor's bid price for geothermal fluids far more strongly than the resource supplier's asking price, any increase in the cost of these fossil fuels will significantly enhance the attractiveness of the geothermal option. From (34), assuming that $U_F = 0.274$, each one cent increase in P_e raises the cost saving to the food processor from substituting geothermal fluids by about \$1.42/1,000 lb product. Thus, if P_e were 0.063 instead of 0.04 as we have assumed (which would imply a natural gas price of 63¢/therm), the cost savings from using geothermal fluids would be about \$5.20/1,000 lb product, which may be compared with the processor's before tax profits of \$76.17/1,000 lb product, as given in Table 21.

B. POUCHED PRODUCT

In section IV.D. we presented estimates of the asking and bid prices for geothermal fluids when they were employed in the pouch process. Here we examine the sensitivity of these estimates with respect to I_G , the capital cost of the geothermal well; i_a^A , the after-tax capital recovery factor for the geothermal resource supplier; U , the utilization factor for the pouch process; and P_e and P_{ng} , the prices of electricity and natural gas. As before, we shall reduce these two fuel prices to a single price by assuming that $P_{ng} = 10P_e$. However, it should be remembered that geothermal fluids substitute for only natural gas, not electricity, in the pouch process. We do not perform a sensitivity analysis on i_a^B , the food processor's capital recovery factor, because we assumed in Chapter IV that he would have no significant incremental investments in substituting the geothermal energy. All of the other parameters will be kept at the values given in section IV.D.

From (21) and (30), the food processor's bid price for geothermal fluids (in \$/1,000 gal) may be written

$$(35) \quad P_G^B = \frac{2,350,308 U P_{ng}}{563,364.4 U} = 4.172 P_{ng} \\ = 41.72 P_e .$$

Thus, P_G^B is independent not only of i_a^B but also of U , which cancels out of the numerator and denominator in (35). When $P_e = 0.04$ (i.e., $P_{ng} = 0.4$), one obtains the value of $P_G^B = \$1.6688$ which was given in Chapter IV. Similarly, from (3) and (20'), the geothermal resource supplier's asking price (also in \$/1,000 gal) may be written in the form

$$(36) \quad P_G^A = \frac{2I_G i_a^A + 178,090.8 U P_e}{563,364.4 U} .$$

Under the assumption that the geothermal well capital cost is $I_G = 667,000$

this becomes

$$(36') \quad P_G^A = \frac{1,334,000 i_a^A + 178,090.8 U P_e}{563,364.4 U}.$$

When $i_a^A = 0.1$, $P_e = 0.04$ and $U = 0.274$, this yields the value $P_G^A = 0.8768$ given above. Combining (35) and (36'), the formula for the maximum cost saving to the food processor from the substitution of the geothermal fluids is

$$(37) \quad \text{Cost saving} = 583.125 U P_e - 33.35 i_a^A. \\ (\$/1,000 \text{ lb product})$$

Equations (35) and (36) are represented graphically in Figure 18 for different values of the utilization factor U , with i_a^A set at 0.1. The asking price P_G^A is clearly very sensitive to the choice of U —even more so than for the frozen product (compare Figure 16). The reason is that for the pouch the quantity of geothermal fluids used depends entirely on the throughput of the processing line. In the case of frozen food processing, on the other hand, we assumed that some geothermal fluids are used for the refrigeration plant of the cold storage facility, which is virtually independent of how much food is being processed. Since the volume of geothermal fluids being sold to the pouch processor depends more directly on the plant utilization factor, so does the supplier's asking price. It is also clear from (36) that P_G^A is very sensitive to the well capital cost, I_G , and the capital recovery factor, i_a^A ; the degree of sensitivity is about the same as for the frozen product. Turning to the food processor's bid price, a comparison of Figures 16 and 18 shows that the line for P_G^B in the pouch case is steeper than that in the frozen food case, and lies above it. Hence, the economic returns to the food processor from switching to geothermal energy are greater for the pouched product, as was noted at the end of section IV.D., and

Figure 18

APPLICATION OF GEOTHERMAL ENERGY IN POUCH PROCESSING

Bid price P_G^B (solid line) and asking price P_G^A (dashed lines) as a function of P_e for varying values of U with $i^A = 0.10$.

increase more rapidly with a rising fossil fuel price. From (35), each one-cent increase in P_e raises the food processor's bid price by about 42¢, compared with about 37¢ in the frozen food case.

Figure 18 is similar to Figure 16 in that the bid price line is considerably steeper than the asking price line. Therefore, any increase in fossil fuel prices significantly raises the economic attractiveness of the geothermal substitution. From (37), assuming that $U = 0.274$, each one cent increase in P_e raises the cost saving from substituting geothermal fluids by about \$1.60/1,000 lb product. Thus, if P_e were 0.063 instead of 0.04, as we have assumed, the cost savings from using geothermal fluids would be \$6.73/1,000 lb product, which may be compared with the food processor's before tax profits of \$71.74, as given in Table 29.

CHAPTER VI - CONCLUSIONS

A. THE FROZEN PRODUCT

Our standard process for this study is the production of 1,000 lb. of frozen grade A broccoli spears in the Imperial Valley, CA, using conventional fossil energy sources. This product was chosen because it is fairly representative of a range of other products, including frozen spinach, asparagus, cauliflower, carrots and string beans. We have traced the production process from the farm to the retail checkout counter. Using input prices for the latter part of 1979, we estimate that the product would retail for about \$903. Of this, about 20% represents value added in farming, 35% is value added in processing, 20% is value added in wholesale distribution, and 25% is value added in retailing.

Our particular concern has been to measure accurately both the direct energy input throughout the production chain and also the indirect energy input embodied in non-energy variable inputs and in physical capital. We estimate that the direct input of gasoline, diesel fuel, natural gas, and electricity from farm to retail is the equivalent of 5.56×10^6 Btu. Adjusting this for the energy efficiency of the fuels and adding the indirect energy inputs embodied in other variable inputs and capital, we estimate that the overall energy input is the equivalent of 14.66×10^6 Btu. About 15% of this total energy input occurs in farming, 19% occurs in hauling from farm to processor and from processor to wholesaler and retailer, 36% occurs in processing, and 30% occurs in cold storage by the processor, wholesaler and retailer. In value terms, the overall energy input represents about 6.8% of the final product price. While not large, this contribution is much larger than has generally been reported in the literature. Moreover, assuming 1980/81 energy

prices, but holding all other input prices at their 1979 levels, the final product prices rises to \$926 and the share of the energy input in this rises to over 9%.

B. THE POUCHED PRODUCT

There has been a growing interest in this country in the potential of the retortable pouch process as a substitute for freezing and canning. The pouch is now widely used in Japan and parts of Europe. It offers a number of obvious advantages over both freezing and canning: it is suitable for a very broad range of food products; it provides a high level of product quality because of the short cooking time; it can be prepared quickly and easily at the final stage in the kitchen; it is completely sterile, requires no refrigeration, and is exceptionally shelf-stable; it is light in weight and therefore has low distribution costs. However, our research here has focused on two other aspects of the pouch process — its cost, and its energy consumption.

Using input prices for the latter part of 1979, we estimate that the pouched product would retail for about \$1,026/1,000 lb., which is more than 13% higher than the price of the frozen product. About 18% of this total is value added in farming, 45% is value added in processing, 17% is value added in wholesale distribution, and 20% is value added in retailing. Thus, the largest increase in the price of the pouched product occurs at the processing stage. The main problem here is the very high cost of the pouch itself and the relatively low productivity of the processing equipment. We have assumed that each individual processing line can handle about 65 pouches per minute, compared to a production rate of up to 200 packages per minute for frozen foods. Taken together, the non-energy purchased inputs at the processing stage are estimated to cost \$236.24 for the pouched product, but only \$66.52 for the frozen product. This extra cost outweighs the savings in transportation and storage costs in wholesale distribution and retailing.

Furthermore, contrary to the common belief, we estimate that the pouched product requires a larger energy input than the frozen product. We estimate that the direct input of gasoline, diesel fuel, natural gas and electricity to the pouched product is equivalent to 6.32×10^6 Btu, and that the total direct and indirect energy input is equivalent to 15.59×10^6 Btu, which is over 6% higher than for the frozen product. About 14% of this total energy input occurs in farming, 19% occurs in hauling, 59% occurs in processing, and 7% occurs in storage by the processor, wholesaler and retailer. Thus, the main increase in energy consumption occurs at the processing stage, and it outweighs the elimination of the energy requirement for refrigeration. The increased energy consumption is due partly to the greater need for natural gas in sterilizing and sealing, and partly to the considerable embodied energy input in the laminated pouch and the cellulose-based overwrap. In value terms, the overall energy input represents the same percentage of the final product price as for the frozen product — about 6.8% — because, although the total energy input is higher, so is the product price. Alternatively, assuming current energy prices but holding all other input prices at their 1979 levels, the final product prices rises to \$1,049, and the share of the energy input in this rises to just under 9%. Thus, the pouched product appears to be vulnerable to increases in conventional fossil fuel prices to about the same degree as the frozen product.

We conclude, therefore, that for the type of vegetable product considered here the pouch process is marginally inferior to the freezing process in terms of both price and energy requirements. It should be recognized, however, that there may be a considerable margin of error in our calculations because the novelty of the pouch process lends much uncertainty to our estimates of key parameters. Moreover, new developments in pouch technology could significantly affect our conclusion: the cost of the pouch itself could be lowered;

it may become possible to operate the filling and sealing equipment at much greater speeds, thereby reducing the number of lines required; perhaps one could dispense with the overwrap entirely, or at least reduce its cost, weight, and energy content; and changes in the design of blanchers, sealers and retorts could bring considerable economies in natural gas consumption. It should also be recognized that our study excludes the final stage of food preparation in the kitchen, where the pouch may require significantly less energy input than the frozen product. Indeed, because of its convenience in preparation and its ease of handling, the pouch may achieve substantial market penetration despite some price differential. This could be especially true in certain specialized markets — military use, hospital and other institutional markets, outdoor recreation use, and the singles market — and for products other than vegetables, such as fruits, juices and formulated foods.

C. GEOTHERMAL ENERGY

In addition to the substitution of the pouch process for freezing, the other major focus of this study has been the substitution of geothermal energy for conventional fossil fuels. Intermediate and higher temperature geothermal resources are possibly quite abundant in California and other Western states where segments of the food processing industry are located. Moreover, the technology for direct applications of geothermal heat is fairly straightforward and has already been tested in projects in this country, New Zealand, and Japan.

For the purpose of this study we focused on geothermal resources with 300° F water of the type that can be found in the Imperial Valley, CA. Our conclusions would certainly apply to similar resources located elsewhere. In the case of the frozen product we considered the substitution of geothermal

energy for electricity in freezing and cold storage, and natural gas in blanching. In the case of the pouched product we considered its substitution for natural gas in blanching, sealing, and sterilizing. We did not consider the possibility of generating electricity from the geothermal fluids for use in other phases of the production chain, which may understate the true savings from switching to geothermal energy.

In both cases we calculated a minimum asking price at which the fluids could be supplied by a resource company, and a maximum bid price which the food processor could afford to offer for the fluids. If the bid price exceeds the asking price, the substitution of geothermal fluids is economically viable. This is indeed the outcome for both the frozen and the pouched products.

For the frozen product, using input prices for the latter part of 1979, the asking price for geothermal fluids is estimated to be \$0.873/1,000 gal., while the bid price is \$1.333. If the fluids were actually supplied at the asking price, so that the food processor captured all of the cost savings from the substitution of geothermal energy, we estimate that this would reduce the cost of processing by \$1.78/1,000 lb product. This cost reduction may be compared with the processor's estimated price to the wholesaler of \$572, and with the processor's before-tax profits of \$76.16 — it represents about 2.3% of these profits.

For the pouched product, the asking price for the geothermal fluids is very similar to that for the frozen product, but the processor's bid price rises to \$1.669/1,000 gal. This is because the operating cost savings from using geothermal energy are somewhat higher, while the capital costs are lower than for the frozen product — indeed, with the pouched product the capital cost of the geothermal heat exchanger is essentially canceled out by the savings from eliminating a conventional natural gas-

fired boiler. If the fluids were actually supplied at the asking price, we estimate that this would reduce the cost of pouch processing by \$3.06/1,000 lb product. This cost reduction may be compared with the processor's estimated price to the wholesaler of \$705 and with the processor's before-tax profits of \$71.14 — it represents about 4.3% of these profits.

These estimates were subjected to a sensitivity analysis involving several technical and economic parameters. For both the frozen and the pouched product, our estimate of the geothermal resource supplier's asking price is sensitive to the assumptions about the capital recovery factor, the capital cost of the geothermal well, and the rate of utilization of the freezing or pouching equipment. In particular, an increase in the utilization factor, arising, for example, from a switch to multiple shift operation, would increase the intensity with which the resource is exploited and this could significantly reduce the supplier's asking price. It is worth noting, however, that changes in conventional fossil fuel prices would have very little effect on the geothermal supply price, since the electricity needs for well operation are minimal. By contrast, our estimate of the food processor's bid price is greatly influenced by the assumption about the price of conventional fossil fuels, but is fairly insensitive to assumptions about the capital recovery factor or plant utilization rate.

Assuming that the geothermal fluids are actually supplied at the asking price, the net effect of an increase in the price of electricity of 10 mills/kWh, or in the price of natural gas of 10¢/therm, is to raise the food processor's savings from using geothermal energy by about \$1.42/1,000 lb product in the case of freezing, and by \$1.60 in the case of the pouch. As a result, if one uses 1980/81 fossil fuel prices rather than the 1979 prices employed above, the total cost saving to the food processor is \$5.20 per 1,000 lb frozen product, or almost 7% of before-tax profits. In the case

of the pouched product, the total cost saving is \$6.73/1,000 lb product, or over 9% of before-tax profits.

We conclude, therefore, that the substitution of geothermal energy for conventional fossil fuels is profitable for the frozen product and, to an even greater degree, for the pouched product. Moreover, the cost advantage grows rapidly with increases in conventional fossil fuel prices. At current energy prices, these cost savings could have a significant impact on profits in the food processing industry.

FOOTNOTES

1. Dual-Usage crops are used for both processing and fresh market.
2. Harvest costs are typically quite high for fresh market crops — see Mayberry et al. (1979), Thor et al. (1970), United Fresh Fruit and Vegetable Association (1971).
3. By "net" we mean net of the weight of the package itself or of any brine added in packing. By "minimal" we mean the minimum weight as specified on the package. Since packed weights vary somewhat, and since every package must contain at least the nominal weight, the average weight is "overscaled" by a small factor, typically on the order of 1/2 to 2%, depending on package size.
4. Data will be in the form of weight (10^3 lb), energy (10^6 BTU for fossil fuels, kWh for electricity) and cost (\$) unless other units are indicated.
5. Sources of documentation will be provided below, except where privately supplied proprietary data are used. Where no attribution is provided, we are responsible for the data.
6. P_{j-1}^A is the asking price for unit output of the preceding process $j-1$.
7. See, for example, Armstead (1978), Cone (1978), Geonomics (1977), and Schmitt and Peterson (1977).
8. Note that pack, wrap and case (6) are treated here as a single stage, even though casing of broccoli occurs after freezing. This is done for convenience and does not affect the materials balance calculation.
9. Following Cervinka (1974) the energy embodied in the seed input is calculated as half of one percent of all the other energy input to stages 1, 2, and 4.
10. For electricity we use the BTU conversion factor given in the second column of Table 15; for natural gas we use the BTU conversion factor given in Table 16.

11. Rao (1980, prepublished draft, quoted with the permission of the author).
The difference is partly explained by the way we accounted for energy conversion efficiencies.
12. Pimentel reaches a similar conclusion.
13. Details of the calculations underlying these estimates are available from the authors; because of their length they are not reproduced here.
14. Natural gas is something of an exception because of the apparatus of federal price regulation on interstate sales and the existence of long-term sales contracts with more or less fixed prices; the latter is also a feature of some coal markets. Nevertheless, the errors introduced by using the price of crude oil as the average price of a BTU of energy are likely to be reasonably small.
15. For simplicity we have aggregated farm machinery (average economic life 11.34 years) and irrigation equipment (average economic life 10 years) into a single category with an average economic life of 11 years.
16. A ton of refrigeration is defined as the capacity to freeze one ton of water at 32° F in one day, or equivalently, to extract 12,000 BTU of heat per hour.
17. This is the cumulative value added through step 8 in Table 21.
18. This is profits before tax but net of depreciation; it is obtained by summing the capital charges for stages 5-8 in Table 21 and subtracting depreciation charges.
19. This is the cumulative value added through step 8 in Table 29.
20. This is profits before tax but net of depreciation; it is the sum of capital charges for stages 5-8 in Table 29 minus depreciation charges.

BIBLIOGRAPHY

- American Frozen Food Institute (AFFI). Nutrients in Frozen Vegetables. 1980. American Frozen Food Institute Nutrient Data Bank.
- Armstead, H. Christopher. 1978. Geothermal Energy. John Wiley.
- ASHRAE 1970 Guide and Data Book, "Heating, Refrigerating, Ventilating, and Air Conditioning." 1970. New York: ASHRAE.
- ASHRAE Handbook and Product Directory, 1973 Systems. 1973. New York: ASHRAE.
- ASHRAE Handbook and Product Directory, 1974 Applications. 1974. New York: ASHRAE.
- ASHRAE Handbook and Product Directory, 1978 Applications. 1978. New York: ASHRAE.
- ASHRAE Handbook of Fundamentals. 1972. New York: ASHRAE.
- Atkins, E.L. April 1979. Analysis of the Agricultural Industry in Relation to Geothermal Development and Agriculture in the Imperial Valley, Imperial County, California. University of California at Riverside, College of Biological Sciences.
- Badenhop, Arthur F. and Howard P. Milleville, 1980. "Special Report: Institutional Size Retort Pouches." Food Processing. January 1980.
- Barton, John A., and Thomas J. Cutton. April 1979. Energy Accounting in the Food Processing Industry. United States Department of Agriculture, ESCS-51.
- Belshaw, Frances R. 1979. "Overview of Retort Pouch and Tray Use - Worldwide." Proceedings of the Conference, Using the Retort Pouch Worldwide. Food Sciences Institute, Purdue University. Indianapolis, Indiana. March 14-15, 1979. pp. 1-4.
- Berry, Maurice R. 1979. "Retort Pouch: Critical Processing Parameters." Food Engineering. June 1979. pp. 94-95.
- Berry, R. Stephen, Thomas V. Long, II, and Hiro Makino. 1975. "5. An International Comparison of Polymers and Their Alternatives," Energy Policy 3, 144.
- Berry, R. Stephen, and Hiro Makino. February 1974. "Energy Thrift in Packaging and Marketing," Technology Review, 76(3).
- Bloomster, C.H., L.L. Fassbender and C.L. McDonald. 1977. "Geothermal Energy Potential for District and Process Heating Applications in the U.S. -- An Economic Analysis." NATO-CCMS.
- Boles, Patrick P. July 1980. "Owner-Operator Costs of Hauling Fresh Fruits and Vegetables in Refrigerated Trucks," U.S.D.A. Economics, Statistics, and Cooperative Service, Report ESCS-82.
- Bomben, J.C. 1977. "Effluent Generation, Energy Use, and Cost of Blanching,"

Food Process Engineering, 1:329. Printed in Proceedings of National Symposium on Food Processing Wastes, EPA-600/2-77-184, August 1977.

Brown, Susan Jean, and J. Clair Batty. July-August 1976. "Energy Allocation in the Food System: A Microscale View," Transactions of the ASAE, 19(4), pp. 758-61.

Burlingame, Burt B., et al., and Farm Advisors. August 1970. "Leafy Green Vegetables, Production and Market Information," University of California Agricultural Extension Service, Giamini Foundation of Agricultural Economics, No. 70-2.

California Crop and Livestock Reporting Service (CCLRS): California Vegetable Crops. 1977-78.

Cargill, B.F., and G.E. Rossmiller, editors. 1969. "Fruit and Vegetable Harvest Mechanization Technological Implications." East Lansing, Michigan: Rural Manpower Center, Michigan State University.

Cervinka, V., et al. January 1974. Energy Requirement for Agriculture in California.

Chapman, P.F., G. Leach and M. Slessor. 1974. "2. The Energy Cost of Fuels," Energy Policy 2, 231.

Chapman, P.F. 1975. "4. The Energy Cost of Materials," Energy Policy 3, 47.

Chapman, P.F. 1974. "1. Energy Costs: A Review of Methods," Energy Policy 2, 91.

Chinman, M.S., et al. Winter 1978. "Analysis of Energy Utilization in Spinach Processing," Paper No. 78-6524 for presentation to the American Society of Agricultural Engineers, Chicago.

Collie, M. J., editor. 1978. "Potential for District and Process Heating in the United States," based on a report by C.H. Bloomster, et al., Geothermal Energy: Recent Developments, pp. 361-90. Battelle Pacific Northwest Laboratories (BNWL-2311).

Cone, Bruce W. February 1978. Economic Analysis of Potential Uses of Geothermal Energy in Agriculture. Battelle (Report to DOE, PNL-2568).

Davey, James. V. March 1977. "Study of Information/Education Discussions with Private Industries and Public Institutions on the Direct Heat Utilization of Geothermal Energy." LBL Report LBL-5988.

Desrosier, Norman, and Donald K. Tessler. 1977. Fundamentals of Food Freezing. Westport, Connecticut: AVI Publishing Co., Inc.

Energy and the Food System. December 1977. Canada: Department of Agriculture.

Environmental Protection Agency: Symposia on Food Processing Wastes: April 1970, March 1971, November 1972, June 1974, August 1977.

Federal Energy Administration. 1975. Energy Consumption in the Food System, Report No. 13392-007-001, prepared for the Federal Energy Administration Technology Office by Booz, Allen and Hamilton.

Food Processing Industry. October 1979. "Heat Processed Foods — Their Packaging Prospects in the Next Decade." 48:575, pp. 40-43.

Food Technology: Overview. March 1977.

Frozen Food Pack Statistics, 1979. American Frozen Food Institute (AFFI), c. 1980.

Geonomics, Inc. Direct Heat Applications of Geothermal Energy in The Geysers/ Clear Lake Region. Vol. I. Geotechnical Assessment, Agribusiness Applications, Socioeconomic Assessment, Engineering Assessment. August 1977. Report to DOE, SAN/1326-1/1.

Goldman, George, and David Strong. October 1979. Economic Considerations of California Coastal Agriculture. University of California Cooperative Extension Service.

Gordon, Theodore J. March 1978. "The Use of Geothermal Heat for Crop Drying and Related Agricultural Applications." The Futures Group, Glastonbury, Connecticut. 100 11628-4.

Greig, W. Smith, and Richard G. Heifner. 1973. "Locational Effects of Raw Product Prices, Labor Costs, Length of Processing Season, and Transportation Costs in Fruit and Vegetable Processing." Michigan State University, Agricultural Experiment Station Research Bulletin 19.

Hannon, Bruce, et al. November 1978. "Energy and Labor in the Construction Sector," Science, 202:24, pp. 837-47.

Harris, R.C., et al. November 1977. "Geothermal Absorption Refrigeration for Food Processing Industries," Aerojet Energy Conversion Co. Report for DOE, #SAN/1319-1.

Heichel, Gary H. July-August 1974. "Energy Needs and Food Yields," Technology Review, 76(8), pp. 19-25.

Henig, Y.S., and H.M. Schoen. September 1976. "Energy Requirements: Freezing vs. Canning," Food Engineering, (48)9, pp. 54-7.

Hunt, V. Daniel. 1979. Energy Dictionary. New York: Van Nostrand Reinhold Company.

Imperial County Agricultural Report. Imperial County, California.

Jet Propulsion Laboratory. 1976. "Geothermal Energy Resources in California: Status Report." Document 5040-25.

Jones, S.C., et al. April 30, 1978. "Overview of the Environmental Control Measures and Problems in the Food Processing Industries." Cincinnati: Industrial Environmental Research Laboratory Office of Research and Development, U.S. EPA.

Judge, Edward E., and Sons, Inc., publishers. 1979. The Almanac of the Canning, Freezing, Preserving Industries. Westminster, Maryland.

Karl, Johann. July 17, 1980. Personal communication re density of concrete.

- Knutson, Gerald D., et al. July 1977. "Pumping Energy Requirements for Irrigation in California." U.C. Division of Agricultural Sciences Special Publication 3215.
- Krochta, John M., and Thomas R. Rumsey. March 1977. "Solar-Energy Cooling and Freezing of Food: A Computer Analysis," Food Technology Overview, 61.
- Layton, David, and Donald Ermak. August 26, 1976. "A Description of Imperial Valley, California, for the Assessment of Impacts of Geothermal Energy Development." California: Lawrence Livermore Laboratory.
- Leader - Post, 1979. "Instant Dimmers Made to Last up to Eight Years." Newspaper article printed July 5, 1979. Regina Saskatchewan.
- Lienau, Paul J. January 1978. "Agribusiness Geothermal Energy Utilization Potential of Klamath and Snake River Basins, Oregon." GRC. November 1977.
- Lockertz, William, ed. 1977. Agriculture and Energy. New York: Academic Press.
- Londahl, Goran. September 1976. "Frozen vs. Canned Peas," Food Engineering, 48(9), pp. 55-6.
- Ludlow Corporation, 1980. "Ludlow Answers Your Questions on the Retort Pouch," Flexible Packaging Division. Reprint from Food Processing, July 1979.
- Ludlow Corporation, 1977. Retort Pouch Consumer Research Study. Flexible Packaging Division, August 1977.
- Luh, Bor S., and Jasper Guy Woodroof. 1975. Commercial Vegetable Processing. AVI Publishing Co., Inc.
- Lund, D.B. 1979. "Energy Considerations in Pouch and Rigid Retortable Packaging," in Proceedings of the Conference, Using the Retort Pouch Worldwide, March 14-15, 1979, p. 149.
- Mayberry, J., et al. 1979. Imperial County: Guidelines to Production Costs and Practices, Imperial County Crops. Circular 102. El Centro: Cooperative Agricultural Extension, University of California, Imperial County Courthouse.
- Mermelstein, Neil H. 1978. "Retort Pouch Earns 1978 IFT Food Technology Industrial Achievement Award." Food Technology. June 1978. pp. 22-23, pp. 26-30, pp. 32-33.
- Mermelstein, Neil H. 1976. "An Overview of the Retort Pouch in the U.S." Food Technology, February 1976. pp. 28-37.
- Morris, Charles E. 1979. "Retort Pouch Moves Forward." Food Engineering. Volume 51, Number 3. pp. 114-115.
- National Canners Association. Liquid Wastes From Canning and Freezing Fruits and Vegetables. U.S. EPA Program No. 12060EDK.

- Thor, Eric, et al. December 1965. "A Guide for Measuring Relative Profitability of Alternative Work Methods in Agricultural Packing and Processing Operations." University of California, Giannini Foundation of Agricultural Economics, Report #65-4.
- Traub, Larry G., and Dianne D. Oaland. August 1979. "Convenience Foods and Home Prepared Foods -- Comparative Costs, Yield and Quality." U.S.D.A. ESCS, Agr. Econ. Report #429.
- Unger, Samuel G. December 1975. "Energy Utilization in the Leading Energy-Consuming Food Processing Industries," Food Technology 29(12), pp. 33-41.
- United Fresh Fruit and Vegetable Association. Fruits and Vegetable Facts and Pointers: Broccoli. March 1971.
- U.S. Bureau of the Census. 1974 Census of Agriculture, Vol. VI, Part 5. California.
- U.S. Bureau of the Census. 1972 Census of Manufactures, Vol. III, Part I, Area Statistics -- California.
- U.S. Bureau of the Census. 1977 Census of Manufactures, Preliminary Report, California. October 1979.
- U.S. Bureau of the Census. 1977 Census of Manufactures, Preliminary Report, Frozen Fruits and Vegetables. (51C 2037). August 1979.
- U.S. Department of Agriculture. 1979a. Agricultural Statistics 1979. U.S. GPO, Washington, D.C.
- U.S. Department of Agriculture. 1979b. Annual Vegetables. Economics, Statistics, and Cooperatives Service, Crop Reporting Board.
- U.S. Department of Agriculture. February 1977. Usual Planting and Harvesting Dates for Fresh Market and Processing Vegetables. U.S.D.A. Crop Reporting Board, Statistical Reporting Service, Agriculture Handbook No. 507.
- U.S. Department of Agriculture. 1975-1978. Food Consumption, Prices and Expenditures. Economic Research Service. Agricultural Economic Report #138, annual supplements. Agriculture Commissioner, 1969-1979.
- Wehlage, Edward F. 1974. "Geothermal Energy: Potential for Heating and Cooling in Food Processing."
- Whittlesey, Norman K. and George Pfeiffer. August 1974. Washington State University, College of Agriculture Circular 575.
- Wittmus, Howard, et al. March-April 1975. "Energy Requirements for Conventional Versus Minimum Tillage," Journal of Soil and Water Conservation, 30:2.
- Wright, David J. 1974. "3. Goods and Services: An Input-Output Analysis," Energy Policy, 2:307.
- Wright, Thomas C. January 1978. "Crop Drying with Geothermal Energy," GRC.

PERSONAL COMMUNICATIONS

Abbott, R.C., Ludlow Co., Lombard, Illinois.

Badenhop, Arthur, Oregon State University, Corvallis, Oregon.

Baumgart, Paul, Vice President, Chief Economist, Safeway Stores, Inc., Oakland, California.

Bomben, John, Research Chemical Engineer, Food Engineering Development, Western Regional Research Laboratory, United States Department of Agriculture, Albany, California.

Boone, Eugene, President, John Inglis Frozen Foods Co., Modesto, California.

Brendler, Robert A., Farm Advisor, Ventura County, California.

Carroad, Paul Al, Ph.D., Assistant Professor, Department of Food Science and Technology, University of California-Davis, Davis, California.

Griffiths, Harold, Tri-Valley Growers, Modesto, California.

Karl Johann, San Francisco, California.

Kenworthy, Ralph, Vice President-Operations Manager, John Inglis Frozen Foods Co., Modesto, California.

Mayberry, Keith, Farm Advisor, Imperial County, California.

McCoy, Orval, Rain For Rent, Imperial County, California.

Mencacci, Sam, FMC Central Engineering Labs, Santa Clara, California.

Powell, Richard, International Association of Refrigerated Warehouses, Washington, D.C.

Purdot, Paul, Accountant, John Inglis Frozen Foods Co., Modesto, California.

Rols, Robert W., Ore-Ida Foods, Inc., Boise, Idaho.

Rose, Wally, National Food Processors Association, Berkeley, California.

Singh, Paul, Ph.D., Department of Food Science and Technology, University of California-Davis, Davis, California.

Strasser, Jurgen, Ph.D., FMC, Santa Clara, California.

Thompson, Jack, Safeway Stores, Inc., Oakland, California.

Thor, Eric, Ph.D., Agricultural Economist, University of California-Berkeley, Berkeley, California.

Weatherspoon, Howard, American Frozen Food Institute, San Mateo/Burlingame, California.

Young, Steve, Case Power and Equipment, Stockton, California.