

BAGASSE PARTICLE BOARD:
A PRODUCTION STUDY AND INVESTMENT ANALYSIS

by

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(1968)

Submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Civil Engineering

at the

Massachusetts Institute of Technology

June 1972

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ABSTRACT

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Submitted to the Department of Civil Engineering on 17 May 1972 in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering.

This study of bagasse particle board covers four basic areas. First, the extent of the occurrence of bagasse fibers as a natural resource is surveyed. The magnitude of the building materials supply which could be manufactured from existing bagasse fiber resources is shown to be significant when compared to the world housing deficit.

Second, the properties of three bagasse boards -- softboard, hardboard, and particle board -- are examined and the relative superiority of particle board as a construction material is indicated. The usefulness of bagasse particle board in the types of construction prevalent in developing countries is also noted.

Third, the production system by which bagasse particle board is manufactured is studied in detail. A study of the sugar mill operating system is appended to this thesis as background for this discussion. The problem of releasing bagasse from its present use as fuel is dealt with in depth.

Fourth, a framework for the analysis and evaluation of proposed bagasse particle board operations is elaborated. This investment analysis

provides the methodology for determining the profitability -- and thus the feasibility -- of alternate modes of production at varying levels of annual output of particle board. The methodology of the investment analysis framework is applied to a hypothetical example of a proposed bagasse particle board plant.

Thesis Supervisor: Fred Moavenzadeh

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ACKNOWLEDGMENTS

The author wishes to express his gratitude to those persons whose cooperation, advice, and encouragement have made the writing of this thesis possible. Among these people, the following deserve special thanks:

To Mr. John Bersch, Technical Vice-President, Honiron, Honolulu, Hawaii, for his expert clarification of many aspects of sugar mill operations.

To Dr. R. L. Cushing, Director, Hawaiian Sugar Planters' Association, Honolulu, Hawaii, for allowing the author to use the HSPA library and project files on bagasse by-products during July and August, 1971.

To Dr. Wayne Hilton, also of the Hawaiian Sugar Planters' Association, for sharing the findings of his own investigations into bagasse by-products of various types.

To Mr. K. Ruckstuhl, President, Standard Building Products Ltd., Spanish Town, Jamaica, West Indies, for allowing the author to visit SBP's bagasse particle board plant and for his very helpful discussions of bagasse particle board production and product development.

To Professor Fred Moavenzadeh, M.I.T. Department of Civil Engineering, for guiding the author not

just in the preparation of this thesis research,
but also through two years of stimulating and
enjoyable study.

And finally to Ms. Mary Chiu, for her expert
assistance in the preparation of the final draft
of this thesis.

DEDICATION

This thesis is dedicated to Molly Muffin,
whose dogged support and companionship
throughout the past two years have added
immeasurably to the quality of my life,
if not of my studies.

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I. INTRODUCTION

One of the chronic problems facing developing countries is the shortage of housing which meets minimum levels of permanency, hygiene, and inhabitability. The rapidly expanding populations of the developing countries, particularly in the already crowded urban areas, coupled with the increasing social expectations of these people, make the provision of sufficient decent housing one of the urgent concerns of developing countries throughout the world.

The obvious first stage in the providing of adequate housing in developing countries is the establishment of a domestic building materials industry which can supply those building materials whose relative ease of manufacture and high cost of transport render direct importation uneconomic. The problem of establishing a building materials industry is a technical one only in its minor aspects, since the technology for the production of materials for satisfactory, low-cost construction of many types is already existant. The crux of the problem is usually the uncertain economics of the new technology.

While the importance of research on the purely technical aspects of building materials development is not to be underrated, it would nevertheless appear that research into the economics of building materials development

and production is of equal importance and perhaps more immediate benefit to developing regions. The research reported in this thesis, therefore, is a study of both the technology and the economics of the production of a relatively new but potentially highly important building material.

Many developing countries--including those with inadequate or under-utilized forest resources--have readily available large quantities of natural fibers which occur as agricultural wastes. Research has been going on for some years to find uses for these fibers, including their use in building materials. In recent years the technology for the manufacture of softboard, hardboard, particle board, and related building components from sugar cane bagasse has been perfected. Bagasse is the residue of fiber, pith, and moisture remaining after the sugar cane has been shredded and crushed and its sugar-laden juices extracted.

Many developing countries have well established sugar industries which harvest several million tons of sugar cane annually, and approximately one-third to one-half of this tonnage becomes the waste product bagasse. Table I-1 shows the estimated annual bagasse production in sugar-cane growing countries of the world. At present, this bagasse is used principally as a fuel in special bagasse furnaces to provide power for the sugar mills. The bagasse produced

by a sugar mill is often 5% to 10% in excess of that needed to generate the power required by the mill, and may reach a surplus of 15% to 20% in efficient mills.¹ This surplus bagasse is normally converted to heat in the mill's boiler, which is then released into the atmosphere as waste steam. Thus, large tonnages of bagasse fibers are wasted each year for lack of an opportunity for better utilization.

Bagasse can be the basic raw material for the manufacture of paper and furfural, as well as the building materials mentioned previously. In point of fact, the profitable manufacture of these products is already a reality in several countries. However, the technical and economic criteria governing the manufacture of bagasse building materials have not been clearly recognized, particularly in the particular circumstances of the developing countries. The economic importance of seasonal cane harvesting, mill efficiencies, capital costs of manufacturing facilities, local production costs, potential markets, etc., have not been coherently dealt with in the literature.

What is being reported in this thesis is a systematic study of the variables affecting the technology and economics of bagasse building materials manufacture with particular reference to bagasse particle board. Some of these variables are related to the actual processing of sugar cane at sugar mills, while other variables are linked to the

process requirements for bagasse building materials manufacture. Still other variables are simply the result of economic conditions in any given region. To take into account all these variables, this study has attempted to include the total production process, from the procurement of raw materials to the marketing of the final product.

Since the primary concern in this study is with the manufacture of a bagasse building material, it is of interest to focus briefly on the housing crisis in those areas of the world with significant domestic sugar cane industries, as these are obviously the areas whose housing supply would benefit most by the local production of bagasse building materials. It can readily be observed that the production of cane sugar is a significant domestic industry in numerous developing regions, particularly in Latin America, Africa, and Asia. The sugar industries in these countries produce, in the normal course of their operations, enormous quantities of bagasse (cane fibers) which can be utilized as the raw material for the production of high quality building boards such as bagasse particle board. The quantities of particle board which can be produced from these fibers is significant when compared to both the national housing needs of many developing countries and the total world housing deficiency. Tables I-2 through I-6 show the potential impact of such utilization of bagasse fiber resources

on the housing deficiencies of the sugar producing countries of the world.

The establishment of a bagasse-based building materials industry also appears to be desirable from the standpoint of the sugar industries. The profitability of sugar production is subject to major fluctuations, owing to the unusual structure of the world market for sugar. More than 60% of the world trade in sugar takes place within preferential markets, wherein the large importers of sugar (the United States and United Kingdom, for example) purchase agreed-upon amounts of sugar from exporting countries at preferential prices determined by international agreement. These preferential prices are generally considerably above the free market prices (see Figure I-1 for comparison), and constitute the largest part of the revenues derived from sugar exportation. The balance of the world trade is made up of the sugar produced in excess of the established quotas in those countries without preferential agreements. Sugar industries in the latter countries are clearly dependent on the free market price, but many of the countries with preferential agreements also rely on free market exportation, which may represent the entire margin of profitability for the industry.

The free market price of sugar, however, is extremely sensitive to the available exports of sugar and can

fluctuate drastically from year to year, as shown in Figure I-1. Thus the production of sugar can yield large profits in one year and incur large operating losses in the next year. The lack of predictability of available profits makes rather difficult the long-range planning of capital improvements and expansion of operations in the sugar industry. Thus, one of the original motivations for the development of sugar industry by-products was the desire of the industry to achieve a steady, predictable source of secondary income which would help to stabilize their long-range planning. The sugar industry has naturally sought to explore the potential of bagasse, its largest "waste" product, as the basis of new products whose sale could provide stable secondary income. Table I-7 shows the value of various products which can currently be produced from one ton of dry bagasse. Clearly, the upgrading of raw bagasse into products such as pulp, paper, and board requires initial capital investments which may approach \$10 million or more. However, reasonable--and in some cases, excellent--returns on investments in these by-products are possible. When markets for these by-products have a history of stable prices, investment in these by-products becomes doubly attractive to sugar industries seeking more stabilized incomes. Building boards similar to bagasse have a history of stable world market prices

and are thus well-suited to play a stabilizing role in sugar operations.

On the basis of a confidence in the benefits to be derived from the production of bagasse-based building materials, especially in several developing countries, the author has in this thesis undertaken an investment-oriented study of the production of bagasse board. Section II of this thesis examines the nature of bagasse, the properties of bagasse boards, the comparative advantages of bagasse boards as a modern building material, and worldwide trends in the consumption of particle board and similar panels. Section III examines the production system for bagasse particle boards, including discussion of both technical and economic considerations. Section IV presents an investment analysis framework for the evaluation of potential investments in bagasse particle board production. Section V applies this analytic framework to a hypothetical proposal to build a bagasse particle board plant. Section VI gives a summary and conclusion of this study and makes suggestions for further research. An Appendix on the Sugar Mill Operating System is included to familiarize the general reader with those aspects of the processing of sugar cane which bear directly on the production of particle boards from the resultant bagasse.

<u>REGION AND COUNTRY</u>	<u>APPROXIMATE ANNUAL TONNAGE OF BAGASSE PRODUCED¹</u>	<u>APPROXIMATE ANNUAL TONNAGE OF BONE-DRY FIBERS PRODUCED²</u>
<u>Latin America</u>		
Argentina	1,200,000	400,000
Bolivia	136,000	45,300
Brazil	5,600,000	1,866,600
British Honduras	53,000	17,600
Colombia	860,000	286,600
Costa Rica	170,000	56,600
Ecuador	260,000	86,600
El Salvador	174,000	58,000
Guatemala	210,000	70,000
Guyana	440,000	146,000
Honduras	53,000	17,600
Mexico	3,000,000	1,000,000
Nicaragua	143,000	47,600
Panama	90,000	30,000
Paraguay	49,000	16,300
Peru	990,000	330,000
Surinam	22,000	7,300
Venezuela	440,000	146,000
<u>Africa</u>		
Angola	84,000	28,000
Congo	59,000	19,600
Ethiopia	98,000	32,600
Kenya	114,000	38,000
Mauritius	820,000	273,300
Mozambique	280,000	93,300
Reunion	350,000	116,600
South Africa	2,200,000	733,300
Uganda	190,000	63,300
United Arab Republic	540,000	180,000

TABLE I-1: WORLD BAGASSE FIBER RESOURCES

(continued on next page)

<u>REGION AND COUNTRY</u>	<u>APPROXIMATE ANNUAL TONNAGE OF BAGASSE PRODUCED¹</u>	<u>APPROXIMATE ANNUAL TONNAGE OF BONE-DRY FIBERS PRODUCED²</u>
<u>Asia</u>		
Burma	98,000	32,600
India	2,860,000	953,300
Indonesia	780,000	260,000
Pakistan	550,000	183,000
Phillipines	2,150,000	716,600
Taiwan	1,060,000	353,300
Thailand	245,000	81,600
<u>Caribbean Area</u>		
Antigua and St. Kitts	49,000	16,300
Barbados	215,000	71,600
Cuba	6,900,000	2,300,000
Dominican Republic	910,000	303,000
Guadeloupe	195,000	65,000
Haiti	87,000	29,000
Jamaica	600,000	200,000
Martinique	52,000	17,300
Puerto Rico	760,000	286,600
Trinidad	325,000	108,300
<u>Other Areas</u>		
Australia	3,650,000	1,216,600
Fiji	495,000	165,000
United States (except Hawaii)	1,600,000	533,300
Hawaii	1,500,000	500,000
<u>World Total</u>	<u>43,910,000</u>	<u>14,636,600</u>

TABLE I-1 (continued): WORLD BAGASSE FIBER RESOURCES.

(See next page)

Sources, by notes:

¹Based on 1.3 tons bagasse per ton of raw sugar produced.
Raw sugar tonnage data from 1968 Sugar Year Book.

²Based on approximately 1/3 bone-dry fibers (BDF) in
fresh bagasse, by weight. See Section II.

TABLE I-1 (continued): WORLD BAGASSE FIBER RESOURCES.

<u>COUNTRY</u>	<u>ANNUAL NEW HOUSING NEED</u> ¹	<u>ANNUAL HOUSING PRODUCED</u> ²	<u>ANNUAL HOUSING DEFICIENCY</u>	<u>ANNUAL HOUSING PRODUCEABLE FROM BAGASSE</u> ³	<u>D/C (%)</u>
Argentina	200,000	[20,000]	180,000	120,000	67%
Bolivia	27,000	[2,700]	24,300	13,600	56%
Brazil	709,700	48,943	660,000	560,000	85%
British Honduras	900	[90]	800	5,300	1040%
Colombia	174,800	22,362	152,500	86,000	57%
Costa Rica	13,360	4,556	8,200	17,600	215%
Ecuador	44,760	[4,500]	40,000	26,000	65%
El Salvador	25,100	1,466	23,500	17,400	74%
Guatemala	42,850	2,335	40,500	21,000	52%
Guyana	5,600	[560]	5,040	44,000	880%
Honduras	18,850	[1,880]	17,000	5,300	31%
Mexico	349,000	26,318	323,000	300,000	93%
Nicaragua	15,350	1,535	13,800	14,300	103%
Panama	10,750	1,709	10,050	9,000	90%
Paraguay	18,000	[1,800]	16,200	4,900	30%
Peru	99,000	(3,740)	95,000	99,000	104%
Surinam	3,200	2,212	1,030	2,200	213%
Venezuela	75,250	11,252	64,000	44,000	69%
TOTAL	1,834,420	158,000	1,675,400	1,390,600	83%

TABLE I-2: POTENTIAL FOR BAGASSE IN HOUSING: LATIN AMERICA

(see notes follow Table I-6)

<u>COUNTRY</u>	A. <u>ANNUAL NEW HOUSING NEED</u> ¹	B. <u>ANNUAL HOUSING PRODUCED</u> ²	C. <u>ANNUAL HOUSING DEFICIENCY</u> (A-B)	D. <u>ANNUAL HOUSING PRODUCEABLE FROM BAGASSE</u> ³	E. <u>D/C (%)</u>
Angola	48,400	(2160)	47,240	8,400	18%
Congo	127,700	(3750)	124,000	5,900	5%
Ethiopia	230,000	[23,000]	207,000	9,800	4%
Kenya	86,000	(658)	85,700	11,400	13%
Mauritius	10,500	2374	8,126	82,000	1010%
Mozambique	65,800	(1940)	63,850	28,000	45%
³⁰ Reunion	3,500	[350]	3,140	35,000	1120%
South Africa	160,000	[16,000]	144,000	220,000	152%
Uganda	65,000	(508)	64,850	19,000	29%
United Arab Republic	300,000	[30,000]	270,000	54,000	20%
TOTAL	1,096,900	80,730	1,016,200	473,500	47%

TABLE I-3: POTENTIAL FOR BAGASSE IN HOUSING: AFRICA

(See notes follow Table I-6)

<u>COUNTRY</u>	A. <u>ANNUAL NEW HOUSING NEED</u> ¹	B. <u>ANNUAL HOUSING PRODUCED</u> ²	C <u>ANNUAL HOUSING DEFICIENCY</u>	D. <u>ANNUAL HOUSING PRODUCEABLE FROM BAGASSE</u> ³	E. <u>$\frac{D}{C}$ (%)</u>
Burma	168,000	[16,800]	151,200	9,800	7%
India	4,355,000	[435,000]	3,920,000	286,000	7%
Indonesia	963,000	[96,000]	867,000	78,000	9%
Pakistan	938,000	[93,800]	845,000	55,000	7%
Philippines	27,900	(27,000)	1,000	215,000	21,500%
Taiwan	133,800	[13,400]	120,000	106,000	88%
³¹ Thailand	262,600	11,585	251,000	24,500	10%
TOTAL	6,848,300	693,600	6,154,700	774,300	13%

TABLE II-4: POTENTIAL FOR BAGASSE IN HOUSING: ASIA

(See notes follow Table I-6)

<u>COUNTRY</u>	A. <u>ANNUAL NEW HOUSING NEED</u> ¹	B. <u>ANNUAL HOUSING PRODUCED</u> ²	C. <u>ANNUAL HOUSING DEFICIENCY</u> (A-B)	D. <u>ANNUAL HOUSING PRODUCEABLE FROM BAGASSE</u> ³	E. <u>D/C (%)</u>
Antigua and St. Kitts	1,100	[110]	1,000	4,900	490%
Barbados	2,300	135	2,165	21,500	985%
Cuba	58,300	[5,830]	52,500	690,000	1320%
Dominican Republic	30,500	[3,050]	27,000	91,000	332%
Guadeloupe	2,800	[280]	2,500	19,500	770%
32 Haiti	31,000	[3,100]	27,900	8,700	31%
Jamaica	16,100	(1,160)	15,000	60,000	405%
Martinique	2,900	1,210	1,700	5,200	305%
Puerto Rico	23,500	20,473	3,022	76,000	2500%
Trinidad	8,300	3,045	5,255	32,500	615%
TOTAL	176,800	38,400	138,400	1,030,300	748%

TABLE I-5: POTENTIAL FOR BAGASSE IN HOUSING: CARIBBEAN AREA

(See notes follow Table I-6)

<u>COUNTRY</u>	A. <u>ANNUAL NEW HOUSING NEED</u> ¹	B. <u>ANNUAL HOUSING PRODUCED</u> ²	C. <u>ANNUAL HOUSING DEFICIENCY</u>	D. <u>ANNUAL HOUSING PRODUCEABLE FROM BAGASSE</u> ³	E. <u>$\frac{D}{C}$ (%)</u>
Australia	115,400	111,962	3,500	365,000	10,400%
Fiji	4,750	475	4,275	49,500	1,140%
United States (except Hawaii)	1,793,000	1,196,200	600,000	160,000	27%
Hawaii	7,500	3,000	4,500	150,000	3,300%
TOTAL	1,920,000	1,311,637	609,000	724,500	119%
33 WORLD TOTAL (of cane sugar countries)	11,876,000	2,282,000	9,599,000	4,391,000	46%

TABLE I-6: POTENTIAL FOR BAGASSE IN HOUSING: REST OF WORLD & WORLD TOTAL

Reference Notes:

- (1) Based on 10 new dwellings per 1000 inhabitants. Population data from United Nations Statistical Yearbook, 1967.
- (2) Figures in parentheses() based on dividing total residential floor area built by 50 m² (500 ft²) per unit. Figures in brackets[] are based on approximation of construction rate of 1 dwelling per year per 1000 inhabitants, since other data are not available. Figures not enclosed in brackets are actual count of building permits or other official government statistics. All data from United Nations Statistical Yearbook, 1967.
- (3) Based on 1.3 tons bagasse produced per ton of raw sugar and 10 tons of bagasse per housing unit (approximately 3 tons 3/4" building board, 4'x8'). Raw sugar data from Sugar Year Book, 1968.

<u>UTILIZATION</u>	<u>VALUE (US\$)</u>
Production of electrical or heat energy at mill	4
Methane gas	5
Producer gas	7
Charcoal	8
Poultry litter	12
Furfural	25
Bleached Pulp	35
Corrugating medium	42
Insulation board	42
Particle board	54
Writing paper	59

TABLE I-7: VALUE OF BY-PRODUCTS PRODUCEABLE FROM ONE TON
OF BAGASSE

Source: J. Paturau, By-Products of the Cane Sugar Industry,
page 261.

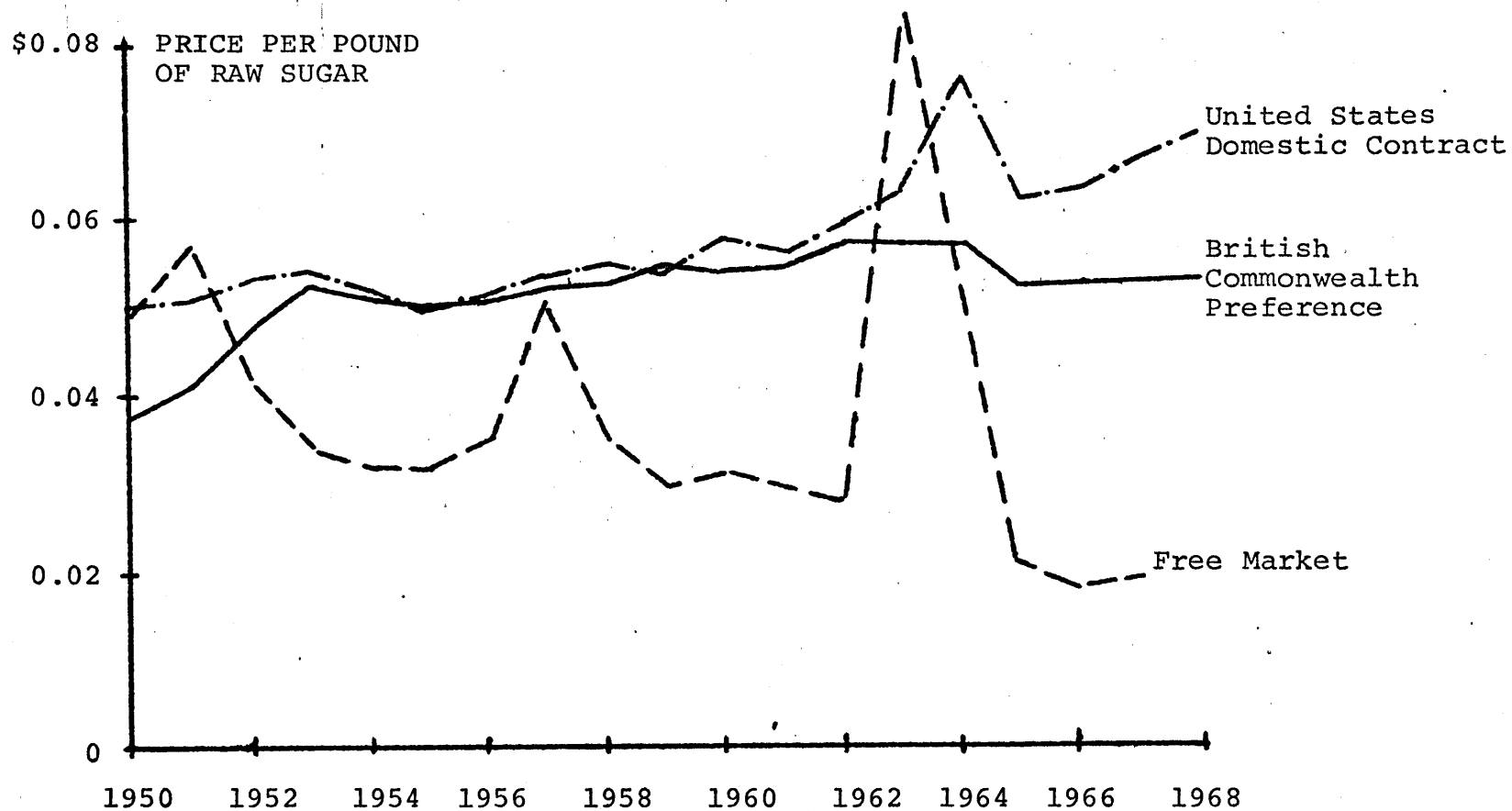


FIGURE I-1: WORLD SUGAR PRICES 1950-1968: FREE AND PREFERENTIAL MARKETS.

Source: Sugar Year Book 1968, page 389, and Sugar Year Book 1965, page 345.

NOTES -- SECTION I

¹J. Paturau, By-Products of the Cane Sugar Industry,
page 6.

II. NATURE OF BAGASSE AND BAGASSE BOARD

A. Bagasse

Bagasse is the name given to the fibrous residue of the sugar cane stalk after the cane has been crushed in the roller mills and most of the sugar-laden juices extracted. Figure II-1a is a photograph of dry bagasse from a Hawaiian sugar mill; it shows a typical configuration and size distribution of bagasse fiber bundles. Fresh bagasse from a sugar mill contains water (moisture), fiber, pith, and soluble solids (mostly sugar) in the following proportions (by weight):¹

Moisture	42-54%
Fibers	31-37%
Pith	12-15%
Soluble solids	2-6%

The moisture content of the bagasse is essentially a function of the manner in which the cane is milled, since water is added to the cane in the milling process. The fiber and pith content depends mainly on the variety of cane being milled. The soluble solids are principally sugar, and the extent of its occurrence in bagasse is inversely related to the thoroughness with which the cane

is milled.

The principal distinction between the so-called "fibers" and "pith" is the length of the fibers present in each. Figure II-1b is a photograph of the bagasse in Figure II-1a after it has been separated into its two components, pith and fibers. Table II-1 gives typical fiber lengths and aspect ratios for both pith and fiber. The pith fibers are, in effect, too short in relation to their width to be suitable for fibrous reinforcement of a composite such as particle board (a composite of fibers and binding resin). The pith does, however, have the property of being highly absorptive, being capable of absorbing many times its own weight in liquids.² For this reason, the principal use of pith is as a carrier for liquids--for example, as a carrier of molasses in the preparation of animal feeds.

The fibers proper in sugar cane are comparable in geometry and composition to wood and certain other cellulose fibers. Table II-2 shows the similarity of bagasse fiber lengths and aspect ratios to those of selected wood and plant fibers. The chemical composition of dry bagasse is similar to that of most hardwoods,³ consisting of approximately 45-60% cellulose, 20-30% pentosans, and 15-22% lignin.⁴

As mentioned previously, the principal use of bagasse

presently is as a fuel in bagasse furnaces at sugar mills. Its usefulness in this respect is based on its fuel value, which has been found to be approximately 7700 BTU/pound in the dry state. The fuel value of fresh bagasse (as it comes from the sugar mill) is considerably less--about 3400 BTU/pound, on the average--since the bagasse contains a large percentage of moisture. The fuel value of bagasse is discussed in detail in the Appendix on the Sugar Mill Operating System, Part D.

B. Properties of Bagasse Boards

Three types of board can be produced from bagasse fibers: (1) softboard, used principally for insulation board and acoustic panels; (2) hardboard, used in furniture manufacture and in the interior parts of buildings; (3) particle board, used principally as an exterior and interior structural component in frame construction, and in the manufacture of furniture. The essential difference in these boards lies in their methods of production; the production of particle board, in particular, is quite different from the production system for softboard and hardboard, which have similar means of production. The production system for particle board is discussed in detail in Section III and subsequently modelled in Section IV. The emphasis in this thesis on particle board is based on

its considerably greater usefulness in housing and other construction, as explained more fully below.

Bagasse softboard is a low density board most notable for its good heat insulation properties, its heat transmission coefficient typically being only 0.320-0.330 BTU/ft²/hr/in/°F.⁵ The strength of bagasse softboard is not very great, however, with the modulus of rupture usually ranging between 380 and 470 psi (27-33 kg/cm²).⁶ Bagasse softboard is, in fact, useful only as a decorative or finishing material (such as acoustic panels), and is not to be considered a primary or structural building material.

Bagasse hardboard is basically similar to the well-known "Masonite" panels in appearance, properties, and uses. The dimensions of the panels most commonly produced are 4 feet by 8 feet by 1/8 to 1/4 inch thick. The density of the various types of bagasse hardboard currently being manufactured varies from 45 to 70 pcf. The strength of bagasse hardboard, moreover, varies directly with the density of the board, ranging from a modulus of rupture of 3000 psi for a board with density of 45 pcf to a modulus of 7400 psi for a board of 70 pcf, as shown in Figure II-2.

Hardboard may also be tempered with an application of oil to improve its water resistance. While untempered hardboard deteriorates rapidly on exposure to water, oil-

tempered hardboard shows a somewhat improved resistance. Nonetheless, oil-tempered hardboard, when exposed to water, still shows significant levels of water absorption, panel swelling, and panel deterioration. Table II-3 shows some of the properties of typical bagasse hardboards, including properties related to water exposure. In spite of its adequate strength and as a result primarily of its poor ability to resist deterioration under exposure to water, bagasse hardboard does not find significant use as a primary construction material, but does enjoy fairly wide use in finishing applications for the interior of buildings.

Bagasse particle boards are in general appearance and usefulness closely related to wood-chip particle boards. Bagasse particle board is usually manufactured in panels 4 feet wide by 8 or 10 feet long by 1/2, 5/8, or 3/4 inch thick. The physical properties of bagasse particle board are summarized in Table II-4, which also compares its properties with those of European wood particle boards and similar boards made from jute, hemp, and flax fibers. On the basis of the properties shown in Table II-4, the bagasse particle board compares very favorably with wood particle board, being in general lighter, stronger, and less susceptible to swelling and warping in water.

Bagasse particle board which is made with a phenolic resin binder is highly resistant to water and is suitable

for exterior as well as interior applications. The high strength of bagasse board makes it an excellent structural component in walls, floors, and roofs of frame-type construction. Highly effective insecticides and fungicides, moreover, have been developed for use in bagasse board and render the boards virtually immune to attack by insects and fungus.

C. Comparative Advantages of Bagasse Particle Boards as a Modern Building Material

The comparative advantages of bagasse particle boards as a building material, particularly in the context of the developing countries, will depend both on the type of housing desired by the countries and on the adaptability and suitability of the particle boards to that type of construction.

C.1 Types of Dwellings Needed in Developing Countries

Not only do developing countries show a consistent need for dwellings, but there also appears to be great similarity in the types of buildings needed. Table II-5 shows, for example, the types of dwellings proposed by various developing countries for their low-cost housing developments. As one can easily see, one- and two-story dwellings are the most common type of dwelling planned.

One- and two-storey construction is, in fact, usually the cheapest type of construction per square foot of habitable space when the cost of land is not a major consideration. Figure II-3 shows the variation in construction cost per square foot with the number of storeys considered in low-cost housing schemes in India. Clearly, costs per square foot rise rapidly with the third and subsequent storeys. In addition to minimizing construction costs per square foot, one- and two-storey construction generally requires lower levels of skill and mechanization than higher types of buildings. From both a technical and economic point of view, then, one- and two-storey dwellings are in most cases the most suitable type of construction in low-cost housing programs in developing countries.

C.2 Building Methods and Materials in Developing Countries

The construction of one- and two-storey dwellings in both developing and developed countries may be accomplished by either traditional or modern building methods and materials. Under certain conditions, traditional methods and materials may be the most advantageous mode of construction, as explained below. Modern building systems and materials do, however, offer considerable economies of cost and time under most conditions, and their advantages must also be considered below.

C.2.a Traditional Building Methods and Materials

In evaluating any building material, the minimum economic scale of manufacture and the potential utilization of the material are prime considerations. Most traditional building materials, like wood and bricks, can be produced locally on a small scale for immediate and local use. The use of these traditional materials, however, is largely dependent on the existing local building trades and contractors. For example, a brick industry was started in the Territory of Papua and New Guinea, largely as a result of the abundant clay deposits there. The industry has not been able to grow, however, because there are not enough bricklayers in the Territory to lay the bricks already being produced.⁶ In other words, the existing building skills in developing regions must be assessed before the suitability of introducing a traditional building material can be judged.

The regional customs or practices relating to building can also be important in judging the suitability of a building material. In East Africa, for example, building constructors commonly manufacture their own building materials (cement blocks, for example) for each job.⁷ Hence, the introduction of a building material which must be produced on a large scale is not impossible in such a situation, but a building material economically produce-

able on a small scale would be much more likely to win quick acceptance.

Many traditional building materials, however, have inherent diseconomies because of their size, shape, placement, or other inherent properties. Bricks, for example, while relatively easy and cheap to produce, are prohibitively expensive to transport, owing to their low value: weight ratio. They are, in addition, relatively costly to put in place. Other traditional building materials--such as unsawn timber, uncut stone, mud, thatch, etc.--do not usually produce dwellings comparable in quality, durability, and appearance to dwellings made with modern building materials. Consequently, modern building materials are usually desired by peoples of developing regions as a matter of social preference. Various such disadvantages of traditional building materials are part of the reason for the growing use of modern building systems and related materials in developing regions.

C.2.b Modern Building Systems and Materials

Where construction activity or needs are of sufficiently large scale, various types of modern building systems and materials can offer significant economies of both cost and time over traditional building materials. For the construction of dwellings, in particular, efficient

building systems have been developed based on the use of building materials which are cheap, serviceable, and easily assembled. The general properties sought in building materials for use in modern building systems are these:

- (1) The building material should, if possible, be made of locally available raw materials;
- (2) The building materials must be cheap to produce;
- (3) The materials must be easy and economical to use in actual construction, whether used by professional builders or by an individual building his own house;
- (4) The materials should be serviceable in all types of small buildings, and should be as adaptable as possible to use in all parts of the building (floors, walls, roofs);
- (5) The materials must meet minimum structural and health requirements, and also any special climatic conditions.

The use and development of such building materials for use in modern building systems is currently grouped around three major approaches to building systems.

The first approach used in modern building systems is based on the use of relatively small, lightweight modular panels, such as the common 4 feet by 8 feet plywood and

particle board panels. Such panels offer considerable economies of placement over ordinary sawnwood when used as exterior cladding, interior finishing, roofing, and flooring in wood-frame or masonry-type construction. These panels are relatively easy to transport and store, especially when compared with bricks, stone, and tiles. Their placement, moreover, does not require a great deal of skill or training. These panels also have sufficient strength to form a lightweight integrated structural unit with a wood-framing system. Bagasse particle boards, in particular, may be produced with a variety of surface applications which require no further finishing for either exterior or interior use and virtually no maintenance after placement. Panels of both plywood and bagasse are, however, combustible, and their use in urban areas of high density must show reasonable regard to fire safety standards.

A second approach to building systems for the construction of dwellings, including but not limited to one- and two-storey dwellings, is based on the use of large panels and slabs. In this system, large panels and slabs up to dimensions of 8 feet by 30 feet are prefabricated from concrete or lightweight panels such as bagasse particle board. Such panels are then assembled on-site as walls, floors, and roofs of the dwelling. Such a

system offers the potential economies of off-site (presumably in-factory) fabrication and reduced on-site labor costs. As a United Nations Study Group⁸ has pointed out, however, these advantages must be weighed against such potential disadvantages as the following:

- (1) The production, transport, and erection of such panels is usually difficult and often costly owing to their large size.
- (2) The considerable weight of such panels necessitates the use of heavy moving and lifting equipment, both in the plant and on site, and such equipment may be very difficult and/or costly to obtain.
- (3) Damage of these panels due to mishandling could be frequent and would be difficult and costly to repair.

A third building systems approach to the construction of dwellings in developing regions is the use of prefabricated, three-dimensional, modular "box" units which are structurally complete. Such units are typically made off-site in large numbers and placed on site individually or in various combinations of juxtaposition and stacking. Boxes of this type are typically made of concrete, but considerable interest has been shown in the use of plastics, typically in foam-filled structural sandwiches. In

evaluating this system of building, the same United Nations Study Group cited above observed:⁹

...Under the present conditions in developing countries there are only very limited applications for this system. The main reservations were with respect to the unwieldiness of these units in delivery and positioning on the site (except when used in large-scale urban developments). The Group believed that this recently developed prefabrication technology might be applicable in the future in developing countries.

Some building materials are versatile and can also be used in a diversity of applications other than direct construction. The local manufacture of such building materials may produce significant secondary economic effects which must also enter into a comparison of building materials. The manufacture of wood and other natural-fiber products, such as bagasse boards, may lead to significant secondary economic benefits on the local level. Furniture industries, in particular, are likely to be encouraged or greatly aided by the local production of sawnwood or particle board. Good quality bagasse particle board may be easily veneered with various types of plastic to form a durable, attractive laminate for use in furniture, cabinets, shelving, bathroom and kitchen finishing, and similar items.

In summary, then, one of the most promising of the modern building systems--at least in the context of the conditions prevailing in the developing countries--is that based on the use of lightweight modular panels such as

bagasse particle boards. Such panels offer relative ease of transport, storage, placement, finishing, and maintenance, in addition to considerable structural strength. While such panels are combustible and must be used under the ordinary restraints imposed by fire safety standards, their overall performance is adequate to qualify them as a permanent, primary, structural building material. Such panels appear to be highly suitable for use in the construction of one- and two-storey dwellings of the type commonly desired in developing countries. In addition, bagasse particle boards have considerable secondary uses in the manufacture of furniture and other interior finishings.

C.3 Economic Comparison of Building Materials Manufacture

The establishment of the production of traditional or modern building materials in developing countries must be evaluated not only on the technical considerations described above, but also on economic considerations. Among the more important economic considerations in evaluating building materials are the capital costs incurred in establishing manufacture and the operating costs of maintaining production.

C.3.a Capital Costs of Establishing Manufacture

Table II-6 gives the approximate minimum capital costs of establishing various types of building materials manufacture. On the basis of the minimum capital costs necessary to begin production, strong advantages over other building materials are held by bricks, wood products, and fiber products. The commencement of cement (rotary kiln), steel, and aluminum manufacture requires large amounts of capital investment even at the lowest levels of production. Within this diversity of capital requirements, the small-scale manufacture of bagasse particle board represents a sizeable capital investment, but one which is nonetheless at the lower end of the range of possible investments in modern building materials production. Large-scale production of bagasse particle boards may require overall investments approaching \$10 million, but similar increases in investment costs can also be expected for the large-scale production of other modern building materials.

C.3.b. Labor and Other Costs of Manufacturing

The adaptability of the production of modern building materials to labor-intensive methods or to methods not requiring large numbers of highly skilled workers is of special concern to developing countries. The degree of labor intensity or skill concentration required in any manufacturing operation will depend on many factors, in-

cluding available capital, local labor costs, the dependence of efficiency on mechanization, etc. Some indication of typical labor costs and the ratios of skilled workers required for the production of common modern building materials is given in Table II-7, which is based on data gathered from building materials industries in India. Wage levels and ratios of skilled workers required are relatively low for brickmaking, sawmilling, and the production of plywood; the production of particle board, while not listed specifically, may be assumed to have cost and skill requirements very close to those for plywood production. The production of cement incurs higher but still moderate labor costs and skill requirements; steel and nonferrous primary metal products are at the top and of the spectrum for both labor costs and skill requirements.

If these figures are typical for developing countries, it would then appear that labor costs and skill requirements for building materials production are proportional to the relative capital costs necessary to establish production, as shown in Table II-6. The energy and overall fuel consumption costs of these industries also follow such a relationship, ranging from relatively modest requirements for a sawmill to the consumption of enormous amounts of electrical energy and fuels by the steel and nonferrous metal industries. Thus, if administrative

and depreciation costs are assumed to be equal for these industries, the total operating costs and capital costs of production for the various modern building materials parallels the order of costs shown in Tables II-6 and II-7.

Thus, the total costs--including both capital and operating costs--incurred in the production of bagasse particle board are relatively moderate and occupy a low-to-medium position in the range of costs incurred in the manufacture of the various modern building materials.

D. Consumption of Wood and Fiber Panels

The world-wide production and consumption of wood and fiber based panels has grown rapidly in the last two decades. Among these types of building materials, the consumption of particle board has grown most rapidly of all the types of panels. Figure II-4 shows the consumption of all wood and fiber panels as a function of per capita Gross Domestic Product for the various regions of the world in 1955, 1960, and 1965. Figure II-5 shows the growth of the consumption of particle boards in these regions for the same period. By comparison, the consumption levels for plywood and fiber board (hardboard and softboard) are shown in Figures II-6 and II-7. These figures clearly indicate the rapid rate of increase of the share of the total wood and fiber panel consumption which is being

captured by particle boards.

In analyzing the consumption levels for wood and fiber panels in numerous countries from 1950-60, the United Nations reports the following relationship between per capita consumption and per capita Gross National Product:¹⁰

For nearly all countries in the group, a reasonably good linear relationship could be obtained between the logarithm of per capita consumption and the logarithm of per capita GNP...A striking characteristic was that there seemed to be no effect of income level on the apparent income elasticity. In other words, the relationship between the changes in consumption and the changes in GNP appeared independent of the magnitude of per capita income. This phenomenon is not common to many products.

The regression analysis of wood and fiber panel consumption referred to above yielded the following equation:¹¹

$$\log (10y) = 1.51 \log x - 2.26 \quad (\text{Equation II-1})$$

where y = per capita national consumption of wood and fiber panels in kilograms (for most panels, 1 kg per capita = 1 m³/1000 persons)

x = per capita Gross Domestic Product in US\$

Equation II-1 for per capita consumption as a function of per capita GDP is based on data gathered from 25 regional surveys in 1961 and was adequate to explain 85% of variances in the data base. The above relationship is graphed in Figure II-8 ; reference to Figure II-4 will show the close correlation of per capita consumption predicted by the U.N. equation with actual per capita consumption.

The proportion of the total demand for wood and fiber

panels which can be captured by bagasse particle boards is, of course, dependent on many factors, the most important of which are the relative quality and cost of the bagasse board. A high-quality, exterior-grade bagasse particle board may reasonably be expected to capture a sizeable portion of the total market if it is competitive with or superior to plywood in durability and price. In Jamaica, for example, locally-produced bagasse particle boards have completely replaced "form-ply," a type of plywood used in formwork for concrete construction, and has largely replaced plywood in other general construction uses.¹² Current annual consumption of particle board--all of which is locally produced--is approximately 6 kg per capita (6 m³ per 1000 persons). This compares very favorably with the 6.5 kg per capita (or 6.5 m³ per 1000 persons) total demand for wood and fiber panels indicated in Figure II-8 , assuming a per capita GDP of \$470 (in 1966). Such complete market penetration clearly represents the upper limit to particle board consumption which may be expected in any given country. At the same time, the U.N. regression analysis equation for the total demand for wood and fiber panels, in conjunction with a reasonable assessment of market penetrability, will give an indication of the ready domestic demand for high-quality particle boards.

<u>CANE VARIETY</u>	<u>FIBER LENGTH (mm)</u>		<u>ASPECT RATIO (length/diameter)</u>	
	<u>PITH</u>	<u>FIBER</u>	<u>PITH</u>	<u>FIBER</u>
44-3098	0.37	1.34	4.6	70.5
37-1933	0.26	1.82	3.3	79.1
38-2915	0.36	1.24	6.3	59.0
32-8560	0.39	1.22	4.6	67.8

TABLE II-1: FIBER LENGTHS AND ASPECT RATIOS OF PITH AND
FIBER COMPONENTS OF FOUR VARIETIES OF HAWAIIAN
BAGASSE

Source: A. C. Barnes, The Sugar Cane, page 369.

<u>TYPE OF FIBER</u>	<u>FIBER LENGTH</u> (mm)	<u>ASPECT RATIO</u> (length/diameter)
Bagasse	1.5	70
Wheat, rye, oat	1.5	110
Rice straw	1.4	170
White Spruce	3.5	120
White Pine	3.5	100
Douglas Fir	5.0	100
Aspen	1.3	56
Birch	1.2	36

TABLE II-2: FIBER LENGTHS AND ASPECT RATIOS FOR
SELECTED NATURAL FIBERS

Source: J. Paturau, By-Products of the Cane Sugar Industry,
page 30.

<u>TYPE OF HARDBOARD</u>	<u>MODULUS OF RUPTURE</u> lbs/in ²	<u>kg/cm²</u>	<u>WATER ABSORPTION</u> (% by weight)	<u>THICKNESS SWELLING</u> (%)
S2S Superior Hard- board, Oil Tempered	6600-7300	470-520	less than 12%	10.5
S2S Standard Hard- board, Untempered	6300-7100	450-500	about 33%	23.0

TABLE II-3: PROPERTIES OF BAGASSE HARDBOARD PRODUCED BY
CHANGHWA FACTORY, TAIWAN SUGAR COMPANY.

Source: H. Tao, "The Manufacture of Fiber Board from Bagasse."

PROPERTY	TYPE OF PARTICLE BOARD					
	<u>BAGASSE</u>	<u>BIRCH-OAK</u>	<u>SPRUCE-PINE</u>	<u>JUTE</u>	<u>HEMP</u>	<u>FLAX</u>
Number of layers	1	3	3	1	1	1
Density (lbs/ft ³)	38	41	41	37	38	37
Thickness of finished board (mm)	19	20	20	19	19	19
Resin content (%)						
Surface layer	8	12	12	8	8	8
Core layer	-	9	8	-	-	-
Modulus of rupture (lbs/in ²)	3100	2900	2350	2150	2450	2700
Tensile strength (lbs/in ²)	90	73	74	77	59	58
Swelling after two hours' immersion (%)	6.1	6.8	9.8	11.2	8.0	6.4
Screw holding (lbs) (4 mm screw at depth of 20 mm)	135	129	218	98	-	198

TABLE II-4: COMPARISON OF PROPERTIES OF VARIOUS PARTICLE BOARDS

Source: Langreny and Hogot, "The Bagapan Particle Board."

<u>COUNTRY</u>	<u>TYPE OF HOUSING PROPOSED</u>	<u>SUGGESTED BUILDING MATERIAL</u>	<u>TOTAL FLOOR AREA (ft²)</u>
Pakistan	One-storey with central courtyard	permanent	275
India	One-storey semi-detached	brick	250-480
India	Village house	mud, thatch	500
Hong Kong	5-6 storey tenement	concrete	120
Hong Kong	11-storey flats	concrete	413
Singapore	Semi-urban small dwelling	timber	530
Kenya	2-storey dwelling	permanent	960
Tanganyika	1-storey dwelling	semi-permanent	1000
Uganda	1-storey detached	semi-permanent	1000
Zanzibar	1-storey house	semi-permanent	660
South Africa	Detached house	permanent	650
West Indies	1-storey detached	timber	500
Latin America	1-storey rural detached house	-	684

TABLE II-5: TYPES OF CONSTRUCTION RECOMMENDED BY VARIOUS
GOVERNMENTS AND REGIONAL AGENCIES FOR LOW-COST
HOUSING PROGRAMS.

Source: Inter-African Conference on Housing and Urbanization,
Housing and Urbanization, pages 151-153.

<u>Building Material</u>	<u>Capital Cost per ton/year Capacity (US\$)</u>	<u>Minimum Plant Size (tons/year)</u>	<u>Capital Costs for Minimum Plant (US\$)</u>
Bricks	variable*	variable*	variable*
Wood:			
Sawnwood	30	variable*	variable*
Plywood ¹	150	10,000	1,500,000
Fiber Products:			
Softboard ¹	125	5,000	625,000
Hardboard ¹	150	10,000	1,500,000
Particle board ²	200	10,000	2,000,000
Cement:			
Vertical kiln ³	35	30,000	1,050,000
Rotary kiln ⁴	50	100,000	5,000,000
Aluminum ⁵	900	10,000	9,000,000
Steel ⁶	250	100,000	25,000,000

TABLE II-6: MINIMUM CAPITAL COSTS AND SCALES OF PRODUCTION FOR VARIOUS MODERN BUILDING MATERIALS

See page 62 for notes.

Notes:

- * May be economically conducted at the village or district level.
- ¹C. Heritage, "The Role of the Forest Products Industry in Economic Development."
- ²J. Paturau, By-Products of the Cane Sugar Industry, page 38.
- ³H. Lafuma, "Le Problème de la Cimenterie au Régard des Besoins de la Construction dans les Pays en Voie de Développement."
- ⁴S. Gottlieb, "New Vertical Kiln Process for Cement Manufacture."
- ⁵J. Ribadeau-Dumas, "l'Industrie de l'Aluminium dans la République Fédérale de Cameroun."
- ⁶Hyde, Old, and Pepper, "Direct Reduction of Iron and Steel in the Less Developed Areas."

TABLE II-6 (continued): MINIMUM CAPITAL COSTS AND SCALES OF PRODUCTION FOR VARIOUS MODERN BUILDING MATERIALS.

<u>Building Material</u>	<u>Average Daily Wage</u>		<u>Ratio Skilled Workers to Total Employment (R_s)</u>	<u>Weighted Labor Cost $W_s R_s + W_u (1 - R_s)$</u>
	<u>Skilled (W_s)</u>	<u>Unskilled (W_u)</u>		
Bricks, Tiles, Lime	\$.51	\$.26	0.284	\$.330
Plywood	\$.71	\$.16	0.384	\$.372
Asbestos Products	\$.56	\$.325	0.444	\$.429
Sawmilling	\$.56	\$.345	0.412	\$.432
Cement Pipes	\$.86	\$.33	0.262	\$.469
Secondary Nonferrous Metal Products	\$.58	\$.35	0.570	\$.481
Secondary Steel Products	\$.65	\$.36	0.480	\$.499
Cement	\$.76	\$.325	0.433	\$.514
Primary Nonferrous Metal Products	\$.78	\$.375	0.499	\$.578
Primary Steel Products	\$.82	\$.39	0.529	\$.618

TABLE II-7: LABOR COSTS AND PROPORTIONS IN BUILDING MATERIALS MANUFACTURE IN INDIA

(Partial Data Source: J. Bhagwati and R. Bharadwaj, "Human Capital and the Indian Pattern of Foreign Trade.")

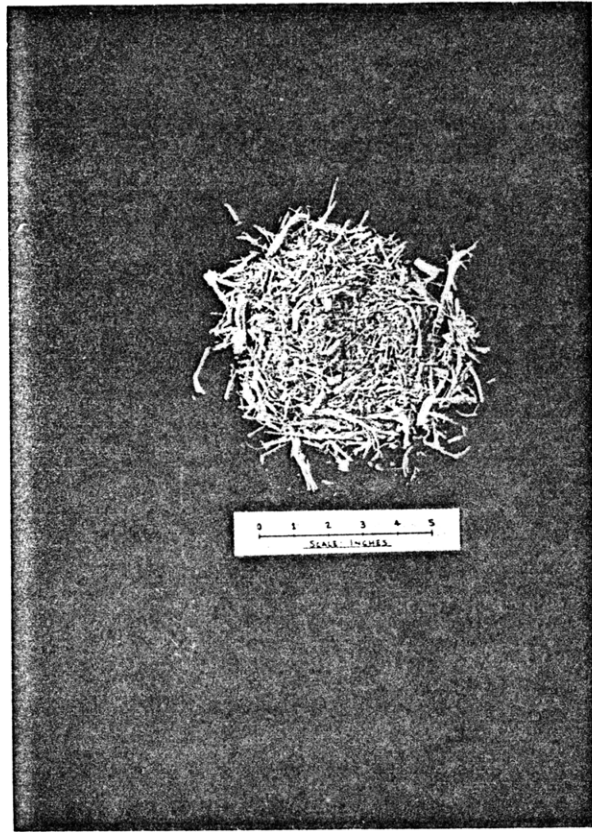


FIGURE II-1a: BAGASSE SAMPLE, TAKEN FROM WAIALUA SUGAR
COMPANY, OAHU, HAWAII.

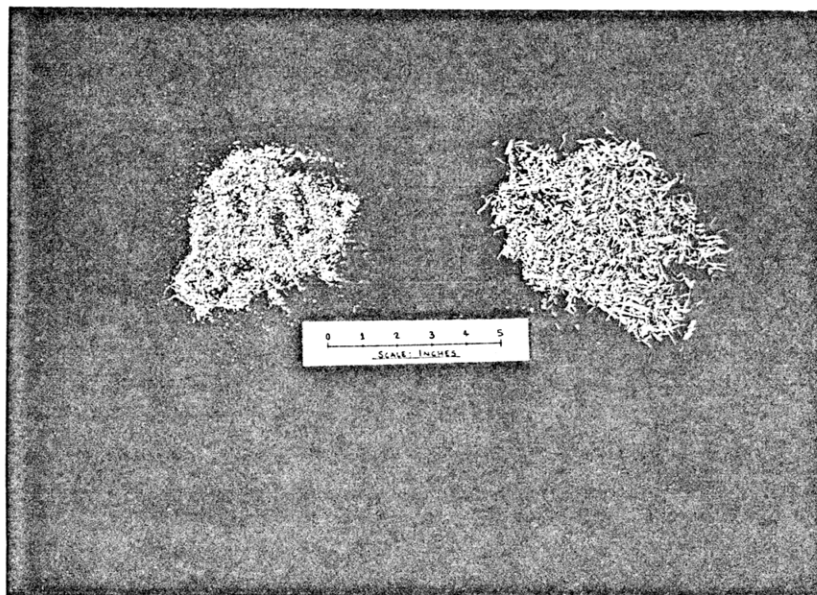


FIGURE II-1b: PITH (LEFT) AND FIBER (RIGHT) COMPONENTS
OF BAGASSE SAMPLE SHOWN IN FIGURE II-1a.

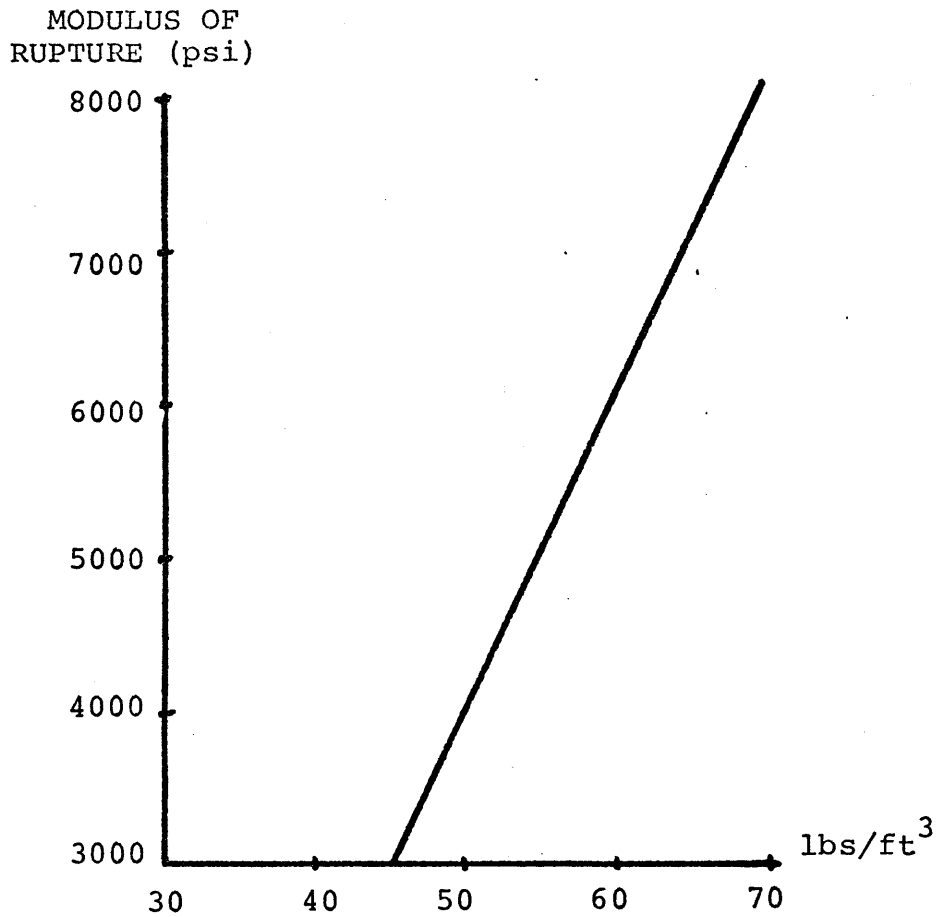


FIGURE II-2: EFFECT OF DENSITY ON MODULUS OF RUPTURE OF BAGASSE HARDBOARD.

Source: H. Wu. "The Manufacture of Hardboard from Bagasse."

CONSTRUCTION COSTS
(Rupees/ft²)

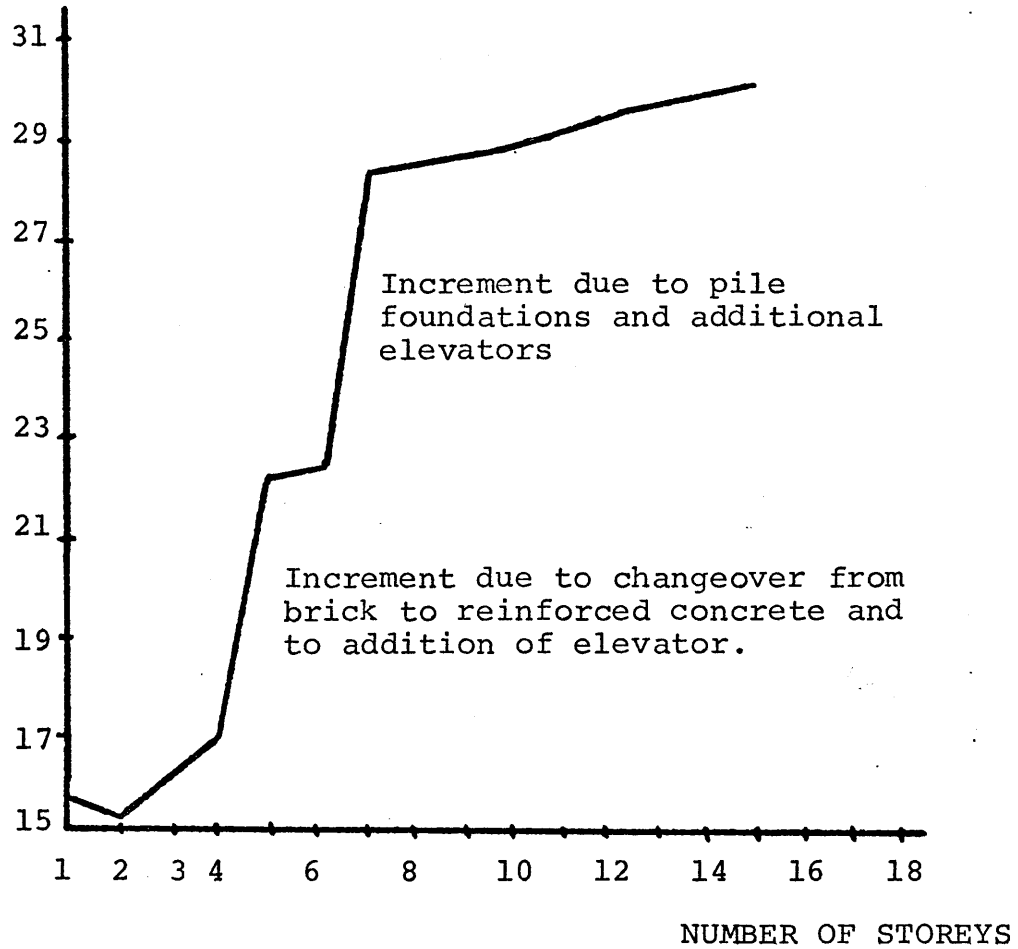
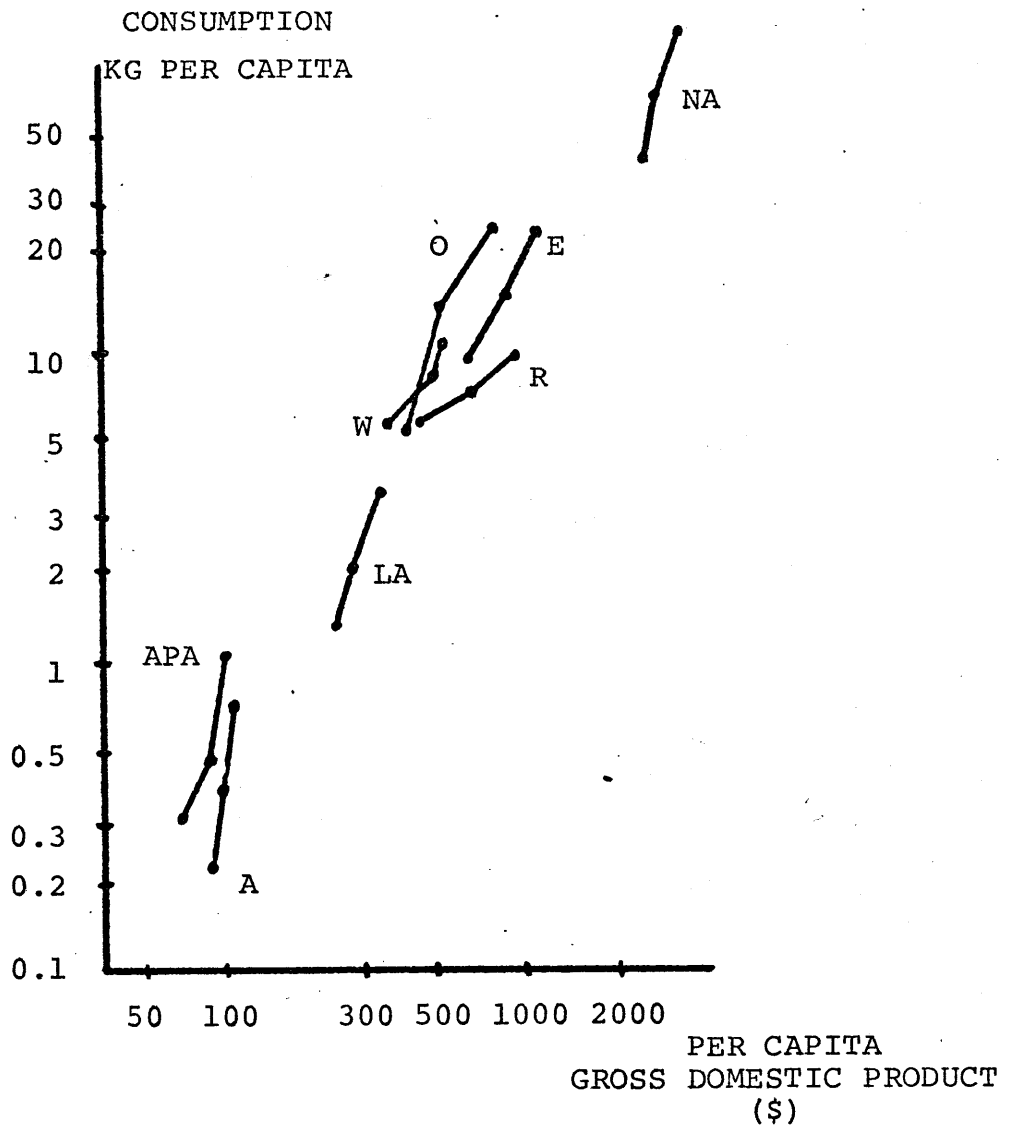


FIGURE II-3: CONSTRUCTION COSTS PER FT² vs. NUMBER OF STOREYS IN LOW COST HOUSING (INDIA).

Source: United Nations Economic Commission for Asia and the Far East, Economic Factors in Multi-storey Construction -- A Case Study.



- W = World
- NA = North America
- LA = Latin America
- R = U.S.S.R.
- A = Africa
- E = Europe
- APA = Asia and Pacific Area
- O = South Africa, Australia, New Zealand, Japan

FIGURE II-4: CONSUMPTION OF WOOD AND FIBER PANELS BY WORLD REGIONS 1955-60-65.

Source: United Nations, 1968 Yearbook of Forest Products.

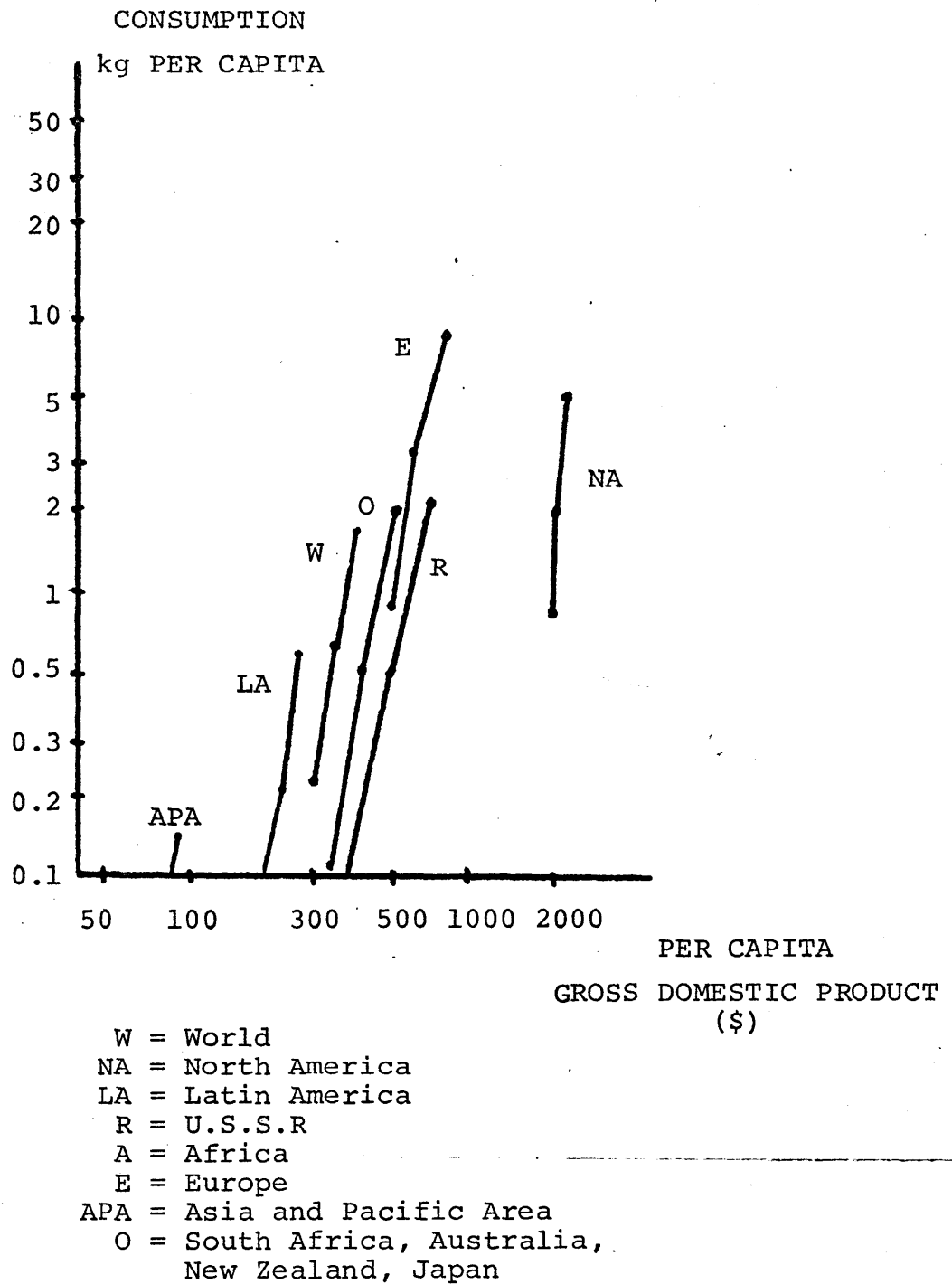


FIGURE II-5: CONSUMPTION OF PARTICLE BOARD BY WORLD REGIONS
1955-60-65.

Source: United Nations, 1968 Yearbook of Forest Products.

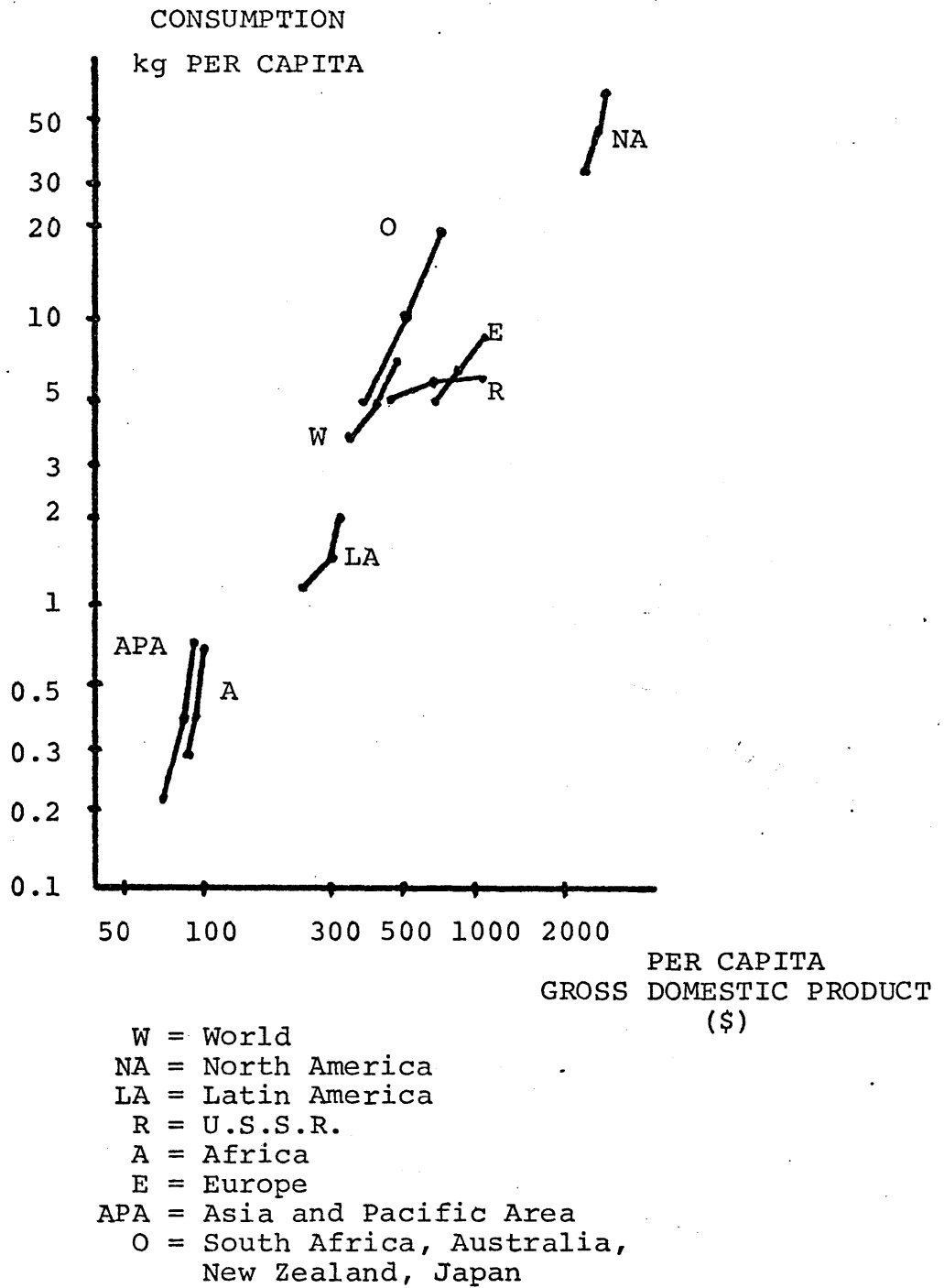


FIGURE II-6: CONSUMPTION OF PLYWOOD BY WORLD REGIONS
1955-60-65.

Source: United Nations, 1968 Yearbook of Forest Products.

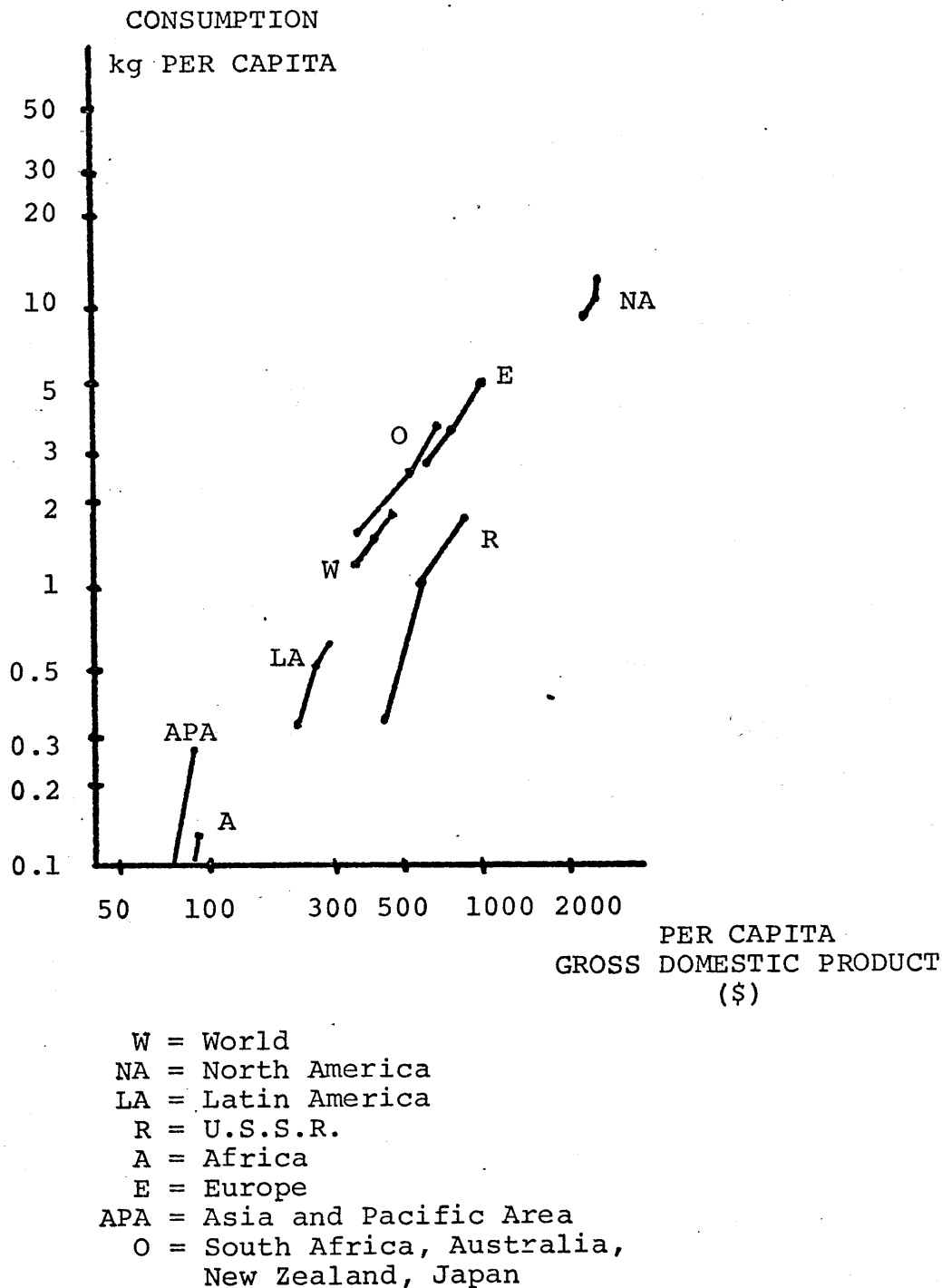


FIGURE II-7: CONSUMPTION OF FIBERBOARD (HARDBOARD AND SOFT-BOARD) BY WORLD REGIONS 1955-60-65.

Source: United Nations, 1968 Yearbook of Forest Products.

y = consumption
kg per capita or m³/1000 people

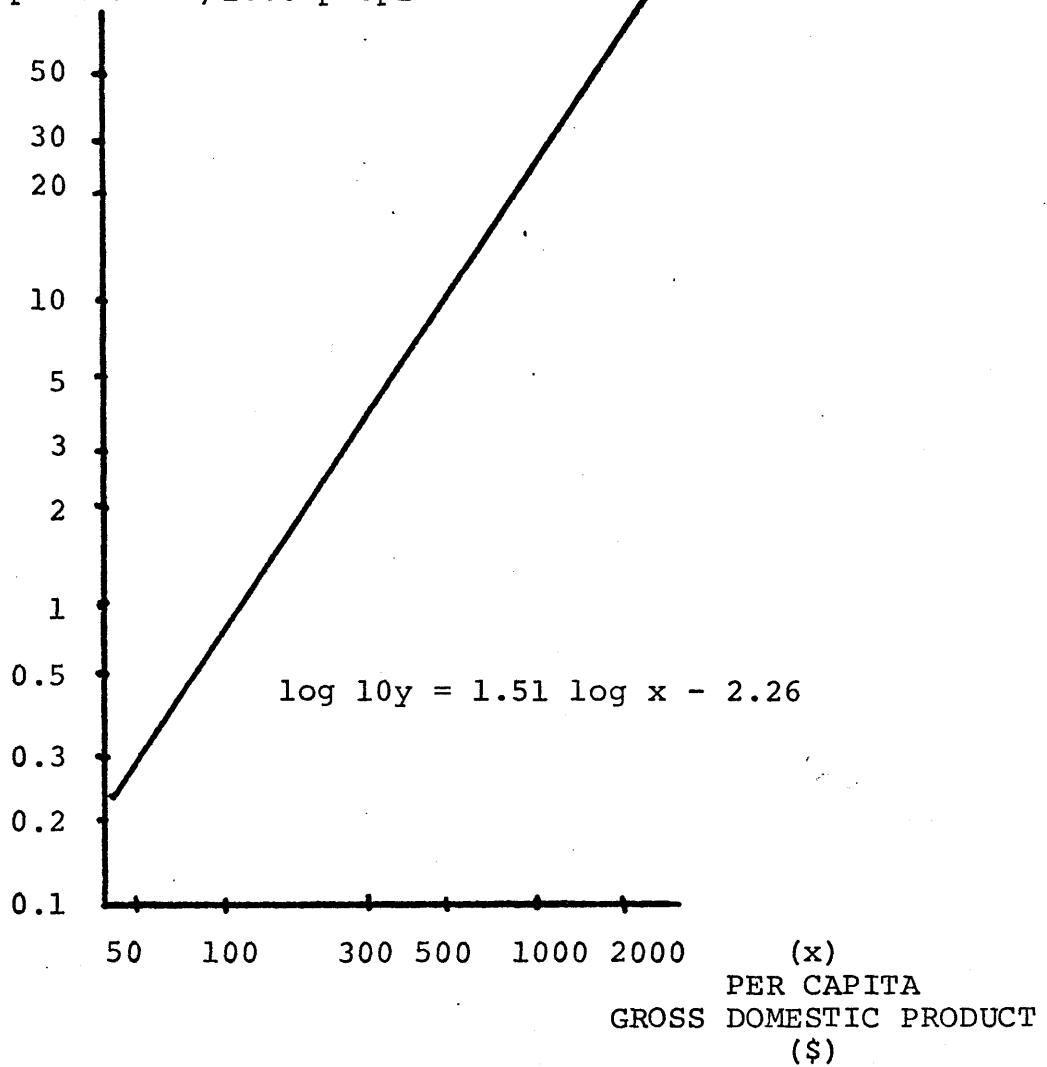


FIGURE II-8: PER CAPITA CONSUMPTION OF WOOD AND FIBER PANELS AS A FUNCTION OF PER CAPITA GROSS DOMESTIC PRODUCT, BY REGRESSION ANALYSIS.

Equation Source: United Nations, Building Materials Industry, pages 18-20.

NOTES -- SECTION II

- ¹J. Paturau, By-Products of the Cane Sugar Industry, page 25.
- ²Ibid., page 29.
- ³A. Barnes, The Sugar Cane, page 369.
- ⁴J. Paturau, op. cit., page 26.
- ⁵H. Tao, "The Manufacture of Fiber Board from Bagasse."
- ⁶G. Moss, "Building Materials in the Territory of Papua and New Guinea."
- ⁷D. Pearson, Industrial Development in East Africa, page 139.
- ⁸United Nations Industrial Development Organization, Production Techniques for the Use of Wood in Housing Under Conditions Prevailing in Developing Countries, page 25.
- ⁹Ibid., pages 25-26.
- ¹⁰United Nations Industrial Development Organization, Building Materials Industry, page 18.
- ¹¹Ibid., page 21.
- ¹²K. Ruckstuhl, personal communication, March 1972.

III. BAGASSE PARTICLE BOARD PRODUCTION SYSTEM

The purpose of this section is to provide a detailed examination of the possible systems for the production of bagasse particle board. This section contains the technical and economic information on which the Investment Analysis of Section IV is largely based. This study of bagasse particle board production is divided into five operational areas: A. Obtaining Bagasse from Sugar Mills; B. Fiber Storage and Handling; C. Fiber Preparation; D. Mixing, Pressing, and Finishing; and E. Administrative and Other Functions. The basic functions in bagasse particle board production may be sequentially related in one of two possible ways, shown by Path 1 and Path 2 in Figure III-1. The discussion in this section includes both possible sequences.

A. Obtaining Bagasse from Sugar Mills

To undertake the production of bagasse particle board, it is essential that an adequate supply of suitable bagasse be obtainable at reasonable cost. Since the bagasse is likely to be obtained from one or more sugar mills located relatively near the bagasse board plant, the characteristics of each sugar mill operating system will determine the suitability and the cost of the bagasse to be used in the board. For the general reader unfamiliar with the cane

sugar industry, the Appendix to this thesis on the Sugar Mill Operating System discusses in detail the operation of a cane sugar mill, with particular reference to those aspects which bear directly on the characteristics and costs of bagasse produced by sugar mills. For the purposes of this present discussion, it is sufficient to mention the principal points to be considered in obtaining bagasse for particle board production.

The physical characteristics of bagasse are in large part determined by the methods of harvesting and milling the sugar cane from which the bagasse is made. Bagasse made from harvested cane which contains large amounts of silt or clay, as often found with mechanized harvesting methods, will also generally have high levels of clay or silt. The removal of such impurities is usually possible, but at some added cost. A persisting discoloration due to fine clay particles may be found, however, and bagasse with such a "tint" may be unsuitable for use in particle board. Bagasse which contains carbonized matter left from partially burnt trash is particularly objectionable, since it results in the discoloration of the particle board in the form of small but visible carbon specks. Such carbonized impurities, moreover, are virtually impossible to remove from bagasse. Other impurities in bagasse include unextracted sugar. Reasonable levels of unextracted sugar -- up to about 5% -- do not ordinarily

interfere with particle board production.

Bagasse of virtually any degree of coarseness may be used in particle board manufacture, but in general the finer the bagasse arriving from the mill, the less difficult and more uniform is the depithing process at the board plant. The coarseness of the bagasse is determined by the milling pressure, the milling rate, the condition of the roller mills, and other factors. As a result of the progressive wearing of the milling equipment during the course of the milling season, the coarseness of the bagasse can be expected to increase as the milling season progresses. Normal equipment wear, however, will not usually affect the suitability of the bagasse produced. In general, bagasse from any sugar mill with normal operations will be an acceptable raw material for particle board manufacture.

Since bagasse is almost universally used as a fuel in the bagasse-fired boilers of sugar mills, its release for use in particle board production must be made possible by effecting significant changes in the sugar mill operating system. Two major modes of change are possible. First, a mill or group of mills may be able to reduce considerably their own bagasse requirements by improving their overall thermal efficiencies. Mills at high levels of thermal efficiency may be able to supply a surplus of bagasse adequate to meet the needs of a bagasse particle board plant.

Alternatively, the second method of releasing bagasse is the burning of supplemental or alternate fuels in the boilers of the sugar mill or mills. This strategy involves either the conversion of the existing bagasse furnace to accept supplemental fuels, or the outright replacement of the bagasse furnace with a furnace which accepts only the alternate fuel. The capital and operating costs incurred in such conversions, or in programs to improve mill thermal efficiency, will be the principal determinants in the cost of the bagasse used by the particle board plant. (See Part E of the Appendix for a discussion of this cost determination.)

Another consideration in the bagasse supply is the length of the milling season of the sugar mill supplying the bagasse, compared to the length of the production season planned for the bagasse board plant. Typically, the particle board plant will operate year-round, while the sugar mill may operate only six months per year or less. Bagasse must therefore be available in sufficient quantities to be stored for the year-round operation of the board plant.

Under most conditions, the cost of the bagasse will be about \$3 to \$5 per ton, fresh basis, or \$6 to \$10 per ton, dry basis, at the sugar mill. Transport of the bagasse to the board plant, plus a profit margin for the cooperating sugar mill, will usually raise the final cost to \$7 to \$12 per ton, dry basis, at the board plant. On the basis of a

25% (by weight) fiber extraction from the bagasse, as explained below under Fiber Storage and Handling, the cost of bagasse fibers as a raw material becomes \$14 to \$24 per ton, not including processing and preparation costs.

B. Fiber Storage and Handling

The production of bagasse particle boards requires the handling and storage of large amounts of bagasse fibers. The storage requirement is clearly significant, for example, when the year-round operation of a board plant is to be based on bagasse produced during a short cane-milling season. The storage capacity required under such conditions may easily reach 30,000 tons of bagasse, dry basis, or 15,000 tons of prepared fiber. Reference to Figure III-1 reveals that the storage of bagasse fibers may either precede (Path 1) or follow (Path 2) the depithing operation in fiber preparation. As a result, the costs and requirements for storage of bagasse fibers will vary significantly according to the production sequence followed.

Since the moisture, fiber, and pith fractions in bagasse may vary considerably from region to region or mill to mill, it will prove useful to base further discussions of the quantities and costs relating to this raw material on a bone dry fiber (BDF) quantity basis. In general, one ton of fresh bagasse contains about 50% moisture, 35% fibers,

12% pith, and 3% soluble solids, by weight, as previously discussed in Part II.A of this thesis. Taking into account fiber losses due to decay, handling, and depithing, one can reasonably expect a yield of about 25% BDF, by weight, from one ton of fresh bagasse. One ton of BDF therefore requires an average of 4 tons of fresh bagasse. A more accurate determination of BDF yield must be made on the basis of local conditions.

B.1 Fiber Storage Before Depithing (Path 1)

There are three methods of storing unprocessed bagasse in current use. The first two methods discussed below are based on the bulk storage of fresh bagasse. The third method requires the compression of bagasse into bales prior to storage.

B.1.a Simple Bulk Storage

Under most climatic conditions, bagasse cannot be kept in unprotected storage areas, since it will ferment and decay, thereby causing damage to the bagasse fibers and also reducing considerably the fuel value of the bagasse. Hugot¹ reports, however, that bagasse may be safely stored in the open in very dry climates. He recommends that the tops of bagasse bulk storage piles be provided with a thatch cover made from cane leaves, in case rain should occur.

The principal requirement of this storage method is a large storage area, as bagasse is a material with a low bulk density. Stacked bagasse with a moisture content of 45% will have a bulk density in the range of 10-15 lbs/ft³; dry bagasse will be about half this value, or 5-8 lbs/ft³. One ton of dry bagasse will therefore require about 350 ft³ of storage space. The storage requirements for 30,000 tons of dry bagasse, or 15,000 tons of BDF, are then 30,000 tons X 350 ft³/ton = 10,500,000 ft³. If the bagasse is stored in piles with a mean height of 40 feet, for example, then the total storage area needed becomes 10,500,000 ft³ ÷ 40 ft = 262,500 ft², or about 6 acres. Thus in the simple bulk storage of bagasse, 5000 tons of dry bagasse, or about 2500 tons BDF, will require about one acre of land.

The transfer of bagasse into and out of this bulk storage area must be accomplished by means of mechanized equipment such as front-end loaders and trucks or railroad cars. If the bagasse is stored in bulk at the particle board plant (the bulk storage of at least some bagasse will be inevitable), additional equipment such as heavy conveyor systems and metering stations will be required. Figure III-2 shows a typical installation of this sort in a bulk storage area normally containing about 3000 tons of dry bagasse, or 1500 tons of BDF.

One potential danger associated with the open storage

of loose bagasse, or with any handling operation which creates bagasse dust, is the health hazard related to the disease bagassosis. Workers who are exposed to prolonged inhalation of bagasse dust may contract a lung disease which is similar to silicosis in effect. Hence, in the open storage and other handling of bagasse, care must be taken to avoid the creation of bagasse dust. In addition, the open storage of bagasse in windy areas will generally result in the blowing about of large numbers of bagasse particles. These wind-borne particles are a definite hazard to the eyes and are a general nuisance to employees and adjacent properties. Covering of the bagasse storage piles may be advisable or necessary, as a result, during windy periods.

B.1.b Bulk Storage with Preservatives -- the "Ritter Method"

As mentioned previously, the simple bulk storage of bagasse is not usually feasible or desirable, except in dry climates. To allow the bulk storage of bagasse in normal or wet climates, a system was devised by Ritter in South Africa whereby bulk piles of bagasse are continually sprayed with a biological liquor which prevents the decay of the bagasse. The spray liquor, consisting mainly of lactic-acid producing bacteria in a nutritive molasses medium, prevents the growth of micro-organisms which would cause fiber deter-

ioration.

In this system, which is illustrated in Figure III-3, fresh bagasse or partially-depithed bagasse is mixed with the biological liquor and conveyed to a large concrete slab which constitutes the storage area. This slab has several parallel channels which permit the drainage and recirculation of the biological liquor. The removal of the bagasse from the storage area may be accomplished by means of flumes built into the concrete slab or by the ordinary mechanical systems used for the bulk transfer of bagasse. The advantages of the Ritter method are claimed to be the following:

- (1) Labor and handling costs are lower than in the baling of bagasse.
- (2) Dust problems and the potential danger of bagassosis are eliminated.
- (3) The quality of the bagasse stored by this method is excellent.

The cost of the Ritter method of storage is approximately \$3 per ton of dry bagasse, or \$6 per ton of BDF, not including land and major capital equipment costs.² The storage area requirements of this method are similar to those for the simple bulk storage of bagasse, with the exception that stack heights of 75-80 feet are reported as common in highly mechanized operations. Thus, one acre of storage area in a highly mechanized Ritter method operation

can accomodate about 10,000 tons of dry bagasse, or about 5000 tons of BDF.

B.l.c Baling

Fresh bagasse may also be baled in a special press which resembles an enlarged and reinforced hay baler. The bagasse is pressed into bales 12 inches by 12 inches by 24 inches or 18 inches by 24 inches by 24 inches, on the average, which are then tied with two or three baling wires. The bagasse bales are then stacked on clean, high, and well-drained areas in such a way as to allow for the circulation of air through the stacks to remove the moisture in the bales. These stacks must be protected from exposure to rain by being covered with asbestos sheets or galvanized-steel sheets dipped in asphalt.

Typical bagasse bale stacks are approximately 30 feet high. One ton of dry bagasse stored by this method requires about 720 ft^3 of space,³ so that $720 \text{ ft}^3 \div 30 \text{ ft} = 24 \text{ ft}^2$ of area are required for one ton of baled dry bagasse. On this basis, one acre can accomodate slightly less than 2000 tons of dry baled bagasse, or about 1000 tons of BDF.

The operating costs incurred in baling bagasse are approximately \$15-\$20 per ton BDF. Capital investment costs for a baling station for 30,000 tons dry bagasse (15,000 tons of BDF) annual capacity are about \$500,000-\$600,000.

Detailed cost breakdowns for operating and capital investment costs for a bagasse baling station are given in Table III-1.

B.2 Fiber Storage After Depithing (Path 2)

It should be evident that the storage requirements and handling costs for bagasse fibers could be lowered significantly if the bagasse fibers were depithed before storage. This depithing process involves the separation of most of the pith and very small fibers from the true bagasse fibers, leaving relatively clean bagasse fibers for use in particle board (or paper) production. Since one ton of BDF is normally obtained from about two tons of dry bagasse, handling and storage costs for depithed fibers should offer considerable economies. At least three methods for the storage of depithed fibers are in current use, as described below. According to the literature of the field, simple bulk storage of bagasse fibers in the depithed state has not been attempted, probably because of the high bulk density and combustibility of the depithed fibers.

B.2.a Baling of Depithed Fibers

The baling operation for depithed fibers is similar to that for fresh bagasse, except that the bagasse is passed through depithing machines before entering the baling machine. This arrangement is shown in Figure III-4. Keller reports

that savings of about 25% in overall handling and processing costs result from the use of bagasse depithed prior to storage, compared with bagasse depithed after storage.⁴ On this basis, operating costs in the range of \$10-\$15 per ton of BDF can be expected. Storage area requirements will also be reduced by about 50%, so that one ton of baled depithed fibers would require about 360 ft³ of storage space. In this case, one acre will accomodate slightly less than 2000 tons of BDF.

B.2.b Briquetting

Depithed bagasse fibers may be compressed to 1/6 to 1/10 of their loose volume by briquetting machines such as those commonly used for the briquetting of sawdust, peat, metal chips, etc. A highly successful briquetting machine manufactured by SPM (Swiss Precision Machinery) of Basle, Switzerland, is shown in Figure III-5a, and a bagasse briquette produced by one of these machines is shown in Figure III-5b. Bagasse briquettes such as the one in Figure III-5b may be produced in densities ranging from 40-70 lbs/ft³, with resulting bulk densities of 30-40 lbs/ft³. These briquettes are then stored in large enclosures such as the one shown in Figure III-6. The briquette storage building in Figure III-6, for example, contains approximately 1,000,000 ft³ of storage space and has a capacity

in excess of 12,000 tons of depithed bagasse briquettes, or 12,000 tons of BDF.

Operating costs for a SPM briquetting machine of 10,000 tons BDF annual capacity are about \$5.50 per ton of BDF, based on 200 days per year operation. Such a machine also represents an investment of about \$215,000, including conveyors for the briquette transport, but not including the storage building. A detailed breakdown of the operating costs for this unit is given in Table III-2.

B.2.c Matting

Another method of storing bagasse fibers, which has reportedly been successful with bagasse fibers containing as little as 3% pith by weight, involves the pressing of fibers into large mats.⁵ These fiber mats are then stored without binding wires. It has not been possible to obtain details on this method of storage for this study. The system was originally designed for use in the Tablopan de Venezuela board plant operating adjacent to Central El Palmar Sugar Mill in Venezuela.

C. Fiber Preparation

To obtain bagasse fibers suitable for bagasse board manufacture, it is necessary to separate the true fibers from the pith. The pith is objectionable in particle board

because it is highly absorptive and thus increases the amount of binding resin which must be used. At the same time, pith does not contribute to the strength of the board; indeed, pith will seriously impair the strength of the particle board if it is present in levels exceeding 5-7% by weight.

The process whereby true fibers are separated from pith is generally referred to as depithing. The depithing process may be accomplished by any of the three methods which follow:⁶

- (1) Dry depithing methods, involving separation of the pith after the bagasse has dried in storage or has been dried in special-purpose dryers.
- (2) Moist or humid depithing methods, in which the bagasse is depithed as it leaves the sugar mill or at other times when its moisture content has been restored to about 50% by weight.
- (3) Wet depithing methods, which are carried out with the bagasse in a dilute suspension, typically 4%-8% bagasse in water, by weight.

The available machinery for depithing bagasse and their possible arrangements in a depithing operation are discussed below.

C.1 Depithing Machines and Costs

Depithing of bagasse is normally accomplished by beating the bagasse in hammermills or agitators and subsequently or

simultaneously screening the material to allow the pith, dirt, and other fines to separate from the larger bagasse fibers. Four types of depithing machines are currently in use, all of which ordinarily (but not necessarily) employ the simultaneous beating and screening of the bagasse. These machines are the following:

- (1) SPM (Swiss Precision Machinery) Depithing Machines. These machines accept either dry or humid bagasse and are available in a range of sizes. Figure III-7 shows an SPM Depithing Machine, Type 1500E, which is currently depithing in excess of 100 tons of dry bagasse daily, with excellent separation of fiber and fines.
- (2) Horkel Depithers.⁷ These machines were developed by Horton and Keller at Louisiana State University. Horkel depithing machines are available in two types. One type accepts either dry or humid bagasse, and the other type accepts only wet bagasse. Both types are widely used in bagasse fiber preparation for the production of paper pulp and bagasse boards.
- (3) Rietz Mills.⁸ These depithing machines were developed by the Hawaiian Sugar Planters' Association for use with humid or, preferably, wet depithing methods. These depithing machines use rigid hammers in a vertical hammermill.

(4) The Hydrapulper.⁹ This machine is widely used in the preparation of bagasse pulp for paper production; it is a wet method of depithing based on agitation.

Depithing is usually accomplished in two stages. The first stage employs one of the depithing machines described above which serves as the primary depither, in which half or more of the pith and other fines in the bagasse is removed. A second stage depithing is then carried out using either another of the primary depithing machines in sequence or using a special secondary depithing machine. These special secondary depithing machines are known as refiners and include disc-type attrition mills, in addition to modified versions of the primary depithers.

The fiber balance at various stages of depithing is shown in Figure III-8 for the depithing process used at Tablopan de Venezuela. The figure illustrates the quantitative changes in the refinement of bagasse into clean fibers for use in board production.

Investments required for complete depithing machinery vary according to the capacity and type used, but in most cases will range from \$1000-\$1500 per ton of BDF daily capacity, including installation costs. Operating costs for the production of clean, pith-free fiber for use in particle board or paper pulp manufacture, will be approximately \$4-\$5 per ton of BDF.¹⁰

C.2 Depithing Station Arrangements

Several arrangements of primary and secondary depithers or refiners have been used for bagasse particle board production. Other arrangements currently in use for the preparation of paper pulp could also be adapted for use in bagasse board production. Figures III-9 through III-16 show some of the arrangements of bagasse depithing equipment in current use around the world.

The successful operation of bagasse depithing equipment requires a certain level of expertise. In some instances, engineers with experience in wood fiber pulping and preparation may be able to adapt their expertise sufficiently to achieve the successful depithing of bagasse fibers. In many instances where this has been attempted, however, the particular characteristics of bagasse as a raw material have led to unforeseen and often insurmountable difficulties for the personnel involved. The successful depithing of bagasse will therefore ordinarily require personnel with previous experience in depithing bagasse.

D. Mixing, Pressing, and Finishing

Once bagasse fibers have been freed from the pith component of bagasse, they are ready for use in the actual manufacture of bagasse particle boards. The production of bagasse particle boards involves three steps: A. Mixing the

fibers with binding resins and other additives; B. Pressing the mats formed from the fiber-resin mixture; and C. Finishing the pressed boards to standard sizes, thicknesses, and surface smoothnesses.

D.1 Mixing

Depithed bagasse fibers are brought from the storage area or from the depithing station to the mixing station, passing through dryers which ensure a uniform moisture level of 12-16% by weight. Fibers which have been baled, briquetted, or matted must be returned to a free, loose condition by appropriate mechanical processes. The flow of bagasse fibers into the mixing station must be carefully controlled for uniformity and continuity. Special intermediate storage bins are installed to fill in any gaps in the supply of fibers from the depithing station or storage area. The flow of fibers is metered by weight, and the addition of resin binders and other additives is accurately controlled.

The fibers, resin, and additives are mixed in special blending machines. One such blending machine, manufactured by Gebr. Loedige, GmbH., in West Germany, is capable of controlling the addition of the binding resins to within 1% of the weight of the fibers in the mixing area, provided that the flow of fibers into the mixing bin not vary by more than 5% at any one time.

The binding resins used in bagasse particle board are of two types -- urea formaldehyde or phenolic resins. Urea resins are soluble in water both before and after setting, and boards made with urea resins are suitable only for interior uses. Phenolic resins are highly water resistant and produce boards which are suitable for all types of exterior applications. Either resin will typically comprise 8-10% of the final weight of the finished particle board.¹¹ The cost of the resins will vary depending on whether the resins are bought or imported "ready to use," or whether they are made at the board plant from their basic components. Imported ready-to-use resins of either type will cost about \$0.20-\$0.30 per pound under most conditions. If the board plant is equipped to produce its own resins from imported phenol, then the cost of the resin produced at the plant can be lowered to about \$0.15 per pound.¹² A phenolic resin production facility for a 100 tons-per-day board plant will cost about \$500,000 initial capital investment, including the required transfer vehicles and stainless steel storage tanks.¹³

The various fungicides and insecticides added at the mixing station do not require special preparation. They will typically cost about \$3-\$6 per ton of board produced.

D.2 Pressing

Bagasse particle boards may be formed by three processes:

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a. Multiplaten Hot Press Process; b. Continuous Pressing or Bartrev Process; c. Extrusion Process. Figure III-17 shows a flow schematic for particle board production by these three alternate production processes.

D.2.a Multiplaten Hot Press Process

In this process the mixture of fibers, resin, and other additives is sent to a mat-forming station, where carefully metered amounts of the mixture are placed on a large conveyor belt. The mat formed at this station may be one homogeneous layer of fiber-resin mixture. Alternatively, mats with three distinct layers may be formed; the outer layers are made of fine fibers and/or fibers mixed with phenolic resin, while the core layer is made of coarser fibers and/or fibers mixed with urea resin. A third type of mat is a graded density mat incorporating a uniform gradation in fiber fineness from the exterior to the core of the board, the core again containing the coarser fibers.

The mat is formed into overall dimensions that are somewhat larger than the dimensions of the board that will ultimately be produced. The length and width of the mat will each be about one inch greater than the final dimensions of the finished board. This one-inch oversizing is generally adequate to avoid undersizing of the board when it is pressed and to allow for trimming to the final finished

size. The thickness of the mat will be determined by the desired thickness and density of the finished board. A mat formed to a 3 1/2 to 4 inch thickness initially will typically yield a finished board 5/8 inch to 3/4 inch thick in the 50-60 lbs/ft³ density range.

The machinery used in the mat-forming operation is large and is usually closely integrated in design and operation with the board press. Figure III-18 shows the mat-forming station of a very large multiplaten hot press for bagasse particle board.

The pre-sized mats leave the mat-forming station and enter the pressing station where they receive a cold pressing which reduces their thickness to 1 1/2 to 2 inches. The mats are then individually loaded into a large stack of loading trays; when all loading trays contain mats, the trays move forward into the press itself and deposit the mats between the plates of the press. The multiplaten hot press consists of a series of stacked steel plates which can be heated (generally by steam) and hydraulically actuated to squeeze together, thereby simultaneously heating and compressing the mats placed between the plates. The mats are kept under pressure for a period of time varying according to the desired thickness and density of the board, but in most instances averaging 7-15 minutes. The temperature of the plates will ordinarily be about 275-300 °F. After the

period, the pressed boards are loaded into discharge trays. New mats are then loaded into the press for a new pressing cycle.

This pressing process on the multiplaten hot press is shown diagrammatically in Figure III-19. A twenty-board capacity hot press manufactured by the Washington Iron Works Company -- currently the world's largest press in use for bagasse particle board production -- is shown in Figure III-20. Machinery of this sort clearly represents a considerable investment, and an initial capital cost of at least \$15,000-\$20,000 per ton of daily capacity is to be expected.

D.2.b Continuous Pressing or Bartrev Process

This process resembles the multiplaten hot press process described above, except that the mats are pressed into boards one at a time in a semi-continuous Bartrev-Bison Press (also known as the Baehre-Bison Press). The mats are formed on a continuous steel belt which passes directly through the press. The mats pass through the press one at a time and are individually pressed at a temperature and duration comparable to the multiplaten hot press. The loading and unloading of this single-press unit is very rapid, and a production rate of 12 tons of board (approximately 120-150 boards) per day is possible for each press of this type. These presses have been used by the National Bagasse

Products Corporation of Vacherie, Louisiana, but no detailed information on capital and operating costs of this press are available for this study.

D.2.c Extrusion Process

The third process for the production of bagasse particle board has not yet been perfected for use with bagasse fibers, although it is in current use with wood fibers. When perfected, however, this process will offer the means to produce a variety of bagasse board types not possible with pressing methods. The upgrading of bagasse boards into complete pre-fabricated or multi-use sections will be greatly facilitated by this method when it is available.

In brief, the extrusion process begins with the introduction of resin-coated fibers into an extrusion press where a ram forces the mixture between heated plates. The mixture, after being compressed in this manner, becomes an increment to the board section being extruded. Repetitions of this cycle produce a continuous length of board which can be cut to desired lengths. Daily production rates of 20 tons are possible if current wood fiber extruding machines are adapted to bagasse fiber use.

D.3 Finishing

As boards leave the pressing station, they are trans-

ferred manually or by machine to a finishing station. This station provides for the sanding of the surface of the board to a prescribed smoothness and thickness. The board is also trimmed to its final length and width by circular saws. A semi-automatic trimming station -- that is, one manned by two workers -- is shown in Figure III-21. Finished boards are then stacked and stored in a warehouse. Figure III-22 shows a typical bagasse particle board warehousing area.

E. Administrative and Other Functions

The operation of a bagasse particle board plant includes several functions in addition to the simple functioning of the production equipment described in the preceding parts of this section. General administrative and engineering needs must also be met. An overview of the operational requirements and costs for the 100-tons-per-day particle board plant of Standard Building Products, Ltd., Spanish Town, Jamaica, may serve as an indication of the general requirements of such a facility. The representative figures from this operation are shown in Table III-3 and give approximate costs for the operation of this plant.

Administrative costs and personnel requirements must also include provision for the marketing and distribution of the particle board. In addition, some effort should be

made in the area of product development. The development of plastic laminated particle boards, for example, could lead to a significant local or regional demand for this type of board. Innovative uses for particle board within the local building industry should also be explored and encouraged by the particle board producer. Standard Building Products, Ltd., for example, is devoting considerable resources to developing and promoting complete prefabricated housing units made from bagasse particle board. Product development costs such as these should be included in normal operating costs and will no doubt prove a profitable allocation of resources in the long run.

The importance of administrative and other overhead costs typically diminishes as the volume of particle board actually produced at the plant approaches the designed capacity of the plant. Figure III-23 shows the relative importance of these and other costs in bagasse fiberboard production at the Tablopan de Venezuela plant, as a function of annual tonnage produced.

CAPITAL COSTS AT 25,000 TONS ANNUAL CAPACITY (FRESH BASIS):

Automatic balers (4)	\$64,000
Bagasse scale	6,000
Conveyors and elevators	45,000
Baling building	40,000
Installation	45,000
Storage site grading	10,000
Fire protection system	10,000
Mobile crane	55,000
Trucks and trailers	25,000
	<hr/>
Total (excluding land)	\$300,000

OPERATING COSTS PER TON BAGASSE (DRY BASIS):

Baling and stacking	\$2.75
Maintenance	.48
Unstacking and loading	1.95
Depreciation (5% yearly)	1.32
Insurance and interest	.68
	<hr/>
Total	\$7.18
Total per ton BDF	\$14.36

MANPOWER REQUIRED PER DAY:

Baling and stacking	408 hours
Unstacking and shipping	40 hours

TABLE III-1: CAPITAL AND OPERATING COSTS OF BAGASSE BALING STATION (Louisiana, 1957).

Source: A. Keller, "The Parsons and Whittemore-Horkel Process for the Mechanical Depithing of Sugar Cane Bagasse."

<u>ITEM</u>	<u>COST</u>
Worn parts replacement	\$0.60
Lubrication	0.10
Labor (0.5 man-hour)	0.50
Power consumption (30 KWH)	0.30
Depreciation (10% yearly)	2.24
Interest on capital	1.34
Total	\$5.08

Not included: Administrative charges

Table III-2: OPERATING COSTS PER TON OF BDF BRIQUETTED BY
SPM BRIQUETTING MACHINE OF 10,000 TONS ANNUAL
CAPACITY, OPERATING 200 DAYS PER YEAR.

Source: J. Paturau, By-Products of the Cane Sugar Industry,
pages 47-48.

<u>ITEM</u>	<u>BASIS</u>	<u>COST PER TON OF BOARD PRODUCED AT VOLUME OF 2000 TONS PER MONTH</u>
Bagasse	Obtained from sugar mill 2 miles distant. SBP installed oil furnace at mill. Final cost per ton is \$4-\$5 including transport by truck at \$0.70 per ton. 3 tons bagasse per ton board.	\$15
Resin and Additives	Phenolic resins made at plant at \$0.15 per pound and 200 lbs per ton board. Additives are \$5 per ton board.	35
Labor	80 workers, 20 foremen, 3 shifts. Manager and 3 engineers, plus clerical.	19
Maintenance	Materials and subcontractors fees.	3
Power	Fuel for 3 1600-KW diesel generators and for bagasse dryers.	4
Depreciation	\$10,000,000 at 10% yearly.	40
Miscellaneous	Including insurance.	3
Total (excluding debt service)		\$119

TABLE III-3: OPERATING COSTS AND REQUIREMENTS AT 2000-TONS-PER-MONTH
BAGASSE PARTICLE BOARD PLANT.

Source: Mr. K. Ruckstuhl, Standard Building Products, Ltd., Jamaica.

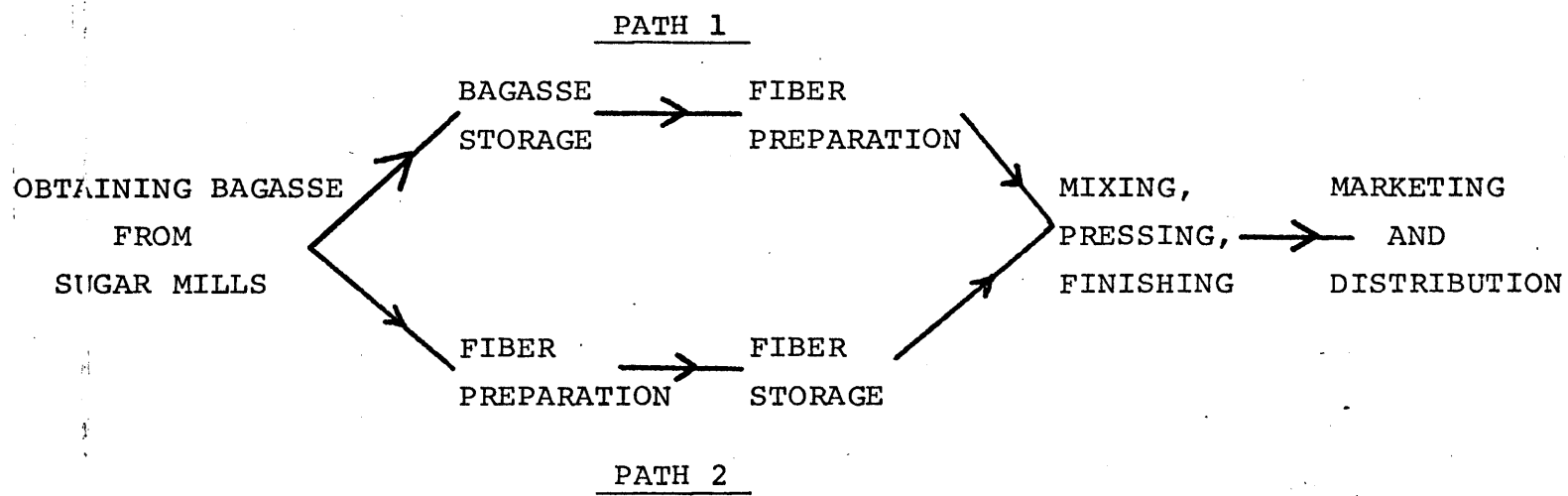


FIGURE III-1: POSSIBLE SEQUENCES OF FUNCTIONS IN BAGASSE PARTICLE BOARD PRODUCTION



FIGURE III-2: INSTALLATION FOR SIMPLE BULK STORAGE AND
TRANSFER OF BAGASSE.

(Photograph by permission of Standard Building
Products, Ltd., Spanish Town, Jamaica, W.I.)

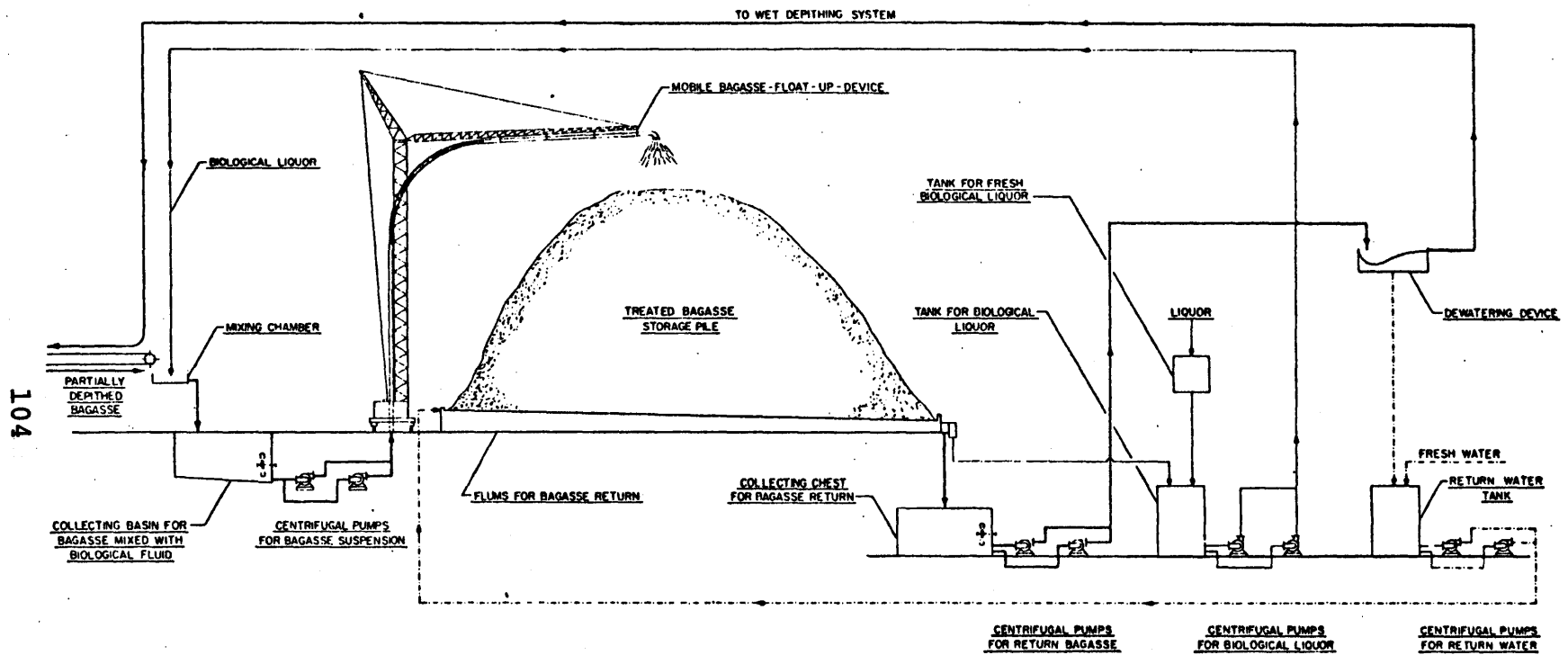


FIGURE III-3: "RITTER METHOD" FOR BULK STORAGE OF BAGASSE.

Source: J. Atchison, "Experiences in Developing, Building, and Operating Bagasse Pulp and Paper Mills."

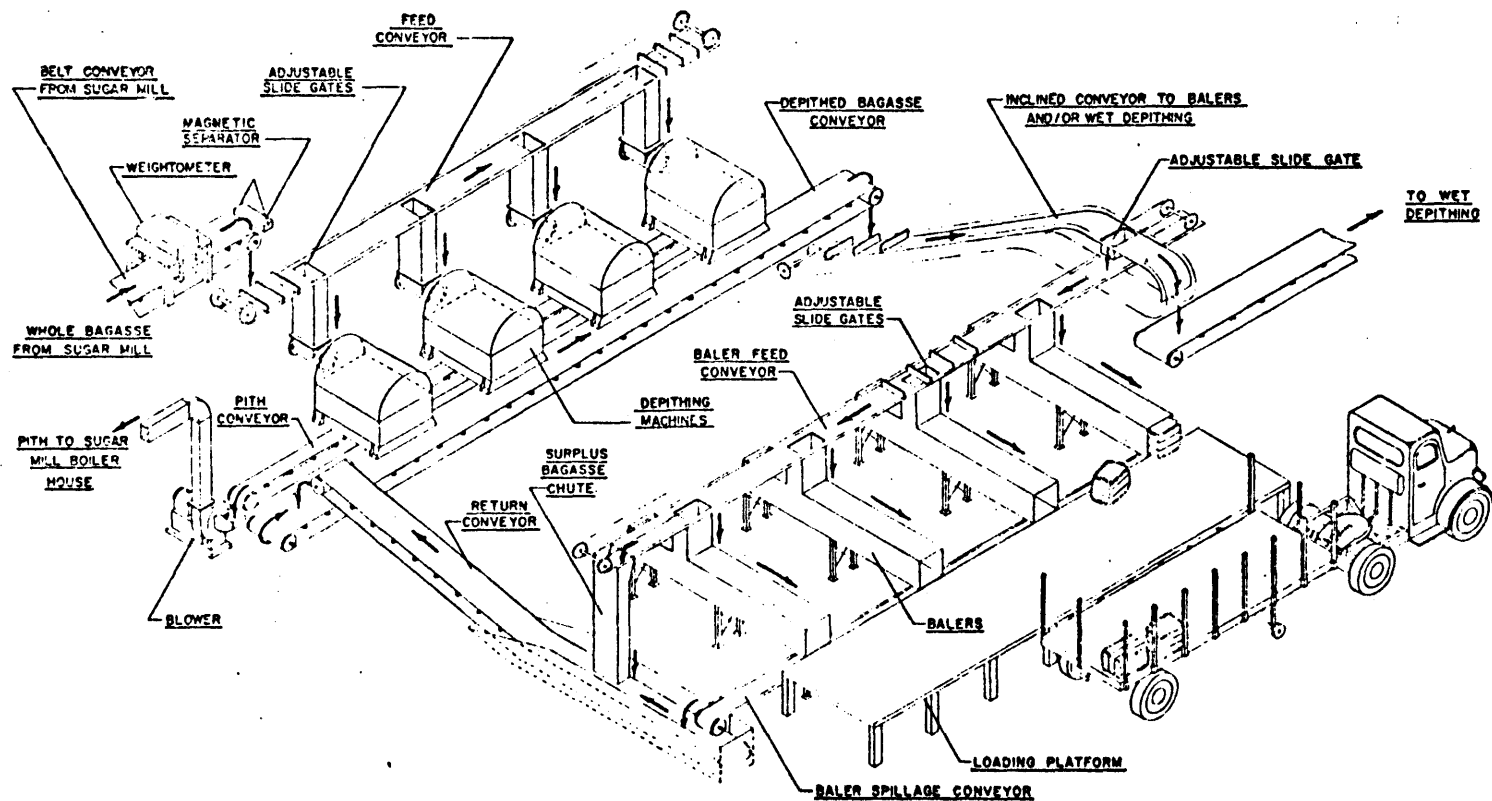


FIGURE II-4: ARRANGEMENT FOR BALING DEPITHED BAGASSE FIBERS

Source: J. Atchison, "Experiences in Developing, Building, and Operating Bagasse Pulp and Paper Mills."

Series type GLOMERA 412

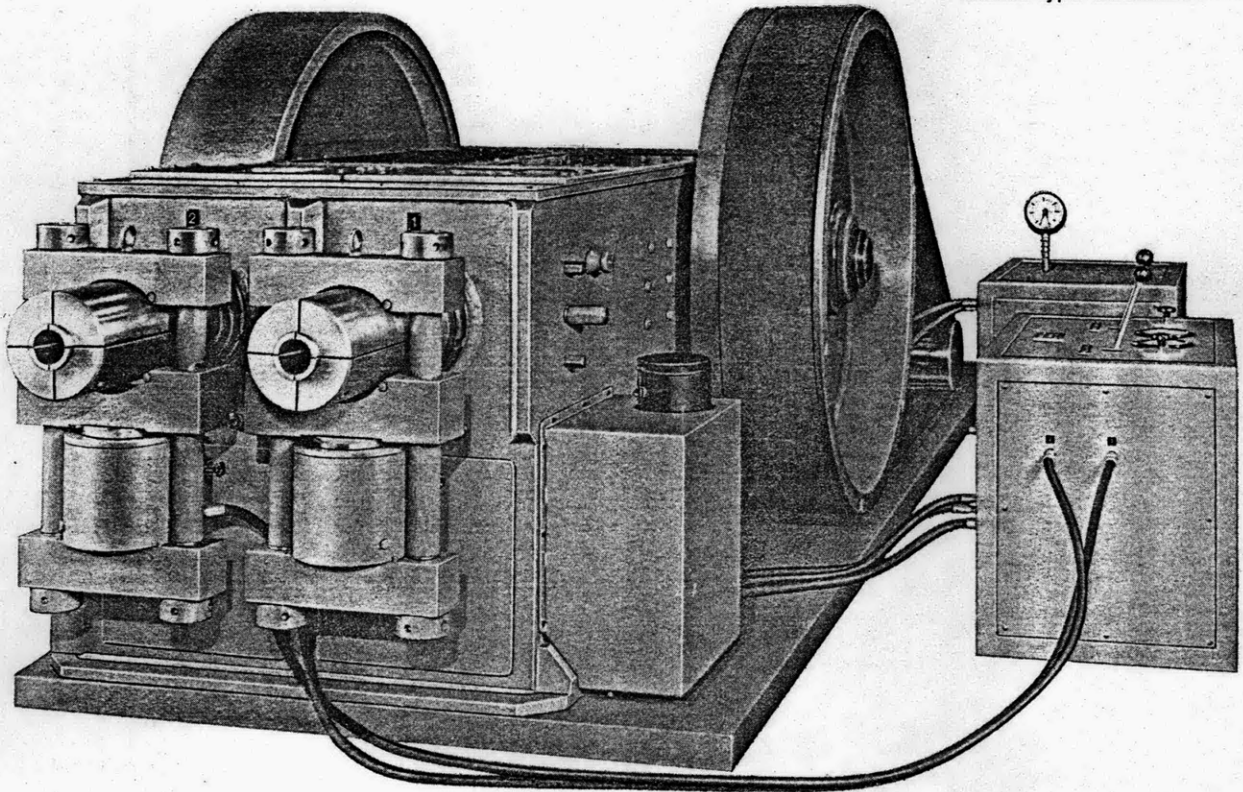


FIGURE III-5a: BAGASSE BRIQUETTING MACHINE BY SWISS PRECISION MACHINERY, BASLE, SWITZERLAND.

(Illustration by permission of Swiss Precision Machinery)

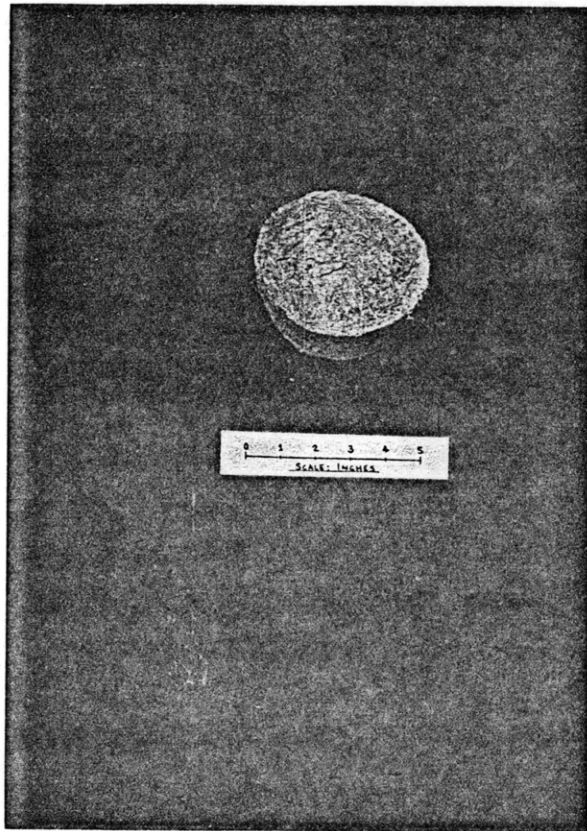


FIGURE III-5b: BAGASSE BRIQUETTE PRODUCED BY SPM
BRIQUETTING MACHINE.

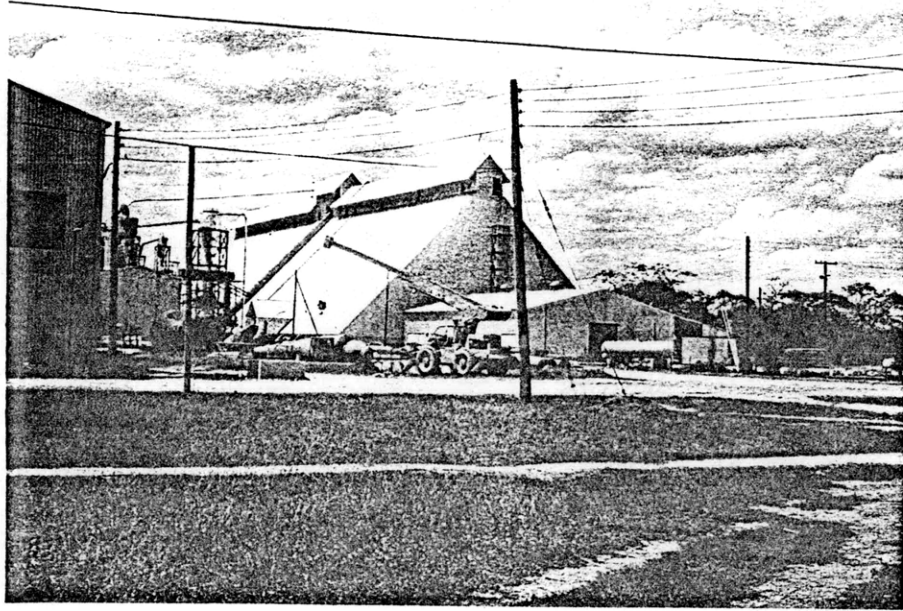


FIGURE III-6: ENCLOSURE FOR STORAGE OF DEPITHED BAGASSE
BRIQUETTES.

(Photograph by permission of Standard Building
Products, Ltd., Spanish Town, Jamaica, W.I.)

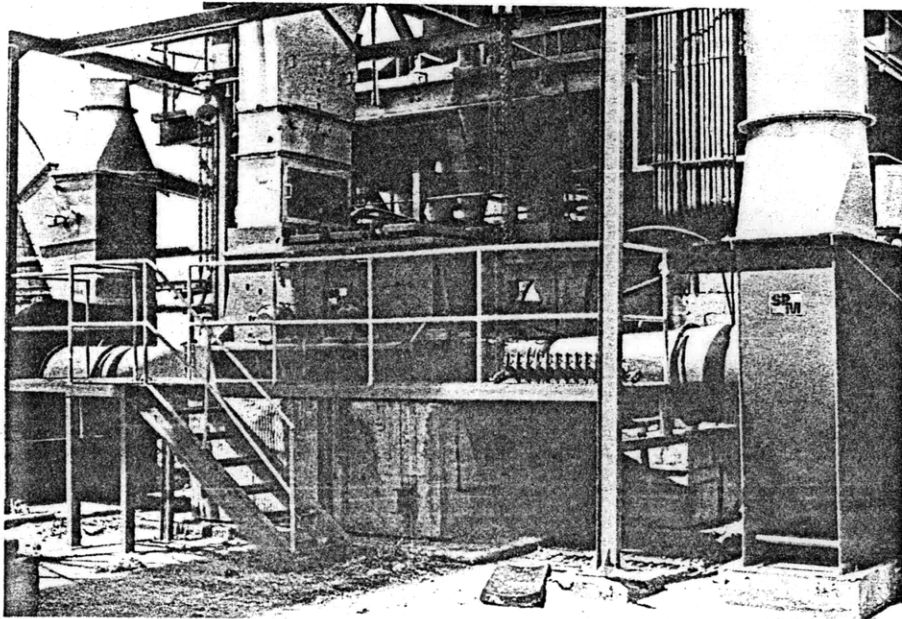


FIGURE III-7: BAGASSE DEPITHING MACHINE, TYPE 1500E, BUILT
BY SWISS PRECISION MACHINERY, BASLE, SWITZER
LAND.

(Photograph by permission of Standard Building
Products, Ltd., Spanish Town, Jamaica, W.I.)

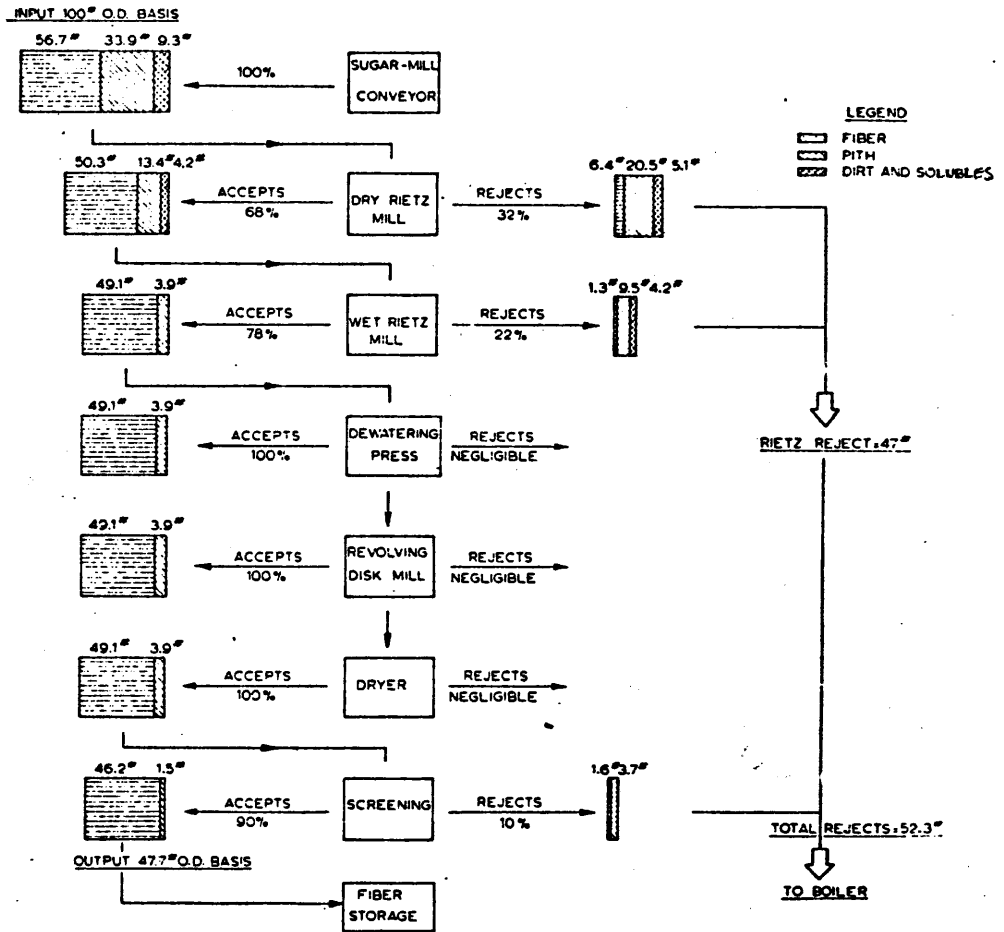


FIGURE III-8: FIBER BALANCE DURING DEPITHING PROCESS AT
TABLOPAN DE VENEZUELA.

Source: D. Lengel, "Investigations to Determine Optimum Methods of Producing Bagasse-Fiber Boards in the Softboard, Particle Board, and Hardboard Density Ranges."

III

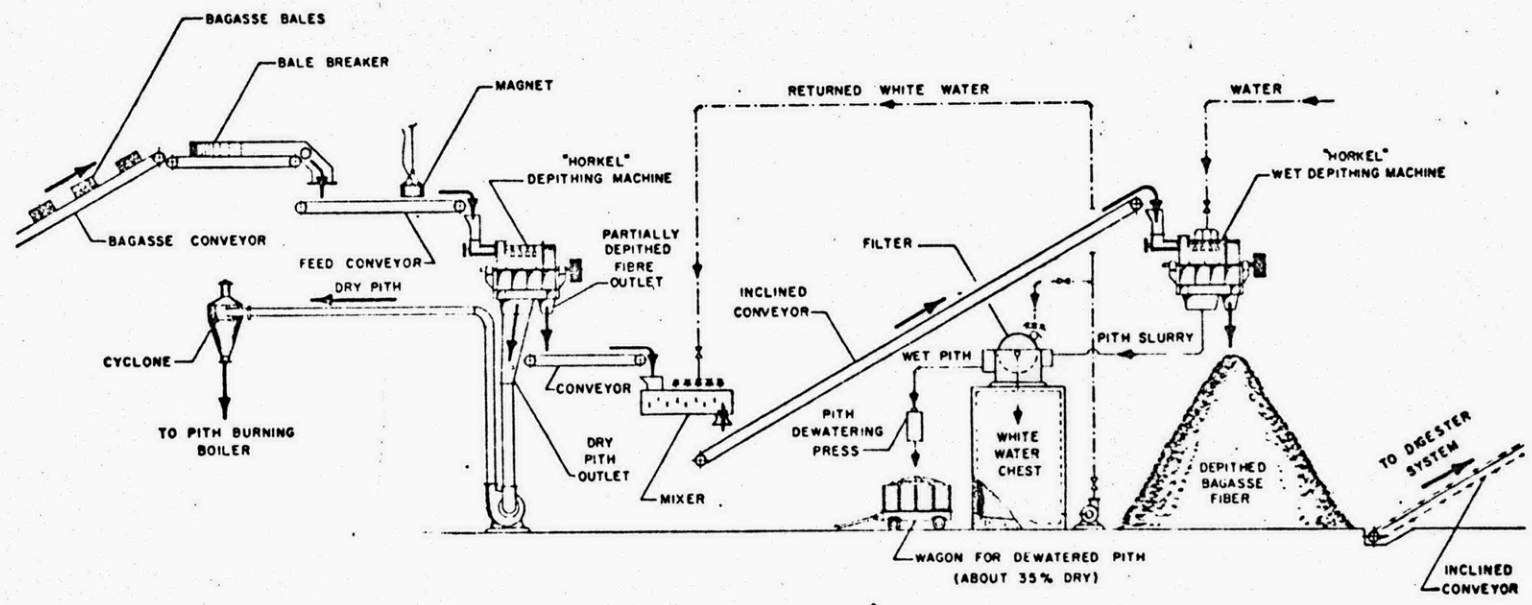


FIGURE III-9: BAGASSE DEPIHING ARRANGEMENT: TWO-STAGE CONTINUOUS SYSTEM.

Source: J. Atchison, "Bagasse Becoming a Major Raw Material for Manufacture of Pulp and Paper -- Background, Present Status, and Future Possibilities."

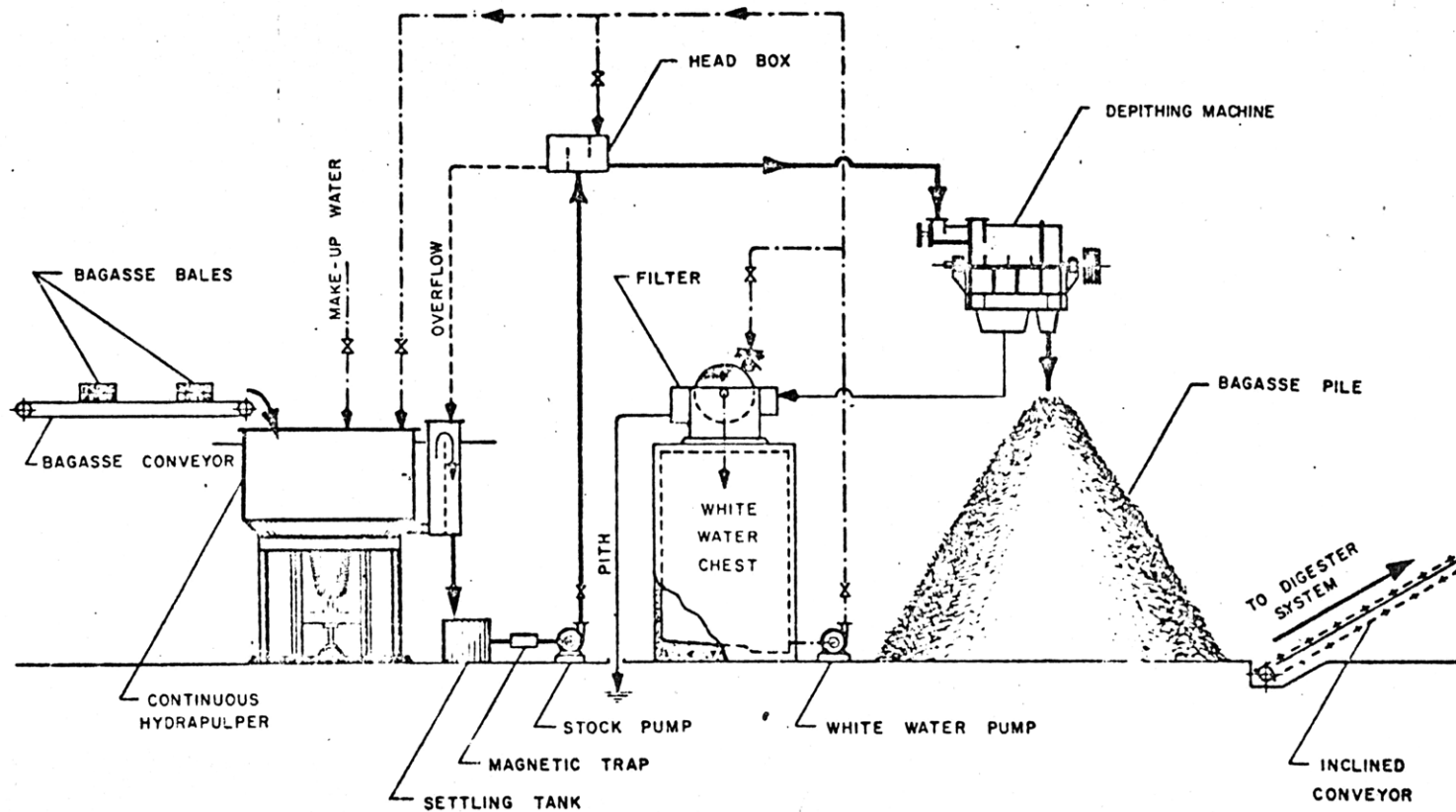
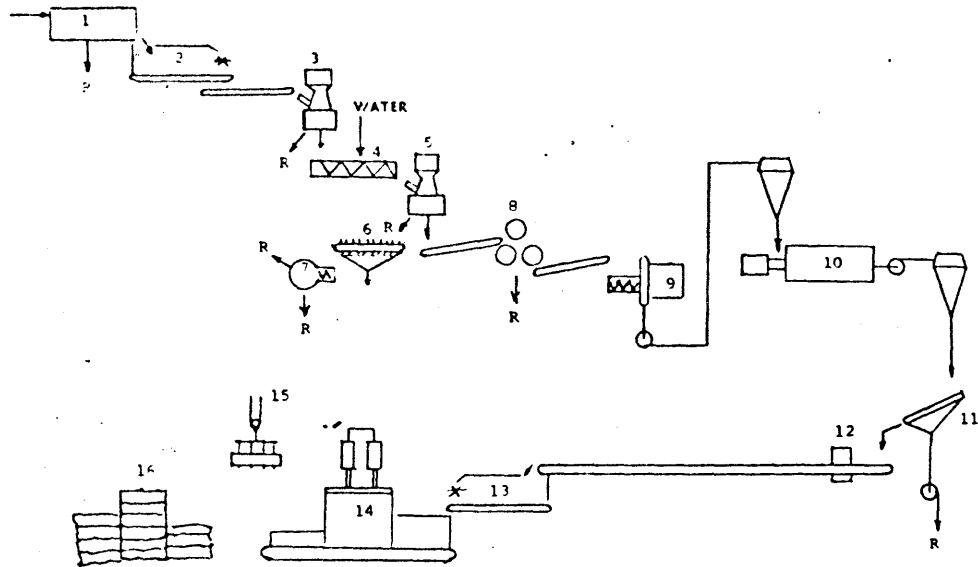


FIGURE III-10: BAGASSE DEPITHING ARRANGEMENT: HYDRAPULPER WITH WET REFINER.

Source: J. Atchison, "Bagasse Becoming a Major Raw Material for Manufacture of Pulp and Paper -- Background, Present Status, and Future Possibilities."

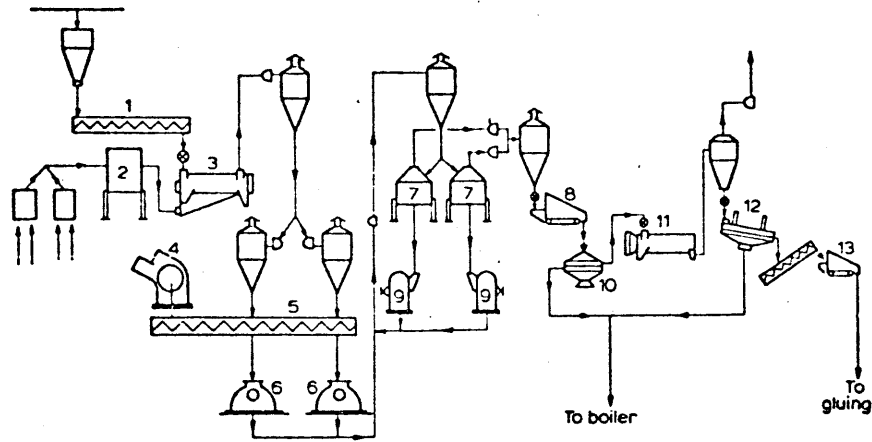
FIBER MANUFACTURING PROCESS



Key: (1) Rotating screen. (2) Bagasse feeder. (3) Dry depither. (4) Mixing screw. (5) Wet depither. (6) Cush-cush. (7) Pith dewatering. (8) Dewatering mill. (9) Attrition mill. (10) Dryer. (11) Screen. (12) Scale. (13) Press feeder. (14) Mat press. (15) Crane. (16) Storage.

FIGURE III-11: BAGASSE DEPITHING ARRANGEMENT: TABLOPAN DE VENEZUELA SYSTEM.

Source: Sugar y Azucar Yearbook, 1968, page 87.



Key: (1) Scroll conveyor. (2) Fly-ash arrestor. (3) Pre-dryer. (4) Bale-breaker. (5) Scroll conveyor. (6) Hammer-mill type depithers. (7) Jigging sieves. (8) Metering station. (9) Refiner mills. (10) Oscillating screen. (11) Dryer. (12) Vibrating screen. (13) Metering station.

FIGURE III-12: BAGASSE DEPITHING ARRANGEMENT: BAGAPAN SYSTEM, REUNION.

Source: Langreny and Hugot, "The Bagapan Particle Board."

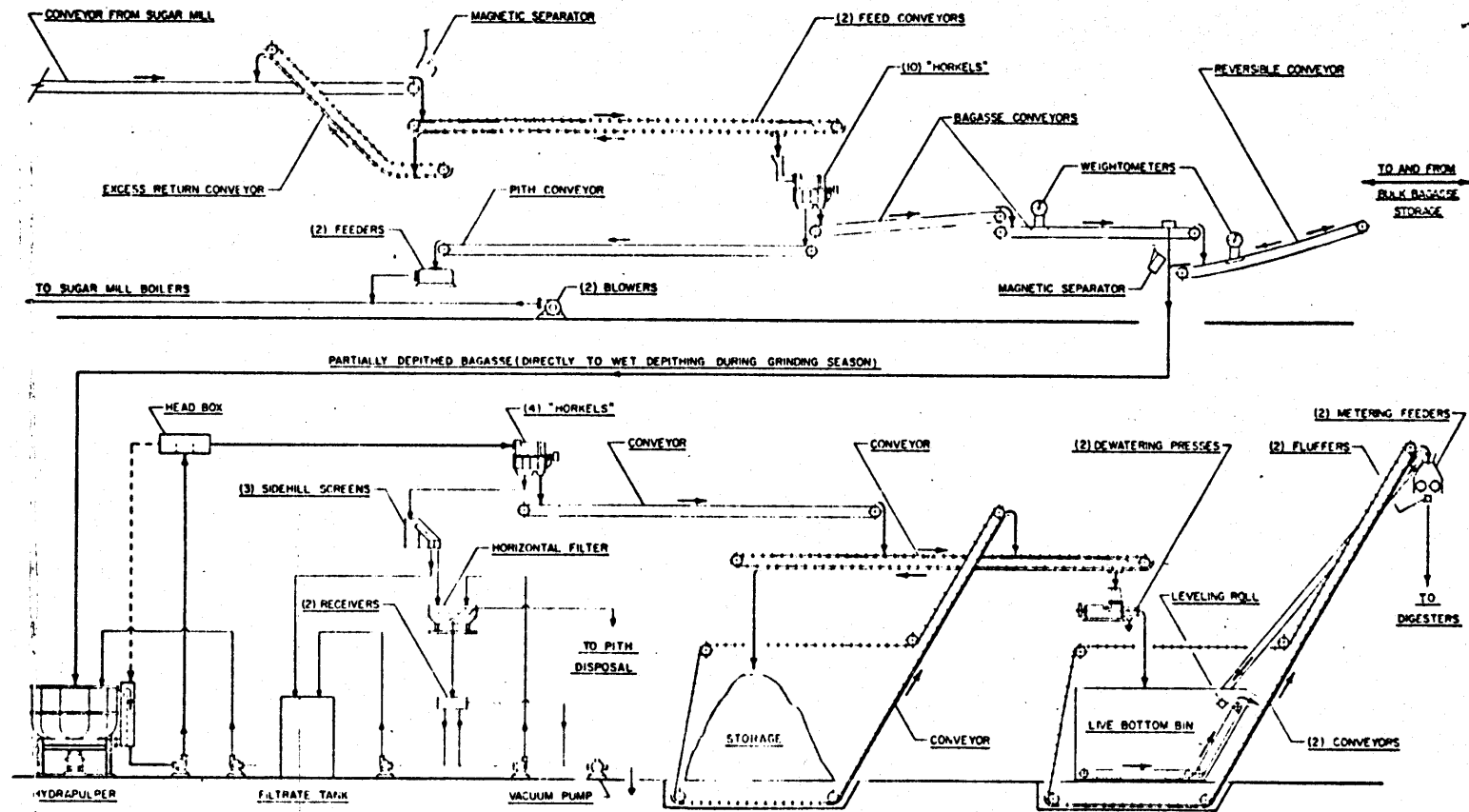


FIGURE III-13: BAGASSE DEPITHING ARRANGEMENT: S.A. AGRICOLA INDUSTRIAL, ARGENTINA.

Source: J. Atchison, "Experiences in Developing, Building, and Operating Bagasse Pulp and Paper Mills."

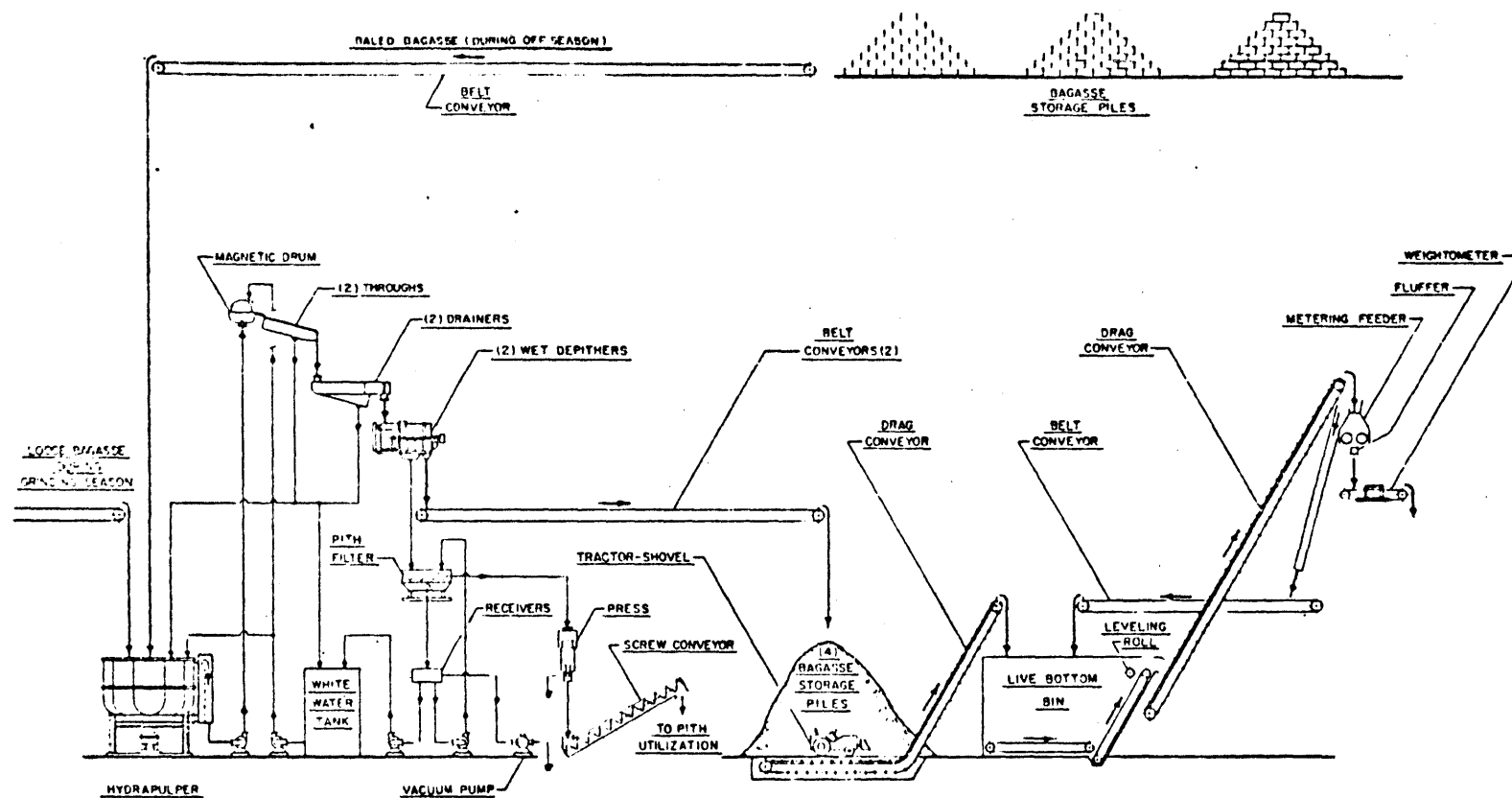


FIGURE III-14: BAGASSE DEPIITHING ARRANGEMENT: EDFU, EGYPT.

Source: J. Atchison, "Experiences in Developing, Building, and Operating Bagasse Pulp and Paper Mills."

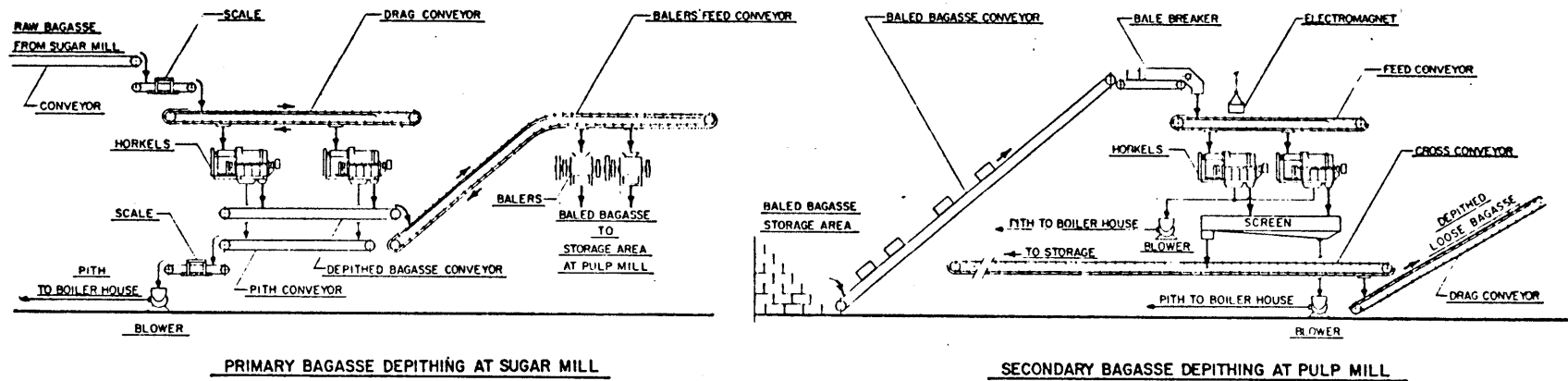


FIGURE III-15: BAGASSE DEPITHING ARRANGEMENT: SESHASAYEE PAPER AND BOARDS, LTD, INDIA

Source: J. Atchison, "Experiences in Developing, Building, and Operating Bagasse Pulp and Paper Mills."

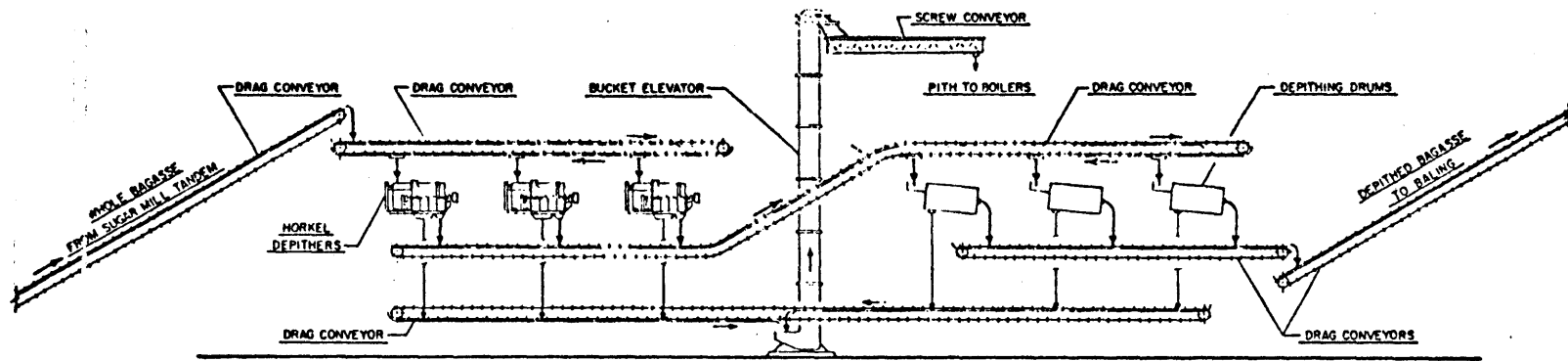
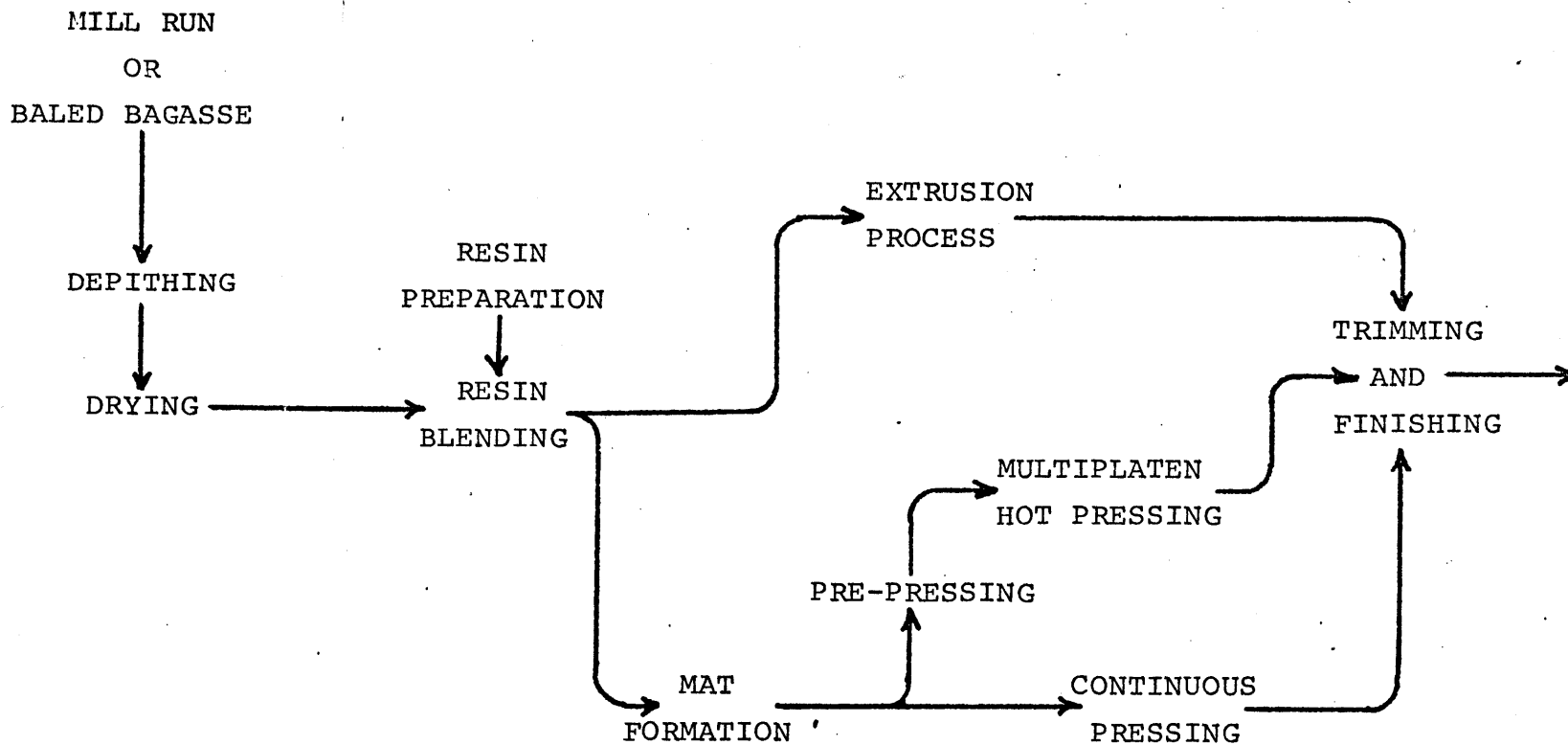


FIGURE III-16: BAGASSE DEPITHING ARRANGEMENT: PAPELERA PULPA-CUBA, S.A., CUBA.

Source: J. Atchison, "Experiences in Developing, Building, and Operating Bagasse Pulp and Paper Mills."



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FIGURE III-17: FLOW SCHEMATIC FOR BAGASSE PARTICLE BOARD PRODUCTION.

Source: J. Paturau, By-Products of the Cane Sugar Industry, page 85.

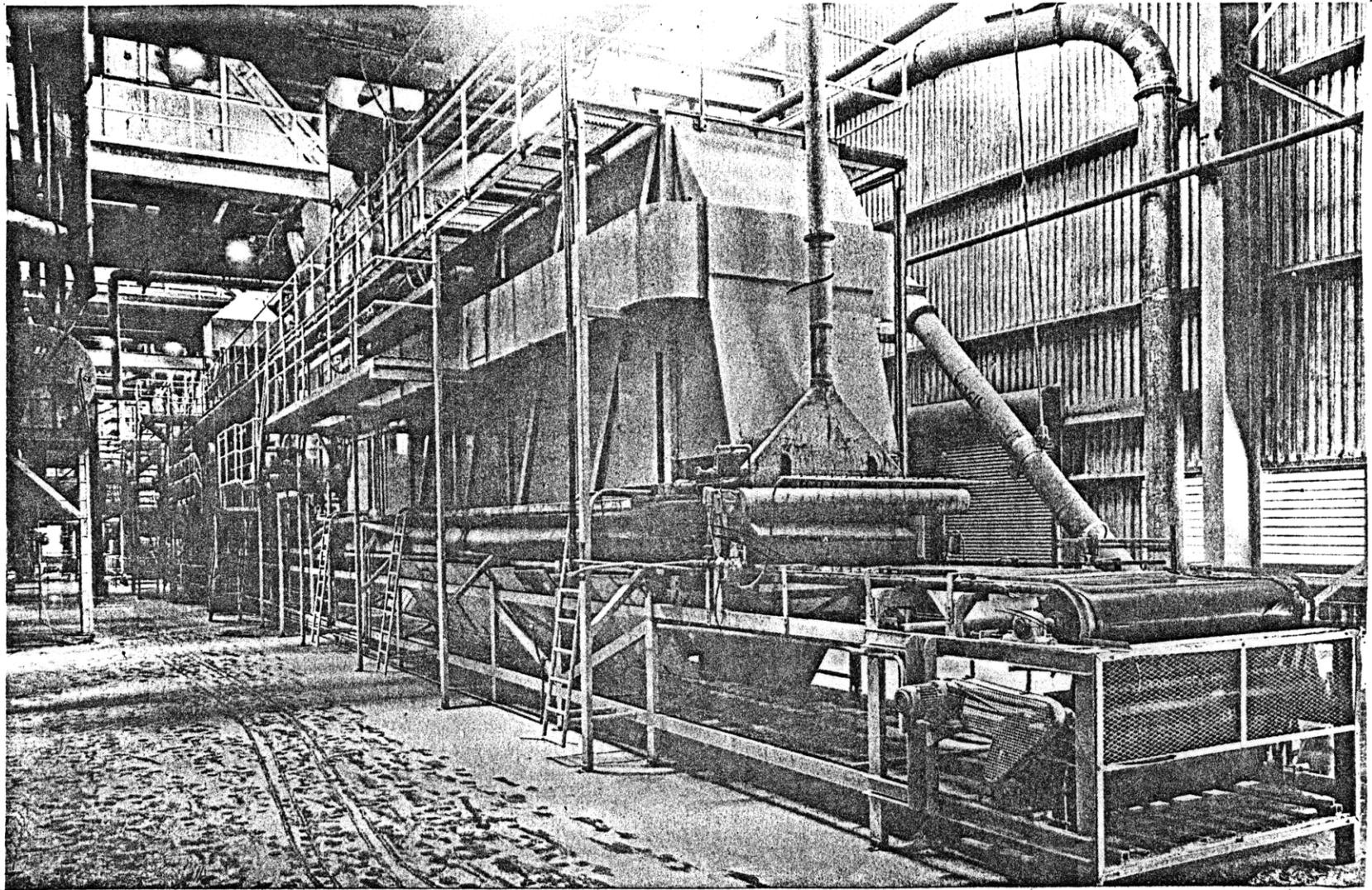
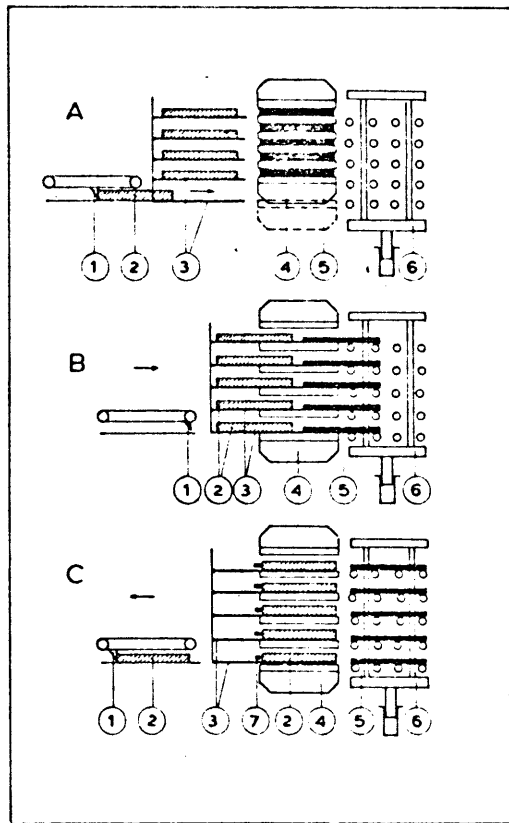


FIGURE III-18: MAT-FORMING STATION OF MULTIPLATEN HOT PRESS.

(Illustration by Permission of Standard Building Products, Ltd., Jamaica, W.I.)



A. (1) transport device pushing a pre-pressed board into the charging device, (2) pre-pressed board, (3) trays, installed in the charging device, (4) multi-opening hot press, (5) pressed particle boards in the hot press, (6) discharging device.

B. (2) pre-pressed mats lying on the trays, (3) charging device enters hot press, pushing the hardened boards out by means of thickened front edges of the trays, (4) hot press open, (5) pressed and hardened boards being discharged.

C. (1) transport starts bringing more pre-pressed boards, (3) charging device being pulled out of hot press, putting pre-pressed boards directly on hot plates, (7) arms hold pre-pressed boards in hot press while trays are pulled out beneath, (5) pressed and hardened boards in discharging device.

FIGURE III-19: PRESSING CYCLE IN MULTIPLATEN HOT PRESS

Source: J. Paturau, By-Products of the Cane Sugar Industry,

page 86.

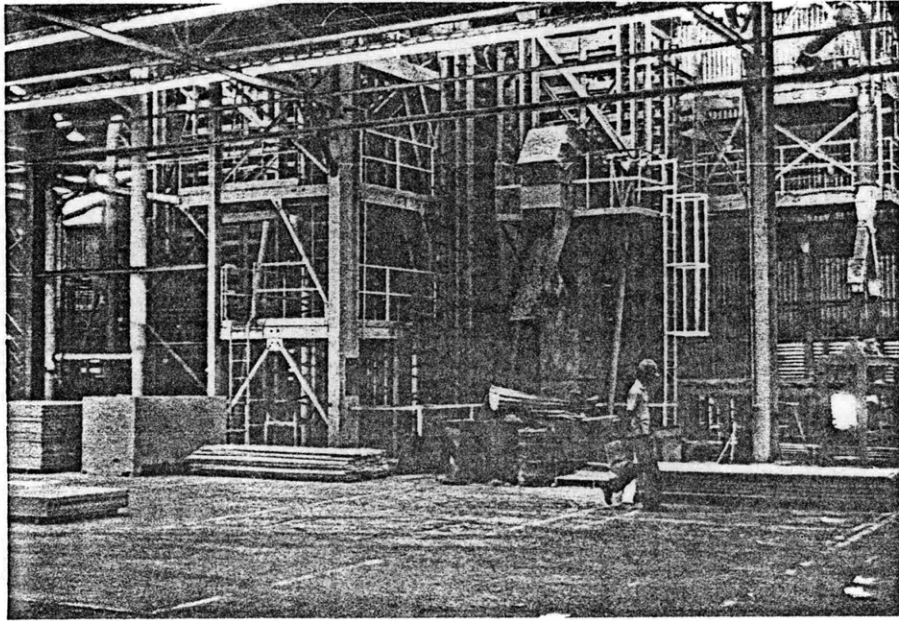


FIGURE III-20: LOADING TRAYS, PRESSING STATION, AND
DISCHARGE TRAYS OF 20-BAY MULTIPLATEN
HOT PRESS.

(Photograph by permission of Standard Building
Products, Ltd., Spanish Town, Jamaica, W.I.)

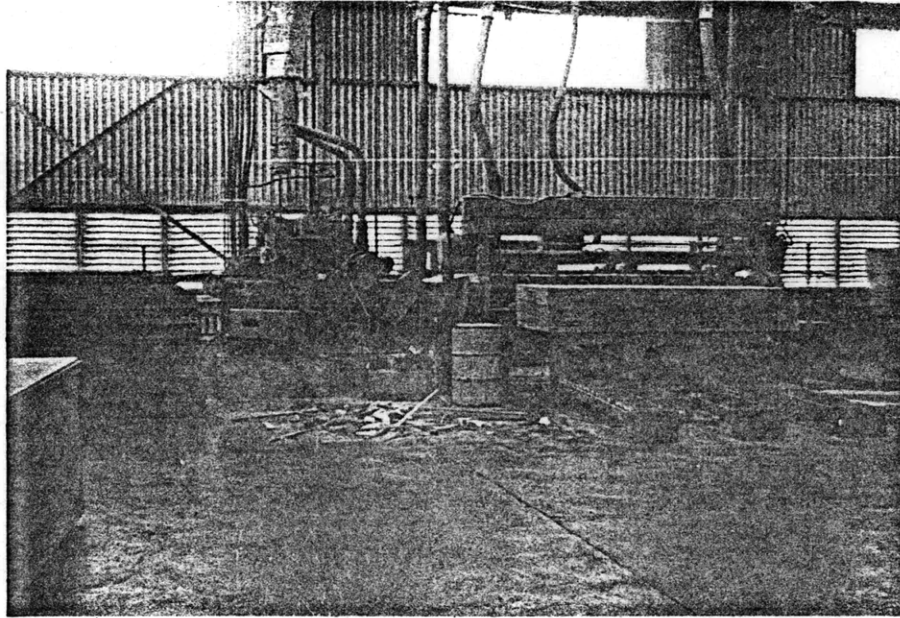


FIGURE III-21: SEMI-AUTOMATIC FINISHING STATION.

(Photograph by permission of Standard Building
Products, Ltd., Spanish Town, Jamaica, W.I.)

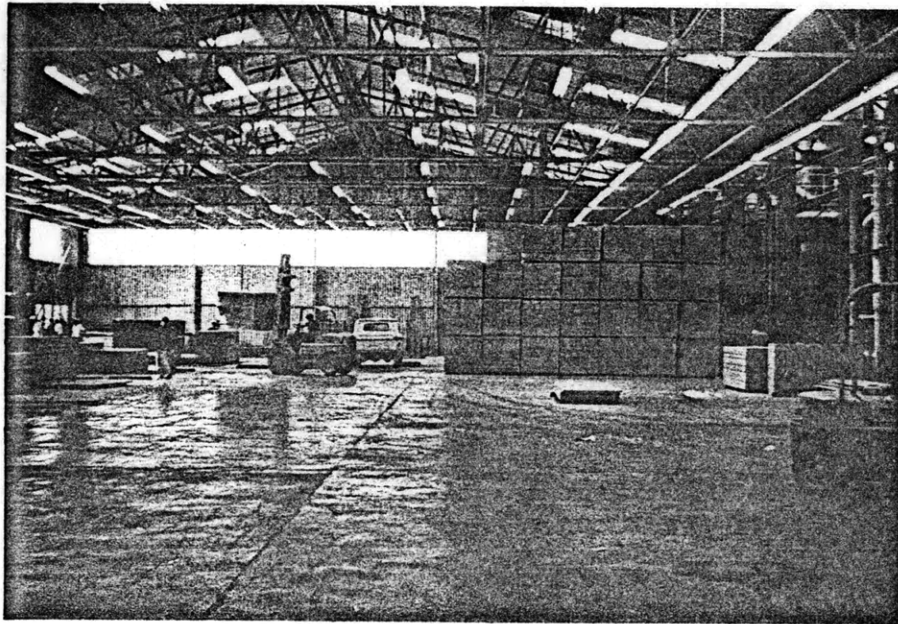


FIGURE III-22: BAGASSE PARTICLE BOARD WAREHOUSING AREA.

(Photograph by permission of Standard Building
Products, Ltd., Spanish Town, Jamaica, W.I.)

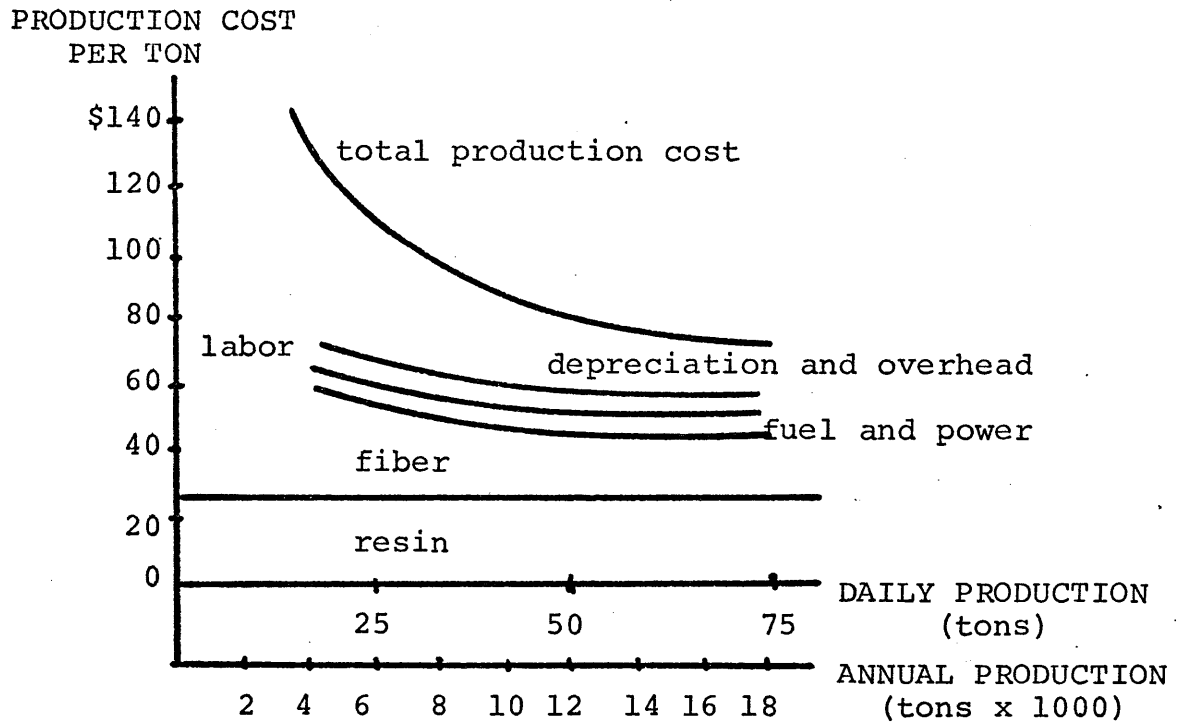


FIGURE III-23: PRODUCTION COSTS FOR 18,000 TON ANNUAL CAPACITY BAGASSE BOARD PLANT.

Source: D. Lengel, "Investigations to Determine the Optimum Methods of Producing Bagasse-fiber Boards in the Softboard, Particle Board, and Hardboard Density Ranges."

NOTES -- SECTION III

- ¹E. Hugot, Handbook of Cane Sugar Engineering, page 679.
- ²J. Paturau, By-Products of the Cane Sugar Industry, page 38.
- ³Ibid., page 35.
- ⁴A. Keller, "The Parsons and Whittemore 'Horkel' Process for the Mechanical Depithing of Sugar Cane Bagasse."
- ⁵D. Lengel, "Investigations to Determine Optimum Methods of Producing Bagasse-fiber Boards in the Softboard, Particle Board, and Hardboard Density Ranges."
- ⁶J. Atchison, "Bagasse Becoming a Major Raw Material for the Manufacture of Pulp and Paper -- Background, Present Status, and Future Possibilities."
- ⁷A. Keller, "Economical Bagasse Separation."
- ⁸J. Paturau, op.cit., page 40.
- ⁹Idem.
- ¹⁰Ibid., page 41.
- ¹¹F. Langreny and E. Hugot, "The Bagapan Particle Board."
- ¹²K. Ruckstuhl, personal communication, March 1972.
- ¹³Idem.
- ¹⁴J. Paturau, op.cit., pages 84-89.

IV. INVESTMENT ANALYSIS

The purpose of this section is to elaborate a framework for the economic analysis of potential investments in bagasse particle board plants. This analytic framework provides the methodology for an evaluation of the various costs anticipated for a proposed plant in order to determine the overall feasibility and the most profitable mode of production of the particle board at various levels of annual output. The evaluation of the proposed investment is made in terms of cost indices for supply, operations, debt service, and depreciation, which are then compared with an anticipated market price index to give an indication of the expected profitability of the plant. These indices are given as functions of the quantity of board produced annually. Thus, the profitability and cost characteristics of the bagasse particle board operation can be evaluated over the full range of production levels.

The analytic framework elaborated in this section will be applied to the analysis of a hypothetical example in Section V.

A. Market Index

The Market Index, M.I., is the effective price paid per ton of board sold by the plant. The M.I. is thus given by

the following relation:

$$M.I. = (DMI)(F_d) + (EMI)(1 - F_d) \quad (\text{Equation IV-1})$$

where

DMI = Domestic Market Index, or the price paid per ton of board sold on the domestic market.

F_d = Fraction of total sales of the board plant resulting from sales to the domestic market.

EMI = Export Market Index, or the price paid per ton of board sold to export markets, f.o.b.

$1 - F_d$ = Fraction of total sales resulting from sales to export markets.

The DMI for bagasse particle board will be determined by the demand curve which defines a given domestic market for all wood and fiber panels and by the degree of penetration of the domestic market for panels achieved by the bagasse particle board. Figure IV-1 shows an example of a demand curve for all wood and fiber panels (Curve $D_t - D_t$) and demand curves representing, for example, 90%, 60%, and 30% market penetrations by the bagasse particle board (Curves $D_1 - D_1$, $D_2 - D_2$, and $D_3 - D_3$), based on the prevailing price level for wood and fiber panels. The prediction of the degree of market penetration which can be expected by the bagasse particle board plant must be made on the basis of an informed evaluation of local

conditions such as:

- (1) Will local architects, engineers, and builders accept the boards as a replacement for plywood and other building materials?
- (2) Will they adapt their future construction plans and methods to include bagasse particle board, if existing methods do not already include use of such panels?
- (3) Will the local availability of bagasse particle board lead to the increased use of wood and fiber panels in general?

The resultant DMI given by the domestic demand curve for bagasse particle board will vary from region to region, but will in general have as its upper limit the prevailing price for exterior grade plywood, for which the bagasse board will be a substitute in its early stages of use. If the prevailing price for plywood contains a significant cost resulting from importation freight charges or tariffs, the DMI for bagasse particle board may be set at a significantly lower level than that of the imported plywood, thereby assuring an even greater share of the market than it would obtain on the basis of even-price competition. The increased domestic demand is then found simply by following the domestic demand curve for bagasse boards to the lower price level.

The Export Market Index, EMI, for bagasse particle board is related to the World Market Price, WMP, for particle board as follows:

$$\text{EMI} + C_t = \text{WMP}$$

or

$$\text{EMI} = \text{WMP} - C_t$$

where

C_t = Transport costs per ton of board from the port serving the board plant to the world market areas.

For a bagasse board plant shipping to major world markets, the demand for particle board will usually be perfectly elastic with respect to the prevailing WMP. In other words, the demand for the board on a world-wide scale is sufficiently large that it is not appreciably affected by the increase in supply represented by the new bagasse particle board plant. The board plant may sell as much of its own output as it wishes to the world markets under these conditions, without altering the prevailing WMP.

It is possible, however, that a bagasse particle board plant may be able to satisfy the demand of adjacent regions, so that it will be necessary for the plant to ship the board to progressively more remote regions if the plant is to con-

tinue to increase its export sales. The transport costs, C_t , will then increase as the board must be shipped greater and greater distances from the plant. Thus, the effective EMI, as perceived by the board plant, will decrease as the volume of bagasse board exported increases. The EMI will typically decrease in step-function fashion, following the discrete increases in transport costs C_t to various discrete regions. If the board plant exports to a number of foreign markets, however, the C_t and EMI functions will, in effect, become more smoothed. The straight-line Curve $D'_e - D'_e$ in Figure IV-2 represents this somewhat idealized EMI function.

Curve $D_e - D_e$ in Figure IV-2 indicates the EMI curve which results when regional EMI's are lowered by the exportation to various regions of quantities of particle board which are greater than the existing regional demand at the normal WMP level. Since the marketing and distribution system of the bagasse particle board plant is not likely to be in perfect harmony with the local markets in various regions, Curve $D_e - D_e$ reflects a more realistic variation of EMI with the quantity of board exported.

The fraction of the total bagasse board production of any plant which is sold on the domestic market, F_d , is given by

$$F_d = \frac{D_d}{D_p}$$

where

D_d = annual domestic demand (the quantity of board supplied by the plant to the domestic market).

D_p = total annual demand (the quantity of board supplied by the plant to all markets).

The export demand, D_e , is then given directly by $D_p - D_d$. Figure IV-3 shows the demand functions for domestic demand and export demand (Curves D-D and E-E, respectively). The value of F_d is then determined by the values of D_d , D_e , and thus D_p given by these functions.

To find D_d , D_e , and D_p under optimal conditions, we assume that the plant will seek to maximize its revenues (total sales from both domestic and export sales). The total revenues of the plant from both domestic and export sales is given by

$$R = (DMI)(D_d) + (EMI)(D_e)$$

as represented by the cross-hatched areas of Figure IV-3. To find the maximum value of R for any given functions of D_d and D_e , we may differentiate R with respect to either D_d or D_e and perform the usual maximization by setting the resulting differential equation equal to zero. Let us assume that we are more interested in the variation of R with domestic demand,

or that better data exists for the domestic demand function than for the export demand function. Hence, differentiation of R with respect to D_d at the maximum value of R gives

$$\frac{\partial [(DMI)(D_d) + (EMI)(D_e)]}{\partial D_d} = \frac{\partial R}{\partial D_d} = 0$$

By substituting $(D_p - D_d)$ for D_e and rearranging, this equation becomes

$$DMI - EMI + D_e \frac{\partial EMI}{\partial D_d} + D_d \frac{\partial DMI}{\partial D_d} + EMI \frac{\partial D_p}{\partial D_d} = 0 \quad (IV-2)$$

Equation IV-2 indicates that the maximization of revenues involves consideration and evaluation of three conditions:

Condition 1: Does EMI depend on domestic demand; that is,

$$\frac{\partial EMI}{\partial D_d} \neq 0$$

Condition 2: Does DMI depend on domestic demand; that is,

$$\frac{\partial DMI}{\partial D_d} \neq 0$$

Condition 3: Does the total annual demand supplied, or

total annual production D_p , vary with annual domestic demand; that is,

$$\frac{\partial D_p}{\partial D_d} \neq 0$$

If all three of these conditions are positive -- that is, the partial derivatives are non-zero -- then the optimal mix of domestic and export demand must be evaluated on the basis of Equation IV-2. This equation can be solved when reliable functions f_d and f_e can be established such that

$$DMI = f_d(D_d) \quad \text{and} \quad EMI = f_e(D_e)$$

It seems reasonable to assume that, in many cases at least, EMI will not vary significantly with domestic demand, so that the derivative of Condition 1 will have a negligible value. Furthermore, for any fixed total annual production, Condition 3 becomes zero, and the maximization of revenues at any given level of production then occurs when

$$DMI - EMI + D_d \frac{\partial DMI}{\partial D_d} = 0 \quad (IV-3)$$

This equation can be solved for the values of D_d and D_e which are the domestic demand and export demand which the plant will supply when maximizing its total revenues from

a total annual production level D_p .

When the values of D_d and D_e which give the maximum value of total revenues R are known, the corresponding value of F_d follows directly. Using this value of F_d and the functions for DMI and EMI given by $F_d(D_d)$ and $f_e(D_e)$, Equation IV-1 can then be solved for the optimal value of the Market Index (M.I.).

It is not likely that the M.I. will have its true optimal value under conditions governed by any number of real restraints. Typical restraints which will cause M.I. to assume a sub-optimal value include:

- (1) Lack of correct perception of domestic and export demand functions in the marketing strategy of the particle board plant.
- (2) Non-economic preferences for either domestic or export markets on the part of the plant operators.
- (3) Other interferences, such as government regulation of trade or domestic sales, which prevent the realization of the optimal mix of domestic and export demands.
- (4) Currency exchange fluctuations which lead to uncertainties in the true-value relationship between DMI and EMI.

In light of the restraints which are likely to prevent the realization of the maximum value of R and M.I., it may be necessary in an investment analysis to make assumptions of reasonable values of DMI, EMI, D_d , and D_e , and of corresponding minimum values, based on evaluations of local conditions. The optimal, expected, and minimum values obtained thereby will define the range of values of M.I. which should be considered in the investment analysis.

B. Supply Index

The Supply Index, S.I., represents the cost to the bagasse particle board plant of the raw materials which are used in the production of one ton of particle board. Since the three raw materials used in bagasse particle board manufacture are bagasse, resin, and additives, the Supply Index is given by

$$S.I. = B.I. + R.I. + A.I. \quad (IV-1)$$

where

B.I. = Bagasse Index

R.I. = Resin Index

A.I. = Additive Index

B.1 Bagasse Index

The cost of the bagasse used in the production of one

ton of bagasse particle board is given by

$$B.I. = Q.I._b \times C_b \quad (IV-2)$$

where

$Q.I._b$ = Quantity Index for bagasse, or the quantity of bagasse used per ton of board.

C_b = Cost of one ton of bagasse delivered to the bagasse particle board plant.

The Quantity Index is given straightforwardly by

$$Q.I._b = \frac{F_f}{F_b \times F_d} \quad (IV-3)$$

where

F_f = fraction of BDF (bone-dry fiber) in final finished board, by weight.

F_b = fraction of BDF in fresh bagasse.

F_d = fraction of BDF remaining after depithing.

The cost per ton of bagasse delivered to the board plant (C_b) will depend on the method employed to release the bagasse for use by the board plant, on the profit margin charged by the sugar mill supplying the bagasse, and on the cost of transporting the bagasse from the sugar mill to the board plant. Thus,

$$C_b = R.I._b + P_m + (C_{tb} \times d_t) \quad (IV-4)$$

where

$R.I._b$ = Release Index for bagasse, or the cost per ton of bagasse incurred in releasing the bagasse for use in particle board.

P_m = profit margin charged by the sugar mill

C_{tb} = cost per ton per mile for transporting the bagasse.

d_t = distance between the sugar mill and the board plant, in miles.

P_m , C_{tb} , and d_t are determined directly on the basis of local conditions. $R.I._b$, however, must be determined by somewhat more complex means, owing to the several possible modes of bagasse release. Basically,

$$R.I._b = (-S_d)(wf_1) + (C_e)(wf_2) + (C_a)(wf_3) + (C_s)(wf_4) \quad (IV-5)$$

where

S_d = savings in surplus bagasse disposal costs per ton of bagasse (S_d is a negative cost).

wf_1 = weighting factor for bagasse obtained as a surplus; this weighting factor is the ratio of bagasse obtained in this manner to the

total amount of bagasse used by the board plant.

C_e = costs per ton of bagasse resulting from a program to improve mill efficiency and thereby release bagasse for use in particle board.

wf_2 = weighting factor for bagasse obtained as a result of a mill efficiency improvement program.

C_a = costs per ton of bagasse resulting from the release of bagasse by the burning of alternate fuels.

wf_3 = weighting factor for bagasse released by the burning of alternate fuels and used by the particle board plant.

C_s = costs per ton of bagasse resulting from the release of bagasse by the burning of supplemental fuels.

wf_4 = weighting factor for bagasse released by the burning of supplemental fuels.

A condition on Equation IV-5 is that a maximum of three of the variables S_d , C_e , C_a , C_s and their associated weighting factors may be non-zero, as shown by the flow path diagram in Figure IV-4. Each of these possible factors in the determina-

tion of the Release Index must be defined in some detail.

B.2 Savings in Surplus Disposal Costs

The annual savings in surplus disposal costs per ton of bagasse used in particle board production (or any other by-product use) is given by

$$S_d = \frac{C_d}{B_s} \quad (IV-6)$$

where

C_d = annual surplus disposal cost (total).

B_s = annual bagasse surplus, in tons.

The annual surplus disposal cost is given by

$$C_d = BD_c + AR_c + SH_c \quad (IV-7)$$

where

BD_c = annual cost of boiler deterioration due to the burning of excess (surplus) bagasse

$$= \frac{BC_i - BC_s}{T_{bl}} \times \frac{B_s}{B_t} \quad (IV-8)$$

where

BC_i = initial cost of the bagasse boiler

BC_s = salvage value of the boiler

T_{bl} = Boiler's useful lifetime

B_s = bagasse surplus used annually in board production.

B_t = Total annual output of bagasse at the sugar mill.

AR_c = annual ash removal costs resulting from the burning of surplus bagasse

$$= AT_{ct} \times \frac{B_s}{B_t} \quad (IV-9)$$

where

AT_{ct} = annual cost of removal of all bagasse ash.

SH_c = annual costs of handling and/or disposal of surplus bagasse (if stored for later burning, for example).

The annual bagasse surplus, B_s , is found by

$$B_s = B_t - B_r \quad (IV-10)$$

where

B_r = total bagasse required for operation of the sugar mill annually

$$= \frac{TC_a \times H_r}{NHV_b} \quad (IV-11)$$

where

TC_a = tons of sugar cane milled annually.

H_r = heat required by mill per ton of cane milled.

NHV_b = net heat value obtained from the bagasse burned in the mill's boiler
 $= NCV_b \times BE_b$ (IV-12)

where

NCV_b = Net Calorific Value of bagasse produced by the sugar mill.

BE_b = Boiler Efficiency of the mill's bagasse boiler. (See Appendix.)

Equations IV-6 through IV-12 can be combined to give the savings in surplus bagasse disposal costs per ton of bagasse taken by the board plant, as follows:

$$S_d = \frac{C_d}{B_s} = \frac{BD_c + AR_c + SH_c}{B_t - B_r}$$

$$= \frac{\left[\frac{BC_i - BC_s}{T_{bl}} \times \frac{B_s}{B_t} \right] + \left[AT_{ct} \times \frac{B_s}{B_t} \right] + SH_c}{B_t - \left[\frac{TC_a \times H_r}{NCV_b - BE_b} \right]} \quad (IV-13)$$

B.3 Costs of Mill Efficiency Improvement

The cost per ton of bagasse released by a program of mill

efficiency improvement is given by

$$C_e = \frac{C_{et}}{B_e} \quad (IV-14)$$

where

C_{et} = total annual cost of the mill efficiency improvement program.

B_e = bagasse released by the improvement of mill efficiency and used by the particle board plant.

The total annual cost of the mill efficiency improvement program is determined by

$$C_{et} = DC_e + AI_e + OC_e \quad (IV-15)$$

where

DC_e = standard annual depreciation charges on equipment installed to improve mill efficiency

$$= \frac{EC_i - EC_s}{T_{el}} \quad (IV-16)$$

where

EC_i = initial cost of equipment installed to improve mill efficiency

EC_s = salvage value of equipment installed to

improve mill efficiency

T_{el} = useful lifetime of equipment

AI_e = standard annual interest charges resulting
from purchase of efficiency equipment

$$= EC_i \times RI_a \quad (IV-17)$$

where

RI_a = Real annual interest rate on price of
equipment purchased, including opportu-
nity cost of down payment, if any.

OC_e = extra annual operating costs resulting from
use of efficiency equipment, less savings in
operating costs, if any.

The total amount of bagasse which can be released annually
by an increase in mill efficiency is given by

$$B_{et} = B_r - B'_r \quad (IV-18)$$

where

B'_r = amount of bagasse required for operation of
mill (annually) after the improvement of mill
efficiency

$$= \frac{TC_a \times H'_r}{NHV'_b} \quad (IV-19)$$

where

H'_r = heat required by mill per ton of cane milled after the improvement of mill efficiency.

NHV'_b = Net Heat Value of bagasse after improvement of mill efficiency
 = $NCV'_b \times BE'_b$ (see Equation IV-12).

The maximum value of B_e , the amount of bagasse released by the improvement of mill efficiency, is then given by

$$B_{et} = TC_a \times \left[\frac{H_r}{NHV_b} - \frac{H'_r}{NHV'_b} \right] \quad (IV-20)$$

Equations IV-14 through IV-19 can be combined to give the total cost per ton of bagasse released by a program of mill efficiency improvement for use in bagasse particle board (or other uses), as follows:

$$C_e = \frac{C_{et}}{B_e} = \frac{[DC_e + AI_e + OC_e]}{B_e}$$

$$= \frac{\frac{EC_i - EC_s}{T_{el}} + (EC_i)(RI_a) + OC_e}{B_e} \quad (IV-21)$$

B.4 Costs of Burning Alternate Fuels

The cost per ton of bagasse released by burning alternate

fuels and actually used in bagasse particle board production is given by

$$C_a = \frac{AC_t}{B_a} \quad (IV-22)$$

where

AC_t = total annual costs incurred in the burning of alternate fuels.

B_a = Amount of bagasse released and actually used in particle board production as a result of the burning of alternate fuels.

The maximum value of B_a is the total amount of bagasse released by the mill as a result of the burning of alternate fuels, B_{at} . The value of B_{at} will, in turn, be equal to B_r or B'_r , which is the amount of bagasse required for the operation of the mill before the burning of alternate fuels. If the mill has undergone a program of mill efficiency improvement, B_{at} will equal B'_r ; if not, B_{at} will equal B_r .

The total annual costs of burning alternate fuels is given by

$$AC_t = DC_a + AI_a + OC_a + FC_a \quad (IV-23)$$

where

DC_a = annual depreciation charges on equipment used

in the burning of alternate fuels

$$= \frac{FE_i - FE_s}{T_{fe}} \quad (\text{See Equation IV-16}) \quad (\text{IV-24})$$

AI_a = annual interest charge on purchase price of equipment used in the burning of alternate fuels

$$= FE_i \times RI_a \quad (\text{See Equation IV-17}) \quad (\text{IV-25})$$

OC_a = annual operating costs incurred in the operation of equipment for burning alternate fuels, less any savings in operating costs resulting from the burning of alternate fuels.

FC_a = annual cost of alternate fuel

$$= \frac{TC_a \times H_r}{NHV_a} \times C_{fl} \quad \text{or} \quad \frac{TC_a \times H'_r}{NHV'_a} \times C_{fl} \quad (\text{IV-26})$$

where

NHV_a = Net Heat Value of alternate fuel burned in mill without improved efficiency (see Equation IV-12).

NHV'_a = Net Heat Value of alternate fuel burned in mill with improved efficiency (see Equation IV-19).

C_{fl} = local cost of alternate fuel.

Equations IV-22 through IV-26 can be combined to give the total cost per ton of bagasse released by the burning of alternate fuels and used in particle board production:

$$C_a = \frac{AC_t}{B_a} = \frac{DC_a + AI_a + OC_a + FC_a}{B_a}$$

$$= \frac{\frac{FE_i - FE_s}{T_{fe}} + (FE_i)(RI_a) + OC_a + \left(\frac{TC_a \times H_r}{NHV_a}\right)(C_{fl})}{B_a}$$

(Equation IV-27)

Equation IV-27 gives C_a for sugar mills which have not undergone a program of mill efficiency improvement; for mills which have had such a program, H'_r is used in place of H_r and NHV'_a in place of NHV_a in this equation.

B.5 Costs of Burning Supplemental Fuels

The cost per ton of bagasse released by the burning of supplemental fuels for use in bagasse particle board production is given as follows:

$$C_s = \frac{SC_t}{B_{sf}} \quad (IV-28)$$

where

SC_t = annual costs of burning supplemental fuels

B_{sf} = amount of bagasse released by the burning of supplemental fuel (a variable quantity).

The total annual costs of burning supplemental fuel are given by

$$SC_t = DC_s + AI_s + OC_s + FC_s \quad (IV-29)$$

in which DC_s , AI_s , and OC_s are similar to DC_a , AI_a , and OC_a as defined in Equation IV-23 and subsequent equations. FC_s is the annual cost of fuel incurred in burning supplemental fuels, and will vary according to the amount of bagasse released for other uses in any year. FC_s is defined by

$$FC_s = \frac{(TC_a)(H_r) - NHV_b(B_r - B_{sf})}{NHV_s} \times C_{sf} \quad (IV-30)$$

where

NHV_s = Net Heat Value of supplemental fuel burned at mill (see Equation IV-12).

C_{sf} = local cost of supplemental fuel.

Equation IV-30 gives FC_s for a mill which has not had a program of efficiency improvement; for a mill with improved efficiency, H'_r , NHV'_b , B'_r , and NHV'_s will replace H_r , NHV_b , B_r , and NHV_s in the equation.

Equations IV-28 through IV-30 can be combined to give

$$C_s = \frac{SC_t}{B_{sf}} = \frac{DC_s + AI_s + OC_s + FC_s}{B_{sf}}$$

$$C_s = \frac{\frac{FE_i - FE_s}{T_{fe}} + (FE_i)(RI_a) + OC_s + \frac{TC_a(H_r) - NHV_b(B_r - B_{sf})}{NHV_s}}{B_{sf}}$$

(Equation IV-31)

B.6 Evaluation of Bagasse Index

The principal factor in the Bagasse Index will in most cases be the Release Index ($R.I._b$), which gives the cost per ton of bagasse released from the sugar mill for use in particle board production. The value of $R.I._b$ will, in turn, depend on the mode or modes of bagasse release which are used to obtain the bagasse, and on certain key factors affecting each release mode.

In the case of savings per ton of bagasse which may result from the reduction or elimination of surplus bagasse disposal costs, as shown in Equation IV-13, the total disposal costs (C_d) are not necessarily a simple linear function of the quantity of surplus bagasse. In situations where the disposal of bagasse is becoming increasingly difficult -- as in Hawaii, for example, where the dumping of surplus bagasse into the ocean is being curtailed by environmental quality protection laws -- the disposal cost per ton of bagasse may increase with the size of the surplus which must be removed. Such relative cost increases will usually be necessitated by the need to install higher capacity or more effec-

tive disposal equipment as the surplus increases in magnitude. Curve S_d in Figure IV-5 represents such a progressive increase in the value of S_d .

In the case of costs per ton of bagasse resulting from the improvement of mill efficiency, as defined in Equation IV-21, DC_e and AI_e are typically sizeable fixed costs determined by the initial investment in the equipment for the improvement of mill efficiency. B_e , on the other hand, is a variable whose maximum value is B_{et} (Equation IV-20). Hence, C_e will vary inversely with B_e and will be at its minimum value only when B_e equals B_{et} , or in other words, when the bagasse actually utilized in the production of particle board is equal to the quantity of bagasse released by the improvement of mill efficiency. The variation of C_e with the quantity of bagasse used by the board plant is shown by Curve C_e in Figure IV-5.

In the case of bagasse released by the burning of alternate fuels, Equation IV-27 shows that the fixed annual costs of burning alternate fuels include costs resulting from the initial investment in the required equipment (DC_a and AI_a) and from the operating costs of burning the alternate fuel (OC_a and FC_a). The bagasse released by the burning of alternate fuel is equal to the quantity of bagasse previously required by the mill for the generation of heat (B_r or B'_r). Thus, the cost of bagasse used by the particle board plant will vary

inversely with B_a and will achieve its minimum value only when B_a equals the total amount released (B_r or B'_r). Curve C_a in Figure IV-5 shows the variation of C_a with the quantity of bagasse used by the particle board plant.

In the case of bagasse released by the burning of supplemental fuels, Equation IV-31 shows that the burning of supplemental fuels incurs fixed costs for equipment investment (DC_s and AI_s), but has variable operating costs (OC_s and FC_s) since the amount of supplemental fuel burned annually depends directly on the quantity of bagasse to be released each year. The net result of the variability of S_{ct} in this manner is that C_s will be equivalent to C_a when all the bagasse produced by the sugar mill is taken by the particle board plant, but C_s will be less than the corresponding value of C_a when less than the full output of bagasse is taken by the board plant. The variation of C_s with the quantity of bagasse taken by the board plant is indicated by Curve C_s in Figure IV-5.

The curves for the various bagasse release modes shown in Figure IV-5 indicate that the value of the Release Index for any given quantity of bagasse will depend on the release mode or modes used. The minimization of the Release Index will then depend on the determination of the release mode curves for any given situation. When the actual functions for S_d , C_e , C_a , and C_s are known, the combination of these modes which gives the lowest Release Index can be found for any

quantity of bagasse used by the particle board plant.

B.7 Resin Index

Resin may be purchased in ready-to-use form or prepared in a special facility at the board plant. In the case of imported or locally purchased prepared resin, the Resin Index is given by

$$R.I. = C_{ir} \times Q_r \quad (IV-32)$$

where

C_{ir} = cost of imported resin per pound

Q_r = quantity of resin required per ton of board
(in pounds).

In the event that the resin is prepared at the plant, the cost of the resin is then given by

$$C_{pr} = M_r + \frac{DC_r + AI_r + OC_r}{R_a} \quad (IV-33)$$

where

M_r = cost of raw materials used in resin production per pound of resin.

R_a = annual resin production used in board plant
(in pounds).

DC_r , AI_r , and OC_r are the depreciation, interest, and operating costs incurred by the resin preparation facility. (See Equation IV-15 and subsequent equations for elaboration of these costs.) Figure IV-6 shows the relative variation of two Resin Indices with the quantity of resin used annually by the board plant; one Resin Index is based on the importation of resin in a ready-to-use form, and the other Resin Index is based on the local production of the resin by the board plant. The slight downward slope of the curve for the Resin Index based on imported resin results from an assumed progressive price reduction for the purchase of increasingly larger quantities of resin. The inverse variation of the Resin Index based on locally prepared resin results from the fact that DC_r and AI_r are fixed quantities, while R_a is a variable, as shown in Equation IV-33.

The point at which then two Resin Index curves cross is the point at which production of resin at the board plant becomes more economical on a long-term basis. Figure IV-6 indicates that the importation of resin is not likely to be economic at high levels of resin consumption, such as those typically found in bagasse particle board plants.

B.8 Additive Index

All additives commonly used in bagasse particle board production, including insecticides and fungicides, are pur-

chased ready-to-use by the plant. Hence, the Additive Index is given directly by

$$\text{A.I.} = C_a \times Q_a \quad \text{for all additives} \quad (\text{IV-34})$$

where

C_a = cost of additive per pound

Q_a = pounds of additive per ton of board

It is likely that large-quantity purchases of additives will result in lower costs per pound of additives. Thus, the Additive Index may be expected to vary with the quantity of board produced in a manner similar to the variation of the Resin Index based on imported resin, shown in Figure IV-6.

B.9 Evaluation of Supply Index

Bagasse for particle board production may be obtained as surplus bagasse from sugar mills or released for use in boards by a program of mill efficiency improvement or by the burning of alternate or supplemental fuels. In the first case, the cost of the bagasse at the mill may be negative -- that is, the removal of the surplus bagasse by the board plant may represent a savings for the sugar mill and thus result in a credit for the board plant. This negative cost will be offset somewhat by the mill's profit margin (if any) and by the transport charges incurred in transferring the bagasse

to the board plant. In the second case, the annual costs of the initial investment in equipment make the cost of the bagasse highly dependent (inversely) on the quantity of bagasse used annually by the board plant.

Resin for bagasse particle board production may be imported at more or less fixed rates. Alternatively, resin may be produced at the board plant, in which case the cost of resin (and thus the Resin Index) varies inversely with the quantity of resin used by the plant.

Additives for bagasse particle board production represent a relatively fixed cost per ton of board produced by the plant.

The two different methods of obtaining both bagasse and resin make possible four alternative means of obtaining the materials needed for bagasse board production:

- (1) Use of surplus bagasse and imported resin;
- (2) Use of surplus bagasse and resin produced at the plant;
- (3) Use of bagasse released by the mills and imported resin;
- (4) Use of bagasse released by the mills and resin produced at the board plant.

Figure IV-7 shows a possible relationship of Supply Indices based on these four alternatives as functions of the quantity

of board produced annually. The determination of the minimum Supply Index for any proposed bagasse board plant will thus depend on the quantity of board to be produced annually, as well as purely local conditions.

C. Operations Index

The Operations Index, O.I., includes all direct costs incurred in the operation of the bagasse particle board plant. These direct costs of operation include labor, fuel, electrical power, maintenance, insurance, and miscellaneous costs. The Operations Index may therefore be defined by

$$O.I. = L.I. + E.I. + M.I.M.I. \quad (IV-35)$$

where

L.I. = Labor Index

E.I. = Energy Index

M.I.M.I. = Maintenance, Insurance, and Miscellaneous
Index

C.1 Labor Index

The number of employees required for the operation of a bagasse particle board plant does not vary greatly over a broad range of plant capacities. The number of employees required to operate a plant designed for 12,000 tons annual capacity, for example, need not be very different from the

number of employees required for the operation of a plant designed for 30,000 tons annual capacity. Both plants would require about the same number of human functions, and one or two workers is usually adequate to perform any given function. A fixed manpower requirement such as this is to be expected, of course, in a largely mechanized operation such as the typical modern bagasse particle board plant. Thus, the distribution and total number of workers shown in Table IV-1 may be taken as typical for a broad range of plant capacities.

The Labor Index can be conveniently defined as

$$\text{L.I.} = \frac{C_1}{Q_b} \quad (\text{IV-36})$$

where

C_1 = total annual payroll

Q_b = annual production of board (tons)

The total annual payroll will vary with the wages and salaries paid to the various types of workers, with the number of days worked per year, and the number of shifts worked per day. For any given number of workdays per year, the annual payroll can be expected to vary with annual production as shown in Figure IV-8a. The increments in the payroll step-function occur at the points of 100% utilization of

plant capacity per shift; that is, when actual plant production reaches one-third of total annual plant capacity, a new shift is added to increase production. The effect of this variability of annual payroll with annual production will be a Labor Index function similar to that shown in Figure IV-8b. The normal range of values of the Labor Index -- excluding Labor Indices based on less than approximately 15% utilization of plant capacity -- is also shown in Figure IV-8b.

C.2 Energy Index

The Energy Index, E.I., gives the cost for energy consumed by the board plant per ton of board produced. Thus,

$$E.I. = (F_c)(C_{lf}) + (E_b)(C_{le}) \quad (IV-37)$$

where

F_c = Fuel (usually oil or natural gas) required per ton of board produced

C_{lf} = local cost per unit of fuel delivered to plant

E_b = Electricity consumed per ton of board, in KWH

C_{le} = cost of electricity per KWH

The fuel consumed in the production of one ton of bagasse particle board will depend on the efficiency of the bagasse fiber dryers and on the consumption of the diesel or other

type generators if electricity is generated at the plant. The cost of the electricity per KWH will also depend on the source of the electricity. If the electricity is purchased directly from a utility system, C_{1e} will be fixed by the local price of electricity. If the electricity is generated at the plant, on the other hand, C_{1e} will then be given by

$$C_{1e} = \frac{DC_{el} + AI_{el} + OC_{el}}{Q_b \times E_b} \quad (IV-38)$$

In this equation, DC_{el} , AI_{el} , and OC_{el} are the usual depreciation, interest, and operating charges associated with the electrical generating equipment installed at the plant (see Equation IV-15 and subsequent equations). If electricity is generated at the plant, then C_{1e} (and therefore the Energy Index) will vary inversely with the quantity of board produced annually. Figure IV-9 shows the variation of the two Energy Indices based on the two alternate modes of obtaining electricity, as functions of the quantity of board produced annually.

C.3 Maintenance, Insurance, and Miscellaneous Index

Insurance and miscellaneous costs are likely to be substantially independent of production levels attained at the bagasse particle board plant. Maintenance costs, however,

will usually vary directly with plant utilization. These variations in costs with levels of production are shown in Figure IV-10a. The resultant variation in the Maintenance, Insurance, and Miscellaneous Index, which is simply the sum of these costs divided by the annual output of board (Q_b), is shown in Figure IV-10b.

C.4 Evaluation of the Operations Index

Labor costs per ton of board produced will vary principally with the production levels achieved at any given number of shifts worked per day (see Figure IV-8b). Energy costs per ton of board produced (E.I.) will be constant over the full range of production levels if the electricity is purchased from a utility system or other outside source, but will vary inversely with the annual output of board (Q_b) if the electricity is generated at the board plant. The costs of maintenance, insurance, and miscellaneous items will vary inversely to some extent with the annual output of board.

Thus, two alternate Operations Indices are possible, depending on the method used to obtain electricity. Figure IV-11 shows a typical variation of Operations Indices based on each alternative, as functions of the quantity of board produced annually by the plant. There clearly exists a level of production at which the generation of electricity at the

plant becomes more economic on a long-term basis than the direct purchase of electricity.

D. Debt Service Index

The Debt Service Index is based on the annual cost of the service to the debt incurred in capitalizing the bagasse particle board plant. The annual debt service is the total interest paid and principal amortized during any year. Thus, the Debt Service Index is defined by

$$\text{D.S.I.} = \frac{\text{DS}_a}{\text{Q}_b} \quad (\text{IV-39})$$

where

DS_a = annual debt service

Q_b = annual board production (tons)

Since the annual debt service in any year is ordinarily fixed by the initial financial arrangements, the actual debt service may have a wide range of possible values. The debt service in any bagasse particle board operation is likely, nevertheless, to be a sizeable annual cost. In addition, the Debt Service Index will vary inversely with the quantity of board produced during any year, and a high utilization of plant capacities will usually be necessary to keep the Debt Service Index at reasonable levels.

Since the Debt Service Index is likely to be sizeable relative to the total cost of the particle board resulting from other expenses, care must be taken in the initial financial arrangements to insure that an undue burden is not placed on the board plant in its initial stages of operation. The reduction of debt service in the early years of operation may be accomplished, in general, by seeking low interest rates, extended periods of amortization, or postponed payment of interest and/or principal. Figure IV-12 shows variations in the annual debt service resulting from

- (1) a loan at 8% interest and a 10-year amortization;
- (2) a loan at 6% interest and a 10-year amortization;
- (3) a loan at 6% interest and a 20-year amortization;
- (4) a loan at 6% interest, 20-year amortization, and a 5-year postponement of principal repayments.

Such variations in the terms of debt service will have considerable impact on the annual debt service in any year and thus on the Debt Service Index. A thorough investigation of all available debt financing schemes should therefore be made in order to obtain the most favorable Debt Service Index in the early years of the plant's operation, consistent with the anticipated ability of the plant to service debt in its later, more stable years of operation.

E. Depreciation Index

Depreciation of the plant equipment, while not representing an immediate outflow of cash, should be viewed as a real and current cost since the plant equipment will inevitably have to be replaced at some real cost at some time in the future. Depreciation rates on the major equipment in a modern bagasse particle board plant may conservatively be taken as 10% of the initial cost per year (10-year straight-line depreciation). Other equipment, such as forklifts and trucks, will ordinarily be depreciated at 20% per year (5-year straight-line depreciation). For any piece of equipment, the depreciation period and the depreciation rate (straight-line, declining balance, or other) should reflect the real deterioration of the equipment in order to provide sufficient allocation of funds for future replacement of equipment.

The Depreciation Index is given directly by

$$D.I. = \frac{D_a}{Q_b} \quad (IV-40)$$

where

D_a = total annual depreciation charges

Q_b = annual board production (tons)

Since depreciation costs are fixed by the initial cost of the plant equipment, the depreciation cost per ton of

board produced (the Depreciation Index) will vary inversely with the total annual production. Depreciation charges are a sizeable item in the overall economics of plant operations, and the degree of utilization of plant capacity will therefore have considerable effect on the total operating costs per ton of board produced.

F. Profit Index

The Profit Index (P.I.) gives the profit margin (before taxes) per ton of board produced by the bagasse particle board plant. The Profit Index is given directly by

$$P.I. = M.I. - (S.I. + O.I. + D.S.I. + D.I.) \quad (IV-41)$$

In the analysis of possible investments in bagasse particle board plants, the Profit Index will serve as a simple and direct measure of the profitability -- and therefore, to a large extent the feasibility -- of each possible production scheme. The iteration of the possible Profit Indices associated with the possible production modes can be made by the procedure shown in simplified form in Figure IV-13 and in expanded form in Figures IV-14 through IV-18, used in conjunction with the simple relationship shown in Equation IV-41.

The Profit Index for any given production mode will be a function which shows the variation of profits per ton of

board produced with the annual quantity of board produced, since the Indices from which the Profit Index is derived are similarly functions of the quantity of board produced (Q_b). Thus, the application of this investment analysis procedure to the specific conditions surrounding a proposed bagasse particle board operation will yield several Profit Index functions, each representing a Profit Index based on a particular unique path through the choice of alternatives available in the various Indices. One possible Profit Index function, for example, might be based on a 75% penetration of a given market (see Figure IV-14), the use of surplus bagasse and imported resin (Figure IV-15), the use of electricity purchased direct from a public utility system (Figure IV-16), a given financing scheme (Figure IV-17), and depreciation charges based on a particular set of equipment (Figure IV-18). Other Profit Index functions would be based on other of the possible alternatives for each Index.

The family of Profit Index functions for a proposed bagasse particle board plant might resemble those shown in Figure IV-19. On the basis of such functions, the profitability of the various modes of production at various levels of production can be determined. The mode of maximum profitability for a given production level is then directly observable.

In sum, then, the investment analysis framework elaborated in this section provides the methodology for the compar-

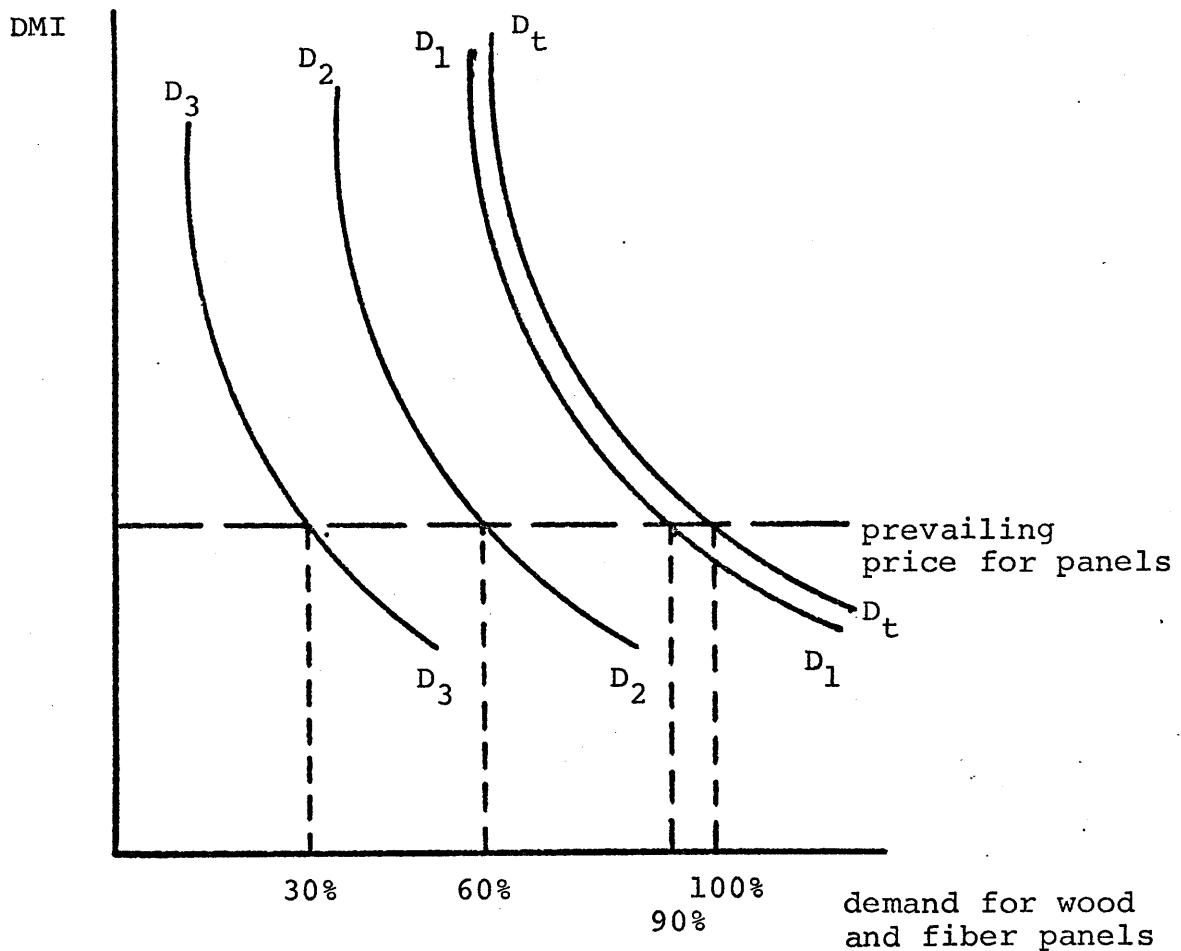
ison and evaluation of the profitability (and feasibility) of the various modes of production which are possible under the restraints and conditions governing any proposed investment in bagasse particle board production.

FUNCTION	LEVEL OF SKILL OF EMPLOYEE			
	<u>Unskilled</u>	<u>Semi-skilled</u>	<u>Skilled</u>	<u>Supervisors</u>
Bagasse Supply:				1
Supply trucks	2			
Front-loader		1		
Conveyor station			1	
Depithing and Briquetting:				1
Machine attendant			1	
Briquette storage		1		
Mixing Station	1		1	
Pressing Station		1	1	1
Finishing Station	2	2		
Warehouse:				
Forklifts		2		
Delivery trucks	2			
Maintenance:				
Mechanic			1	
Electrician			1	
Total Production Workers/Shift	<u>7</u>	<u>7</u>	<u>6</u>	<u>3</u>

Administration:

- 1 General manager
- 3 Plant engineers (one per shift)
- 3 Clerical and bookkeeping

TABLE IV-1: LABOR REQUIRED FOR OPERATION OF TYPICAL BAGASSE
PARTICLE BOARD PLANT.



Curve D_t - D_t : Total demand for all wood and fiber panels

Curve D_1 - D_1 : Demand curve for 90% market penetration by bagasse particle board

Curve D_2 - D_2 : Demand curve for 60% market penetration

Curve D_3 - D_3 : Demand curve for 30% market penetration

FIGURE IV-1: DEMAND FUNCTIONS FOR BAGASSE PARTICLE BOARDS

AT 100%, 90%, 60%, and 30% MARKET PENETRATIONS

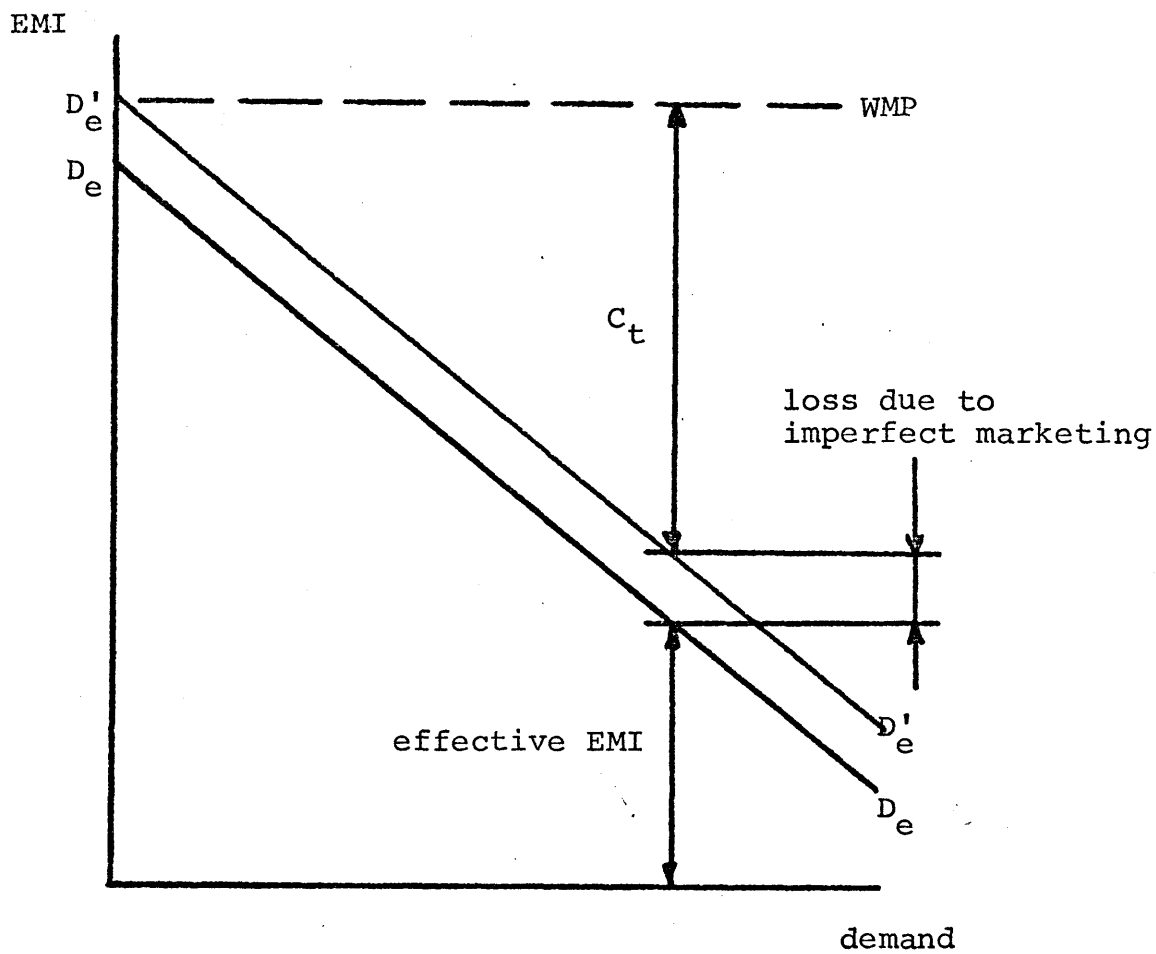
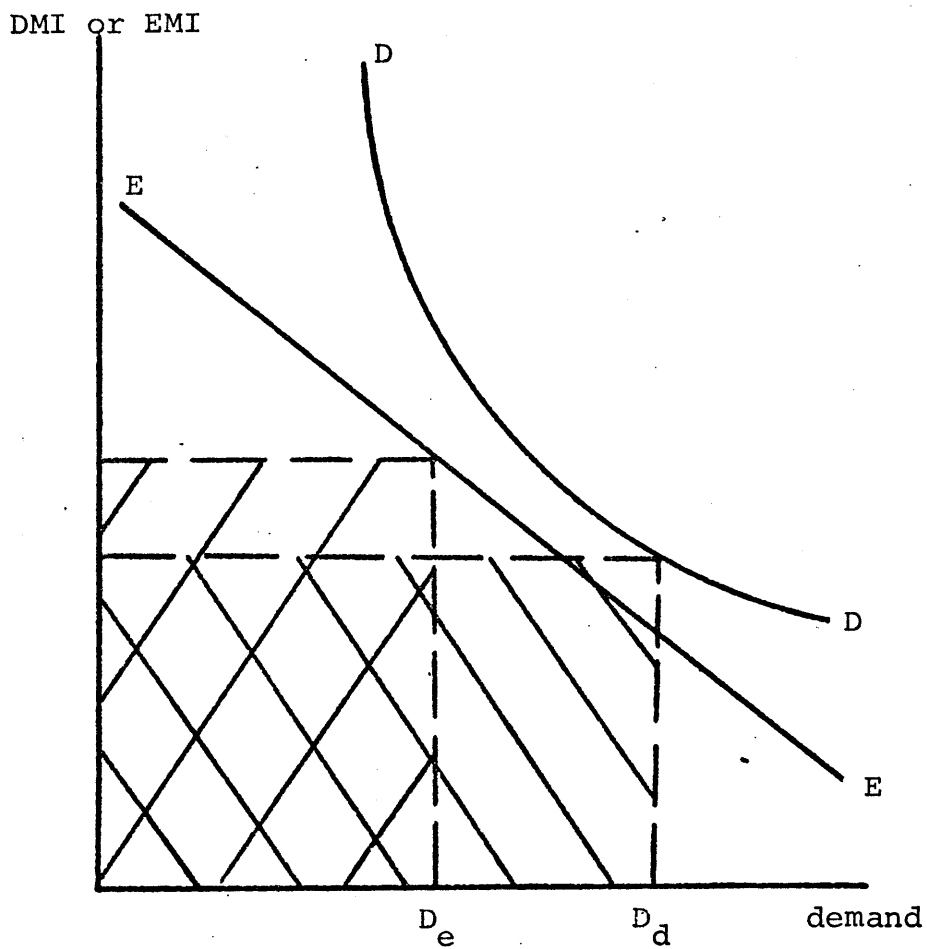


FIGURE IV-2: EXPORT MARKET INDEX (EMI) AS A FUNCTION OF EXPORT DEMAND SUPPLIED BY BOARD PLANT.



Curve D-D: Domestic demand function

Curve E-E: Export demand function

FIGURE IV-3: DOMESTIC AND EXPORT DEMAND FUNCTIONS.

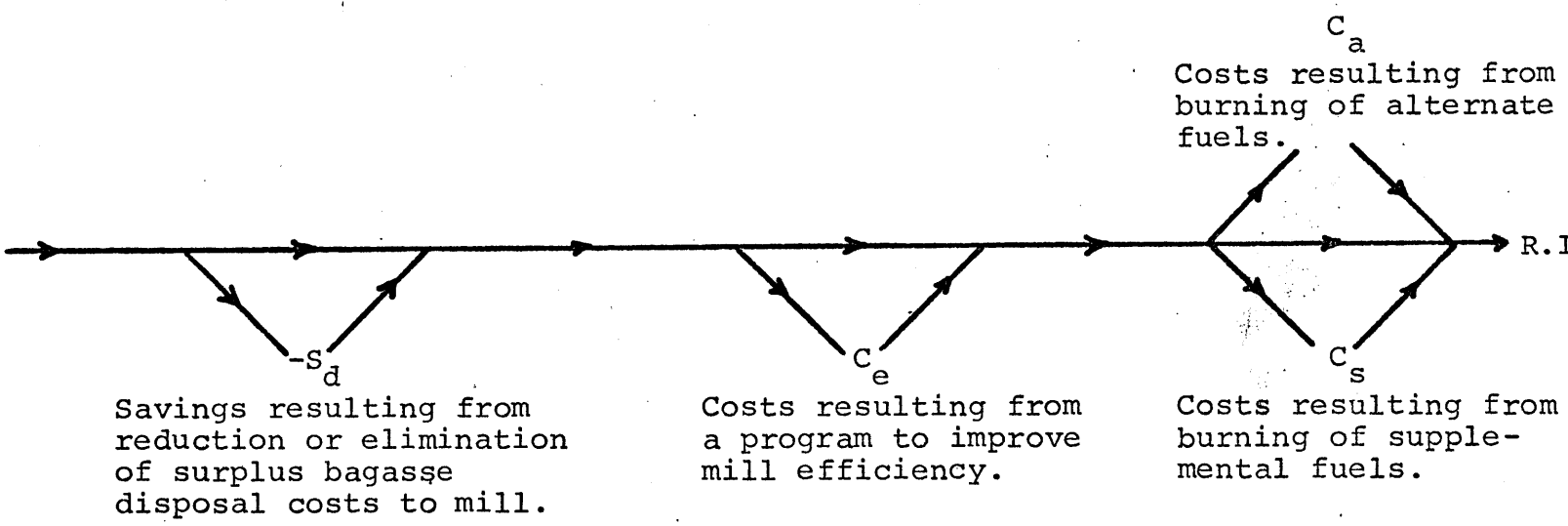


FIGURE IV-4: FLOW PATH FOR DETERMINATION OF RELEASE INDEX (R.I._b)

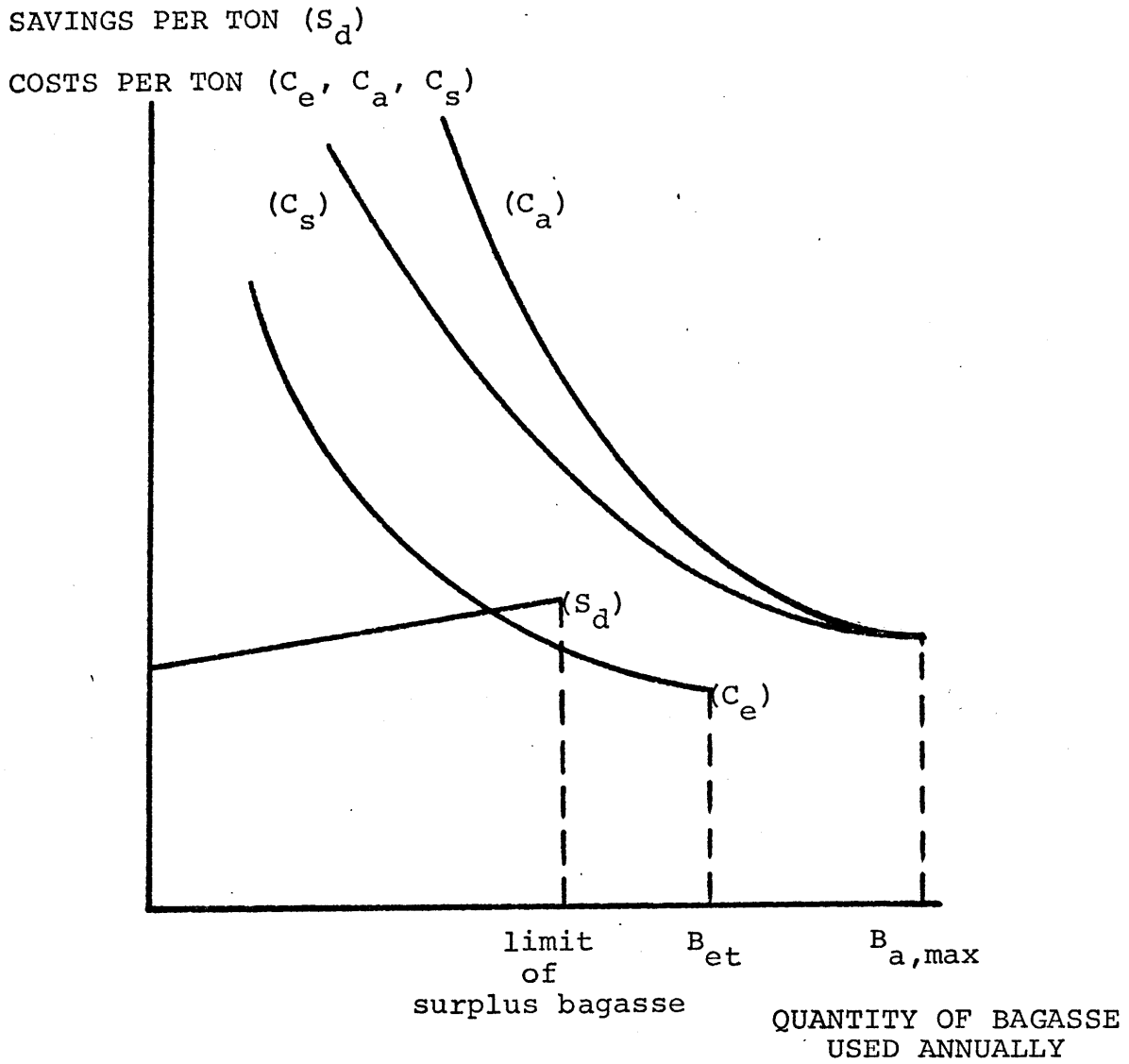
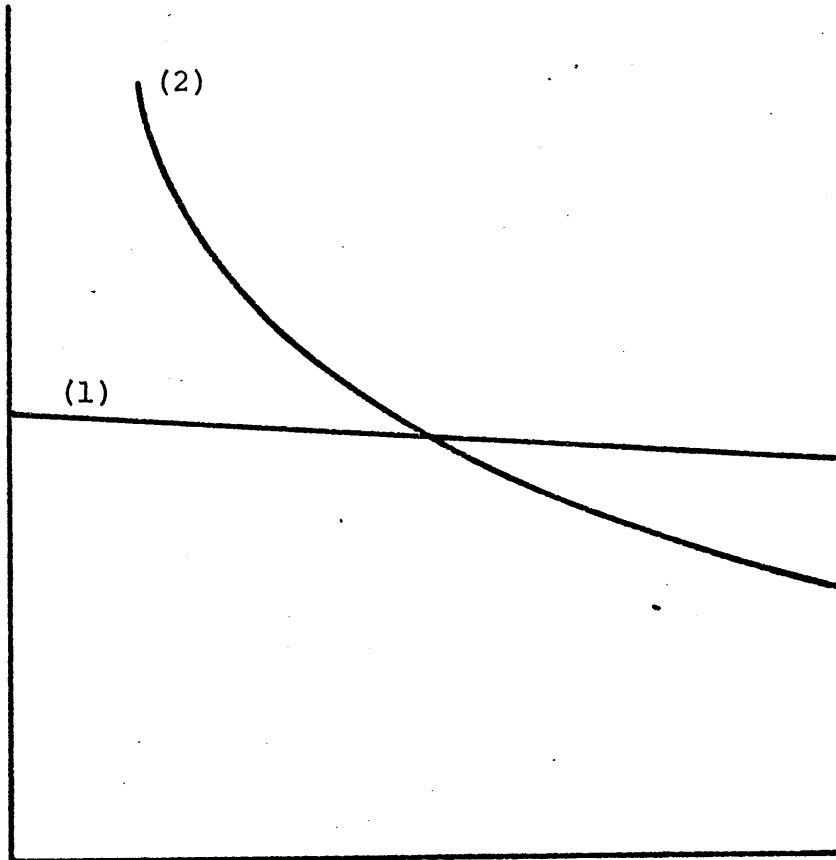


FIGURE IV-5: SAVINGS PER TON AND COSTS PER TON ASSOCIATED WITH FOUR BAGASSE RELEASE MODES, AS FUNCTIONS OF ANNUAL QUANTITY OF BAGASSE USED BY PLANT.

RESIN INDEX

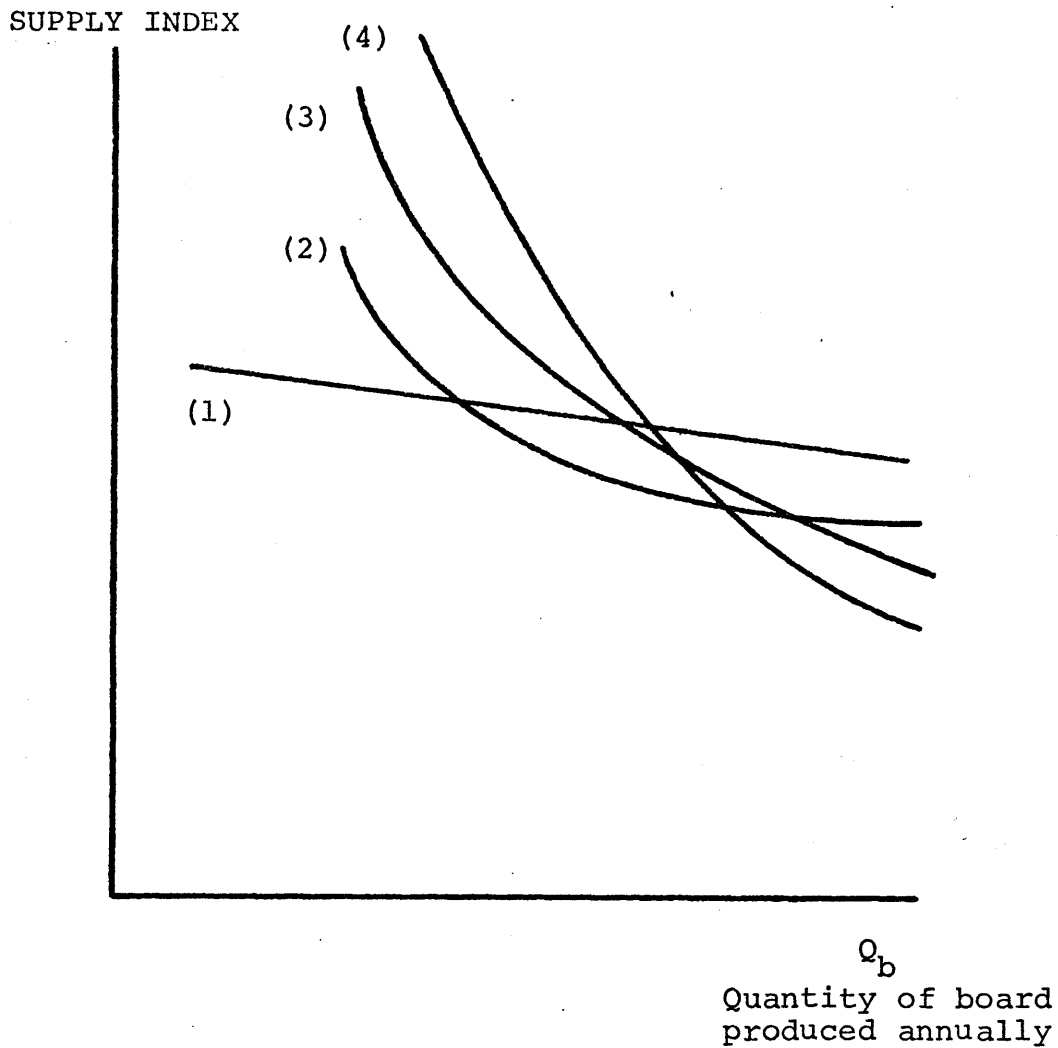


Quantity of resin
used by board
plant annually

Resin Index functions based on:

- (1) imported resin
- (2) resin produced at board plant

FIGURE IV-6: ALTERNATE RESIN INDICES AS FUNCTIONS OF
RESIN USED ANNUALLY BY PLANT.



Supply Index functions based on:

- (1) surplus bagasse and imported resin
- (2) surplus bagasse and resin produced at board plant
- (3) released bagasse and imported resin
- (4) released bagasse and resin produced at board plant

FIGURE IV-7: ALTERNATE SUPPLY INDICES AS FUNCTIONS OF BOARD PRODUCED ANNUALLY.

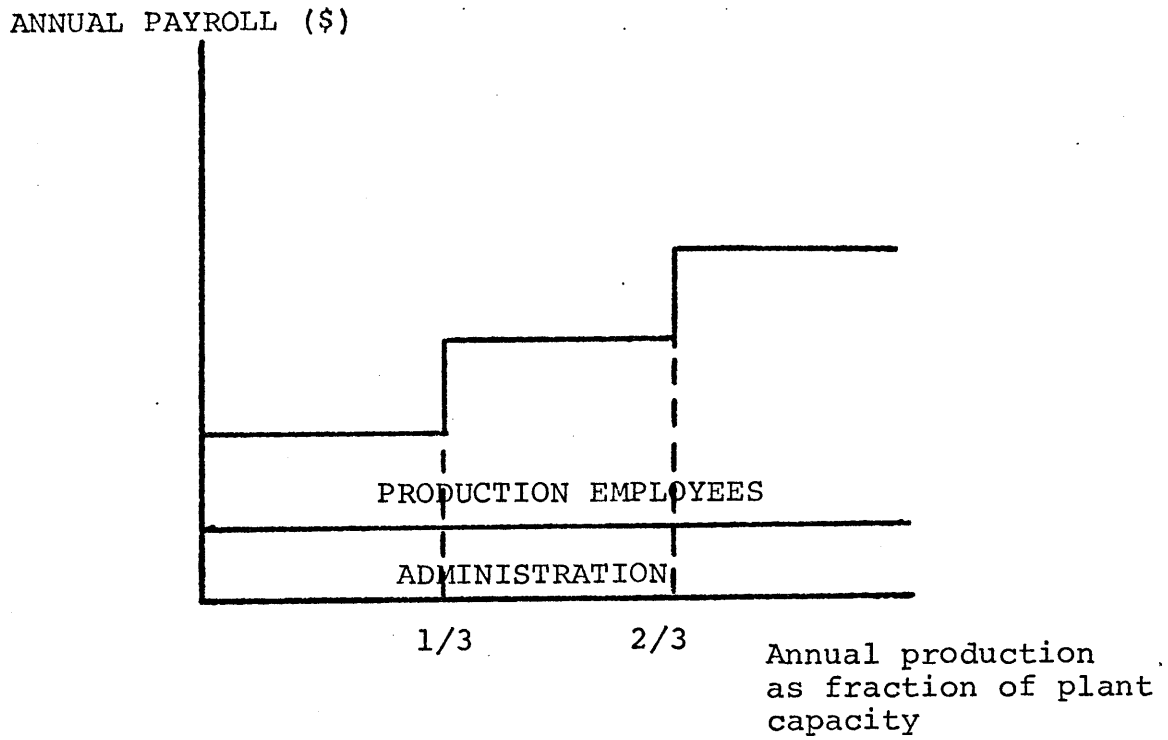


FIGURE IV-8a: VARIATION OF ANNUAL PAYROLL WITH PRODUCTION.

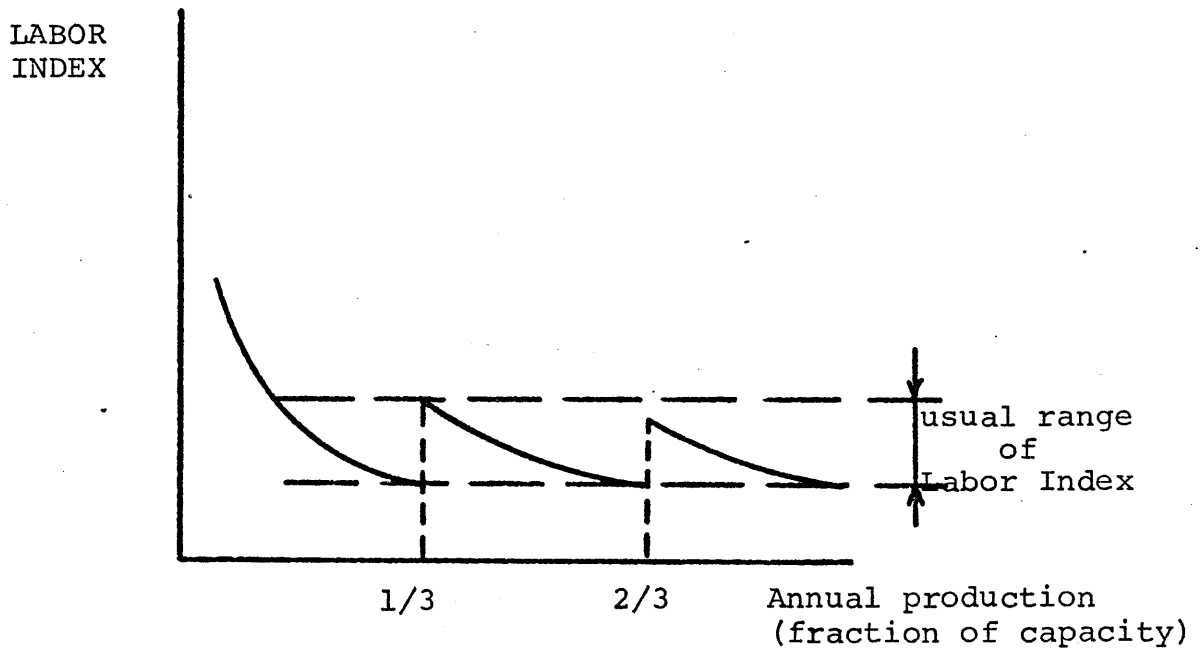
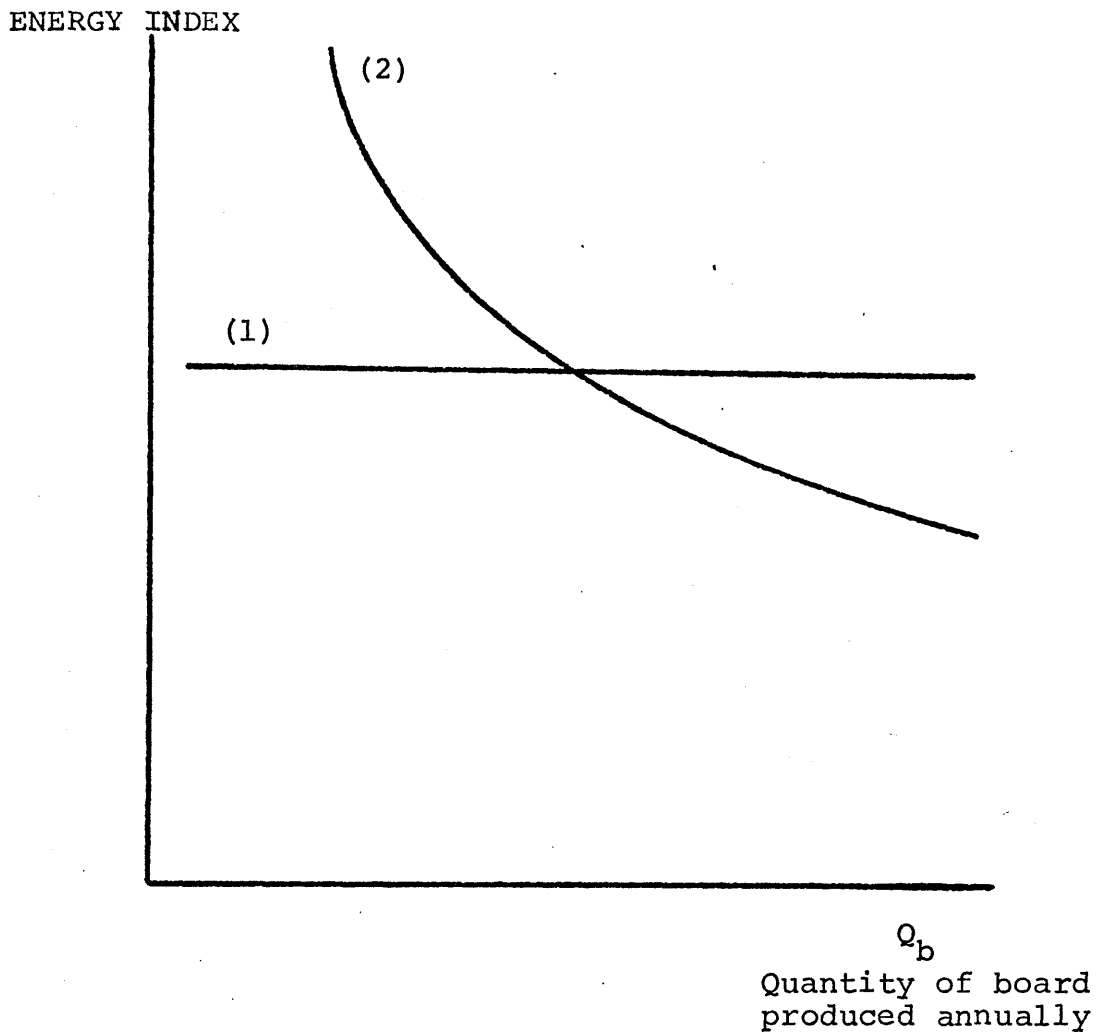


FIGURE IV- 8 b: VARIATION OF LABOR INDEX WITH ANNUAL PRODUCTION



Energy Index functions based on:

- (1) purchase of electricity from utility system
- (2) generation of electricity at board plant

FIGURE IV-9: VARIATION OF ENERGY INDEX WITH ANNUAL BOARD PRODUCTION, BY SOURCE OF ELECTRICITY.

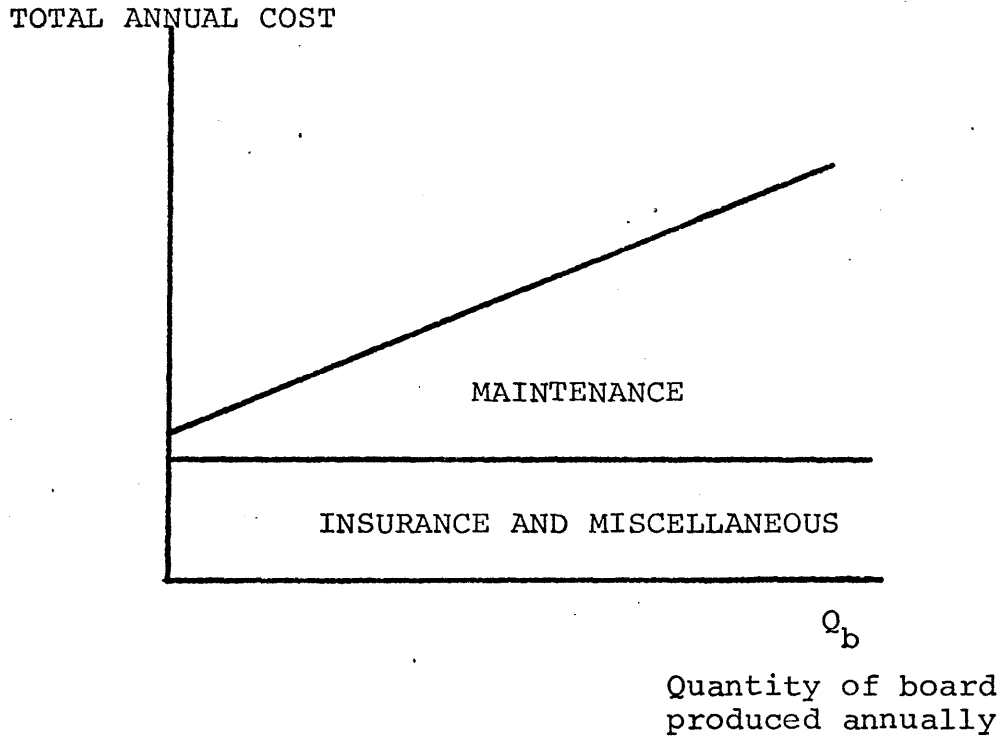


FIGURE IV-10a: VARIATION IN MAINTENANCE, INSURANCE, AND MISCELLANEOUS COSTS WITH ANNUAL PRODUCTION.

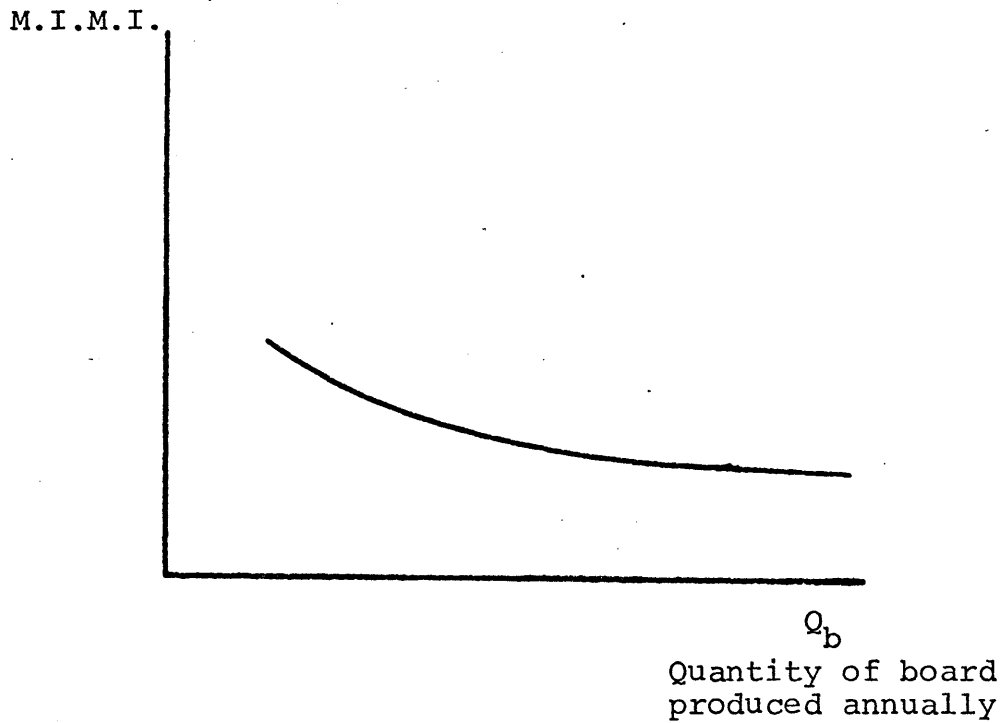
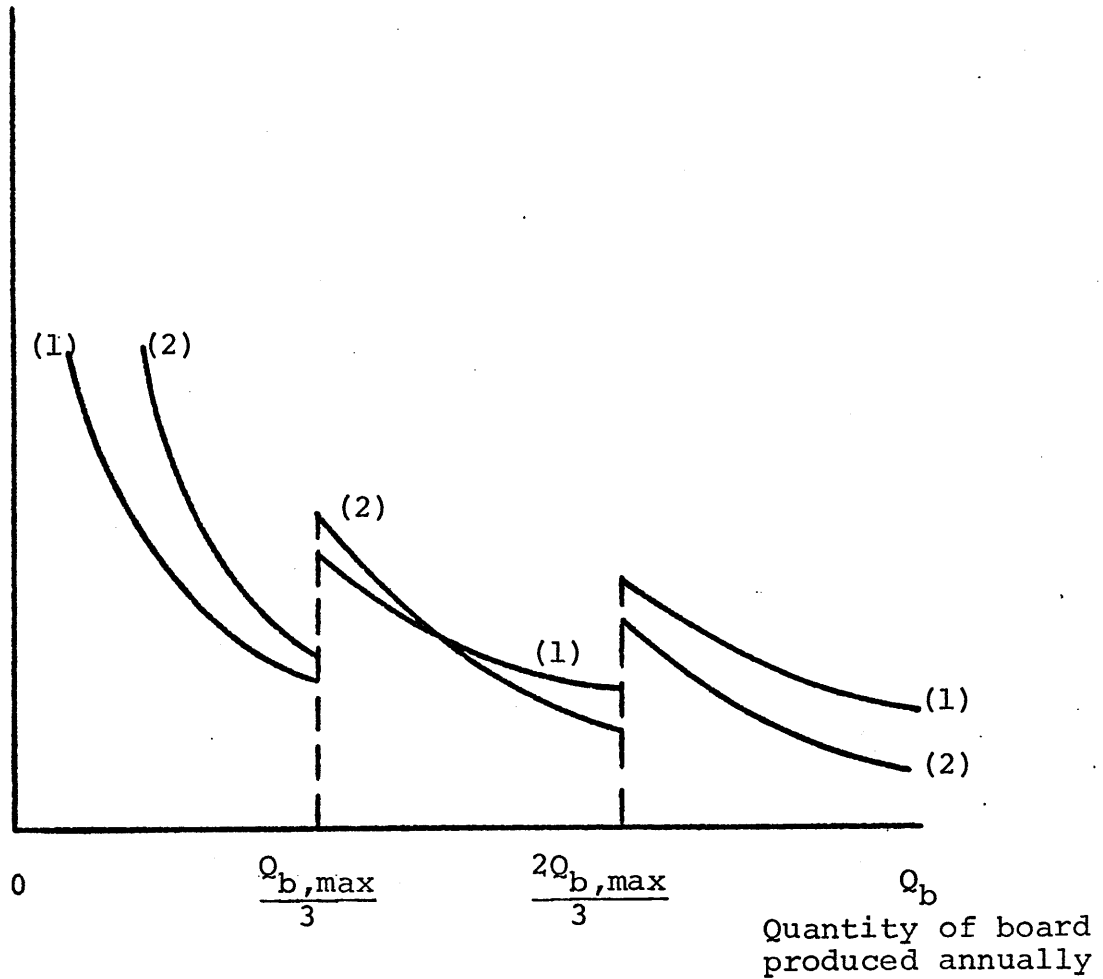


FIGURE IV-10b: VARIATION OF M.I.M.I. WITH ANNUAL PRODUCTION

OPERATIONS INDEX

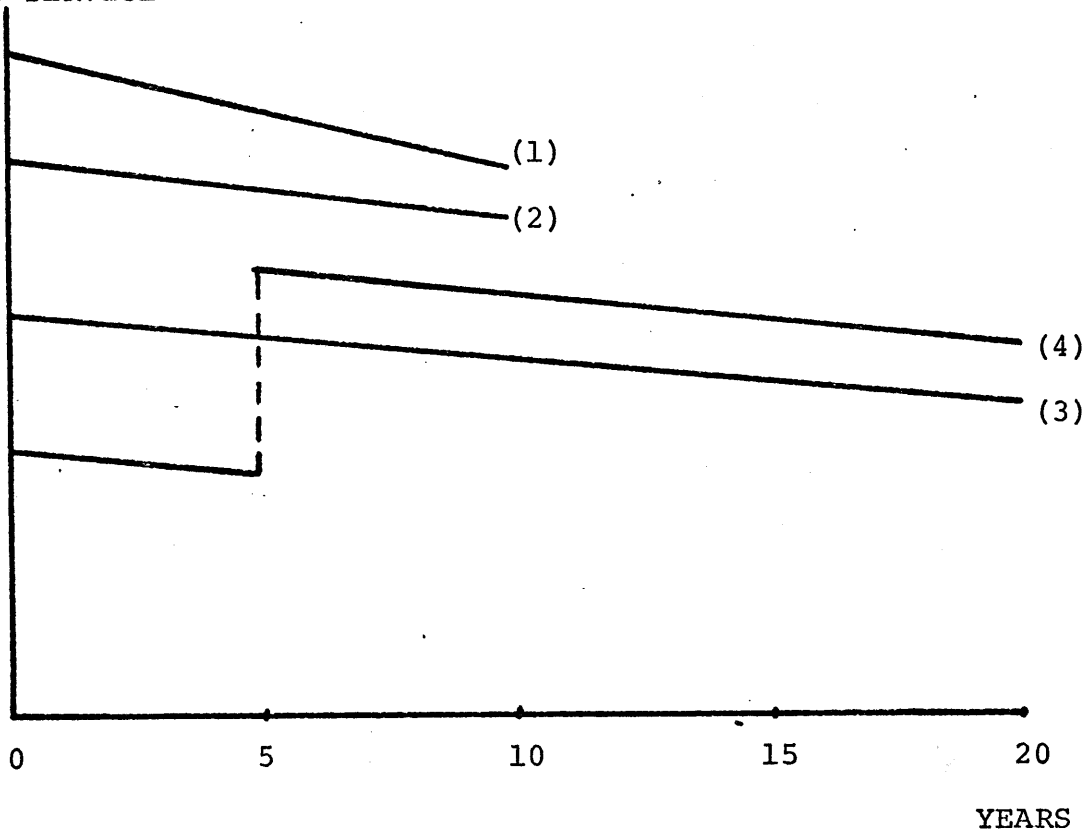


Operations Index functions based on:

- (1) Purchase of electricity from utility system
- (2) Generation of electricity at board plant

FIGURE IV-11: VARIATION OF OPERATIONS INDICES WITH ANNUAL PRODUCTION LEVELS, BY SOURCE OF ELECTRICITY.

ANNUAL
DEBT SERVICE



Annual Debt Service based on:

- (1) 8% interest and 10-year amortization
- (2) 6% interest and 10-year amortization
- (3) 6% interest and 20-year amortization
- (4) 6% interest, 20-year amortization, and postponement of repayment of principal for 5 years

FIGURE IV-12: ANNUAL DEBT SERVICE FOR FOUR FINANCING SCHEMES

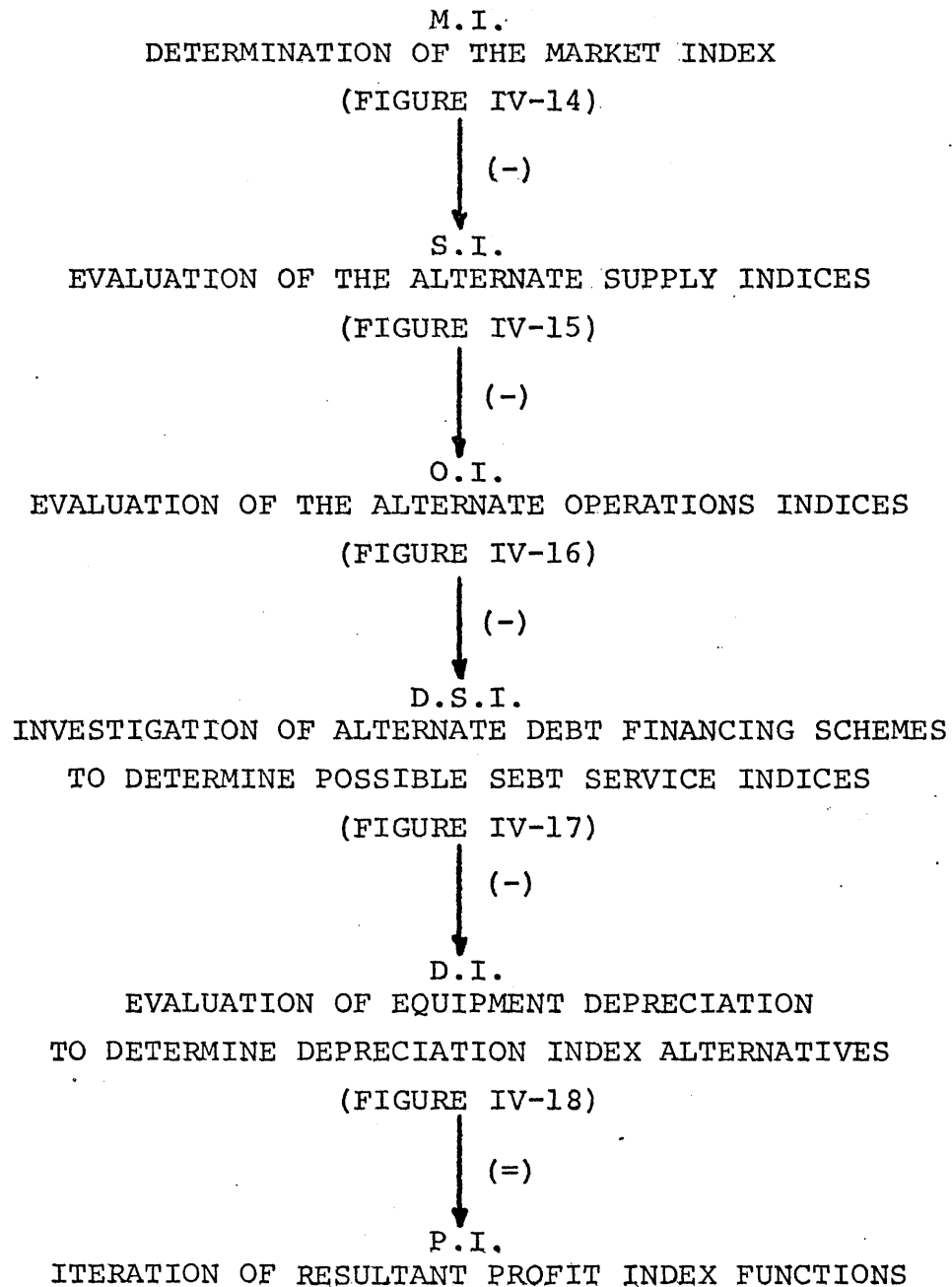


FIGURE IV-13: INVESTMENT ANALYSIS PROCEDURE FLOW CHART

DOMESTIC MARKET INDEX (DMI)

Determination of domestic market demand function for all wood and fiber panels. Estimation of market penetration by bagasse particle boards.

DOMESTIC DEMAND

Determination of optimal domestic demand D_d and evaluation of expected and minimum domestic demand.

EXPORT MARKET INDEX (EMI)

Determination of export market demand function based on World Market Price (WMP) for particle board and transport costs (C_t).

EXPORT DEMAND

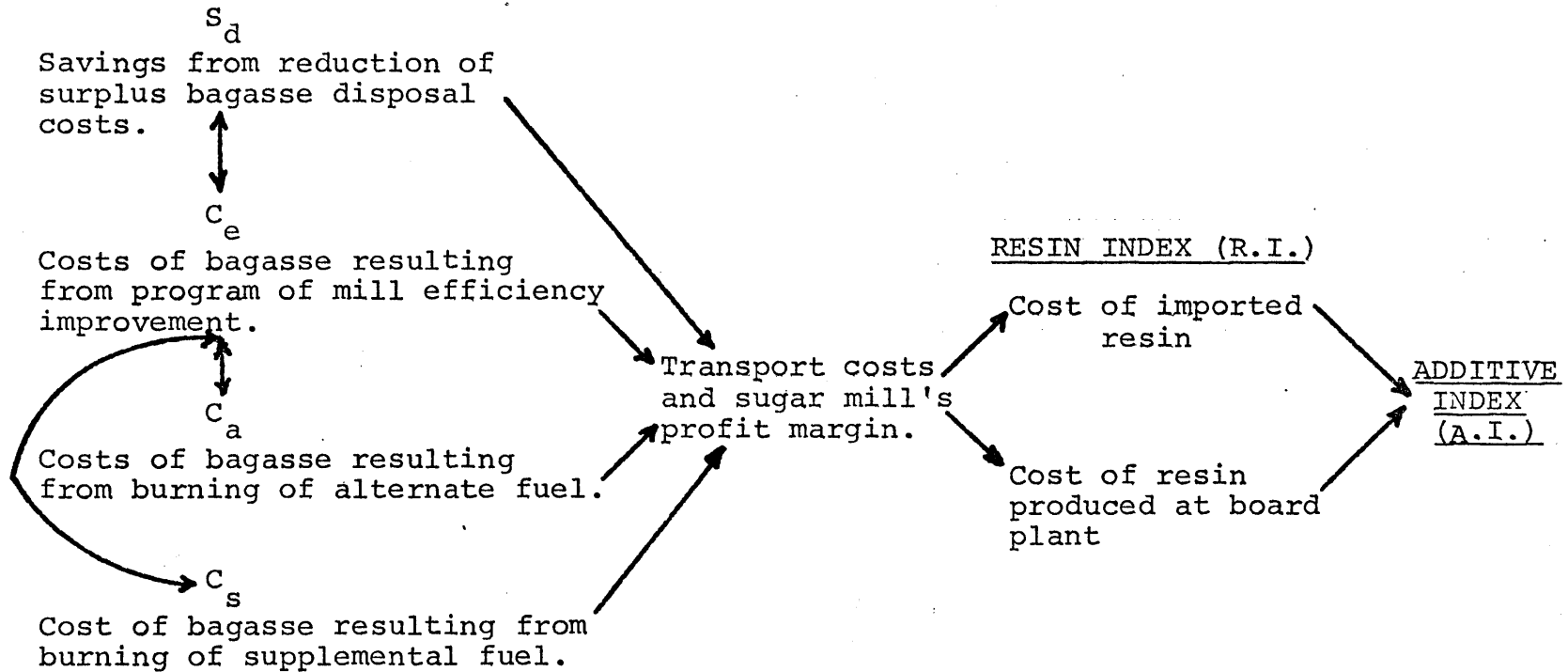
Determination of optimal export demand D_e and evaluation of expected and minimum export demand.

MARKET INDEX (M.I.)

Determination of optimal, expected, and minimum Market Indices and demand levels for bagasse particle board.

FIGURE IV-14: DETERMINATION OF THE MARKET INDEX.

BAGASSE INDEX (B.I.)



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FIGURE IV-15: EVALUATION OF THE ALTERNATE SUPPLY INDICES

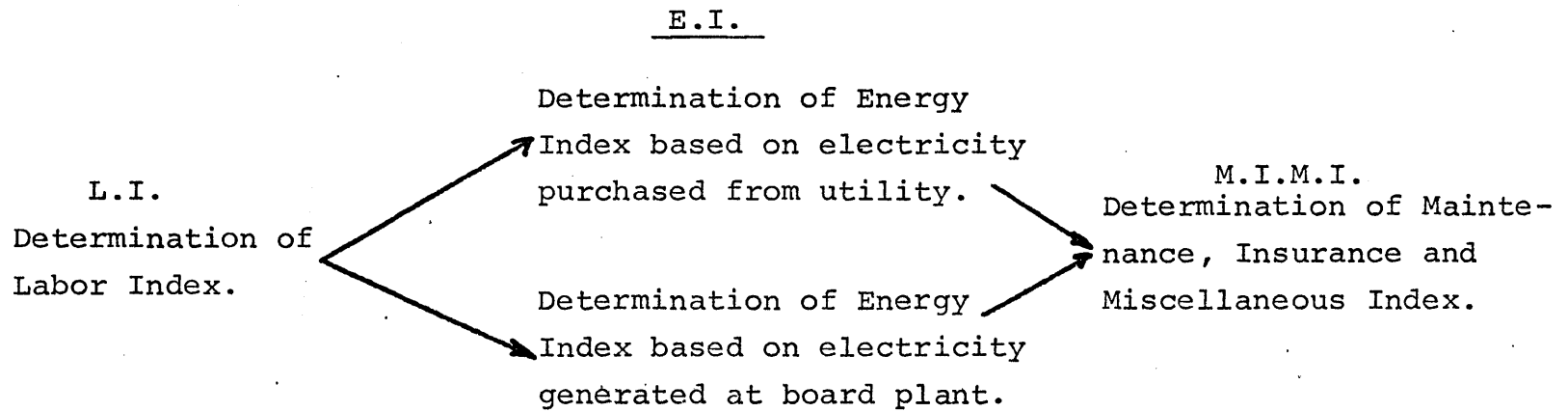


FIGURE IV-16: EVALUATION OF THE ALTERNATE OPERATIONS INDICES

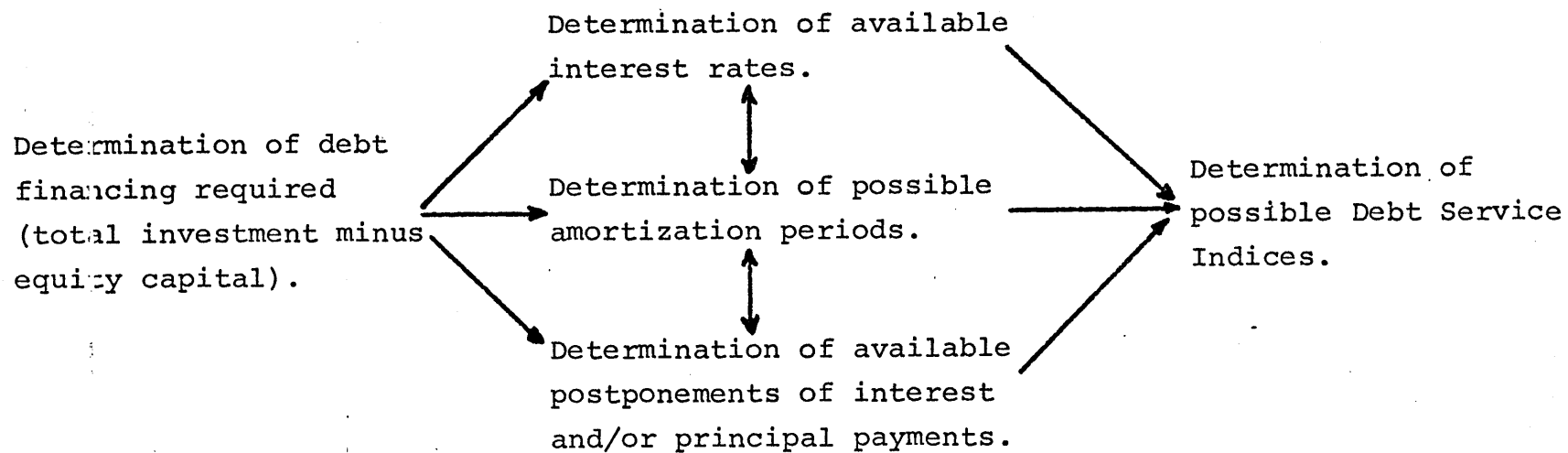


FIGURE IV-17: INVESTIGATION OF ALTERNATE DEBT FINANCING SCHEMES.

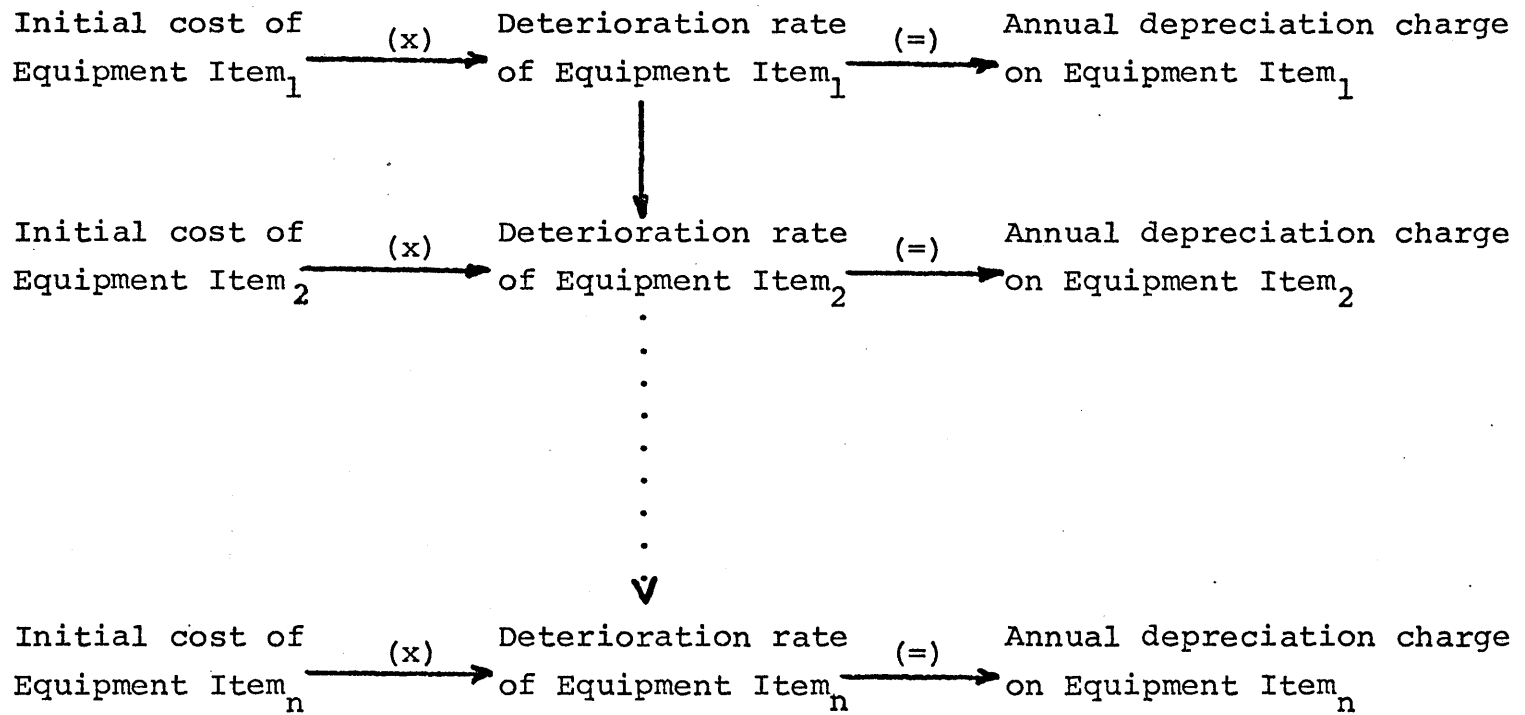


FIGURE IV-18: EVALUATION OF ALTERNATIVE DEPRECIATION INDICES.

PROFIT INDEX

(+)

(-)

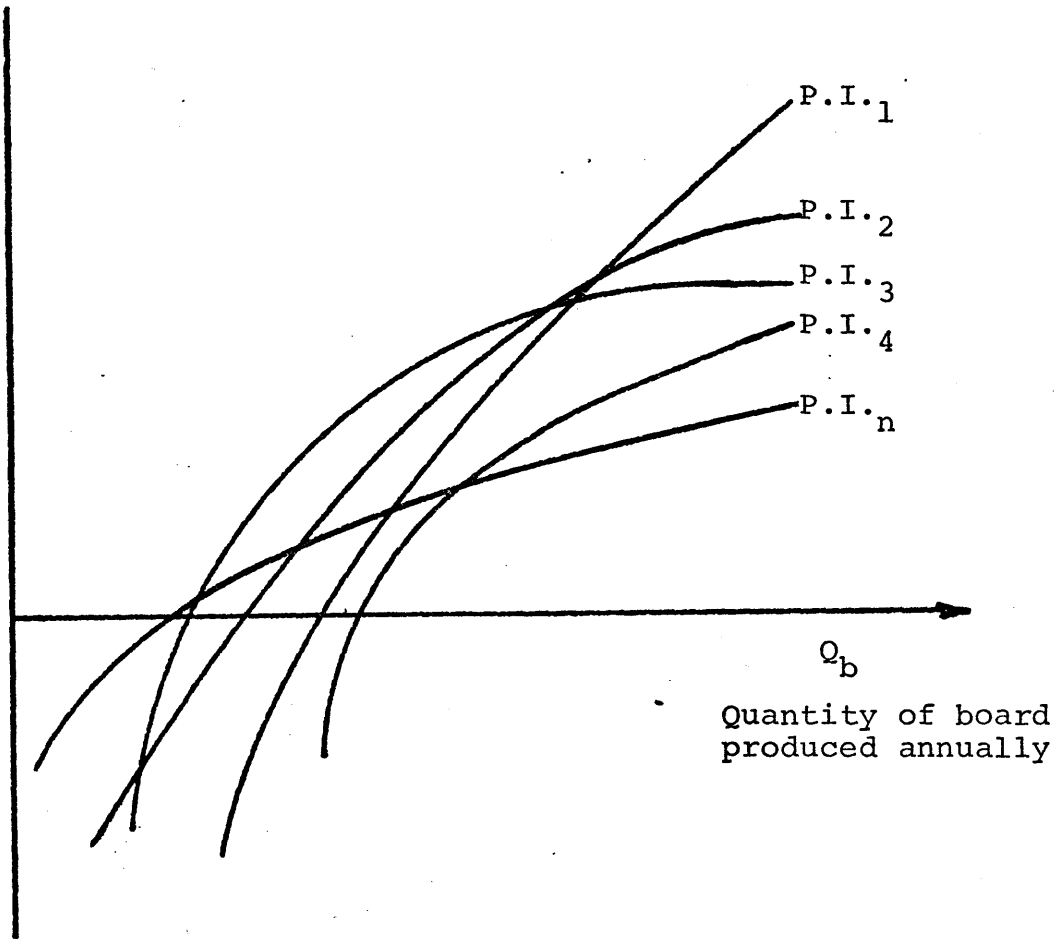


FIGURE IV-19: FAMILY OF PROFIT INDEX FUNCTIONS FOR A GIVEN BAGASSE PARTICLE BOARD OPERATION.

V. APPLICATION OF INVESTMENT ANALYSIS

To lend some specificity to the investment analysis framework elaborated in Section IV, a hypothetical investment proposal for a bagasse particle board plant is used as an example for analysis in this section. In this hypothetical example, every effort has been made to incorporate accurate estimates of actual costs and other requirements likely to be encountered in such a project. Thus a reading of this investment analysis will provide the reader not only with the methodology for the evaluation of the economic soundness of the proposal, but also with a sampling of typical or possible costs and other requirements associated with such a project.

Part A of this section states the hypothetical investment proposal for a bagasse board plant to be established in the mythical developing country of Azucaria. In part B, the investment analysis methodology is applied to the example to determine the optimum choices among the alternative production modes given in the example.

The investment analysis of part B has been facilitated by the use of computer simulation based on DYNAMO II, a compiler language available on the IBM 360/65 computer at the M.I.T. Computation Center. For the reader familiar with DYNAMO II, it may be useful to mention that the time increment DT was used to represent increments in the quantity

of board produced annually (the independent variable in all the Indices of the investment analysis). Table V-1 shows the program used for the simulation of several of the variables in the Indices.

A. An Investment Proposal for a Bagasse Particle Board

Plant -- A Hypothetical Example

It is proposed to establish a plant for the production of bagasse particle board in Azucaria, a developing country of 8,000,000 persons. The proposed facility -- to be owned and operated by the newly-formed ParBoard Company of Azucaria -- will manufacture first-quality, exterior-grade particle board from sugar cane bagasse, which is available in large quantities from the domestic sugar industries of Azucaria.

The marketing expectations for ParBoard are as follows: All wood and fiber panels in use in Azucaria are currently imported. Large amounts of plywood and lesser amounts of fiberboards and particle board are known to be imported annually, but precise figures are lacking. A local market survey by a competent consulting firm has yielded the domestic demand curve shown in Figure V-1 and has indicated that a market penetration of 75% is to be expected for ParBoard if it is competitively priced with plywood. The consultants further estimated that 90% and 50% would be the maximum and minimum market penetrations for ParBoard if competitively

priced. The market survey also noted that the existing transport network of Azucaria would permit distribution of ParBoard to only 6,000,000 persons. Noting also that the per capita GDP of Azucaria is \$375, the market survey predicted an annual per capita consumption of all wood and fiber panels of 4.5 kg, based on the United Nations regression analysis equation (see Figure II-8). Thus the total anticipated domestic demand for ParBoard is estimated to be 20,250,000 kg annually (6,000,000 persons x 4.5 kg per person x 0.75 market penetration). This is equivalent to 22,275 tons of ParBoard annually. In addition, an evaluation of export potential to neighboring countries and regions has yielded the effective export demand curve shown in Figure V-2.

The bagasse for the plant will be obtained from a single local sugar mill five-miles distant from the proposed plant site. The mill has agreed to sell its bagasse to ParBoard at a fixed profit margin of \$1.00/ton of bagasse. Local transport costs are about \$0.25/ton/mile. The mill has also required ParBoard Company to install the equipment for the improvement of mill efficiency or the burning of alternate or supplemental fuels, whichever ParBoard prefers. ParBoard must also pay the operating costs associated with this equipment. Evaluation of the heat balance of the mill has indicated that the mill currently has a bagasse surplus

of 7500 tons annually, which represents an annual disposal expense of \$30,000 to the sugar mill. It is further estimated that improvements in mill efficiency costing initially \$350,000 would lead to the release of an additional 60,000 tons of bagasse annually. This equipment would have a useful lifetime of 10 years. Alternatively, a boiler for the burning of oil as a supplemental fuel could release the entire amount of bagasse currently required by the mill (142,500 tons annually). Such a boiler would have an initial cost of \$750,000 and would last about 15 years.

Phenolic resin will be used exclusively at the plant. Phenolic resin may be imported at a fixed \$0.35 per pound in a ready-to-use state. Alternatively, phenolic resin may be produced at the plant from raw phenol costing \$0.16 per pound. It is estimated that a complete resin production facility would have an initial cost of \$585,000 and a lifetime of 15 years.

The production system favored for use in the ParBoard plant has been selected largely on the basis of the experiences and preferences of the engineering personnel available to operate the plant. In brief, the production system is as follows: Bagasse will be brought from the supplying sugar mill in its fresh state, depithed by a humid depithing process, dried in a rotary dryer, briquetted, and stored in an appropriate enclosure. The boards will be pressed on

a multiplaten hot press. A full production capacity of 100 press cycles per day is anticipated; this is equivalent to an annual capacity of 36,000 tons of particle board at 100% utilization. Approximately three tons of bagasse are estimated to be required per ton of particle board produced. The total capital investment required for this plant is estimated to be \$8,000,000, of which land and other non-depreciable costs are not a significant part.

Available local labor is plentiful but largely unskilled. Local hourly wage rates are \$0.50 for unskilled workers, \$0.75 for semi-skilled workers, \$1.50 for skilled workers, and \$2.50 for local supervisors. The plant manager and engineers are not available locally, but must be imported at annual salaries of \$20,000 for the manager and \$15,000 each for the three engineers. Additional local living allowances are paid to such expatriate employees, typically \$7500 annually for the manager and \$5000 each for the engineers.

Electricity is available in ample amounts from the local utility system at \$0.012 per KWH. Alternatively, a diesel generating station is estimated to have an initial cost of \$600,000 and an estimated lifetime of 20 years. The local cost of diesel fuel is \$48.00 per ton.

The ParBoard currently has commitments of equity capital totaling \$4,000,000 which will be applied to the construction and operation of its plant. In addition, an international

development agency has made available a loan of \$2,000,000 at 6% interest and a 20-year amortization period. The government of Azucaria, acting through the Bank of Azucaria, has also offered its support in the form of a \$2,000,000 loan at 7% interest and a 10-year amortization period. These arrangements constitute the only financing scheme available to the ParBoard Company.

B. Investment Analysis of Proposed ParBoard Plant

The various Indices utilized in the investment analysis framework of Section IV are determined here for the ParBoard plant on the basis of the information given in the example of part A. Each of these Indices is evaluated and related according to Equation IV-41 to give the Profit Indices associated with the various possible modes of production.

B.1 Market Index

The total domestic demand for wood and fiber panels in Azucaria is shown in Figure V-1, and the estimated export demand function is shown in Figure V-2. Also included in Figure V-1 are the demand functions for ParBoard based on 90%, 75%, and 50% market penetrations. To find the optimum Market Index associated with these demand functions, we recall Equation IV-3:

$$DMI - EMI + D_d \frac{dDMI}{dD_d} = 0 \quad (IV-3)$$

Using the demand function for the 75% market penetration expected for ParBoard, as shown in Figure V-1, we have

$$DMI = 228 - 0.8 D_d$$

The export demand function for ParBoard, as shown in Figure V-2, is given by

$$EMI = 250 - 2.5 D_e$$

Equation IV-3 then becomes

$$(228 - 0.8 D_d) - (250 - 2.5 D_e) + D_d(-0.8) = 0$$

By substituting $D_e = D_p - D_d$, we obtain

$$D_p = 1.64 D_d - 8.8$$

or

$$D_d = 0.61 D_p + 5.4$$

The optimum Market Index at 75% market penetration is thus realized when F_d of Equation IV-1 is given by

$$F_d = \frac{D_d}{D_p} = \frac{0.61 D_p + 5.4}{D_p} \quad (V-1)$$

The variation of F_d , the optimum ratio of domestic sales to total sales, as a function of Q_b , the total annual production of ParBoard, is shown in Figure V-3.

By expressing the three variables of Equation IV-1 in terms of Q_b , we obtain the equation for the optimum Market Index based on a 75% market penetration by ParBoard:

$$\begin{aligned} \text{M.I.} = & (228 - 0.49 Q_b - 4.3) \left(\frac{0.61 Q_b + 5.4}{Q_b} \right) \\ & + (250 - 0.98 Q_b + 13.5) \left(\frac{0.61 Q_b + 5.4}{Q_b} \right) \end{aligned}$$

(Equation V-2)

The resultant variation of the Market Index with the total demand D_p or total production Q_b (which are identical in this analysis) is shown in Figure V-4. The Market Index function shown in this figure gives the maximum Market Index to be expected at any level of production, assuming the optimum mix of domestic and export sales.

B.2 Supply Index

The ParBoard Company is considering two alternative

means of releasing bagasse from the sugar mill, beyond the existing surplus of 7500 tons of bagasse annually. The first alternative is the improvement of mill efficiency at a cost of \$350,000, which will yield a maximum of 60,000 tons of bagasse, not including the surplus of 7500 tons. The second alternative is the burning of supplemental fuel, which will require an initial investment of \$750,000 and operating costs which include \$48/ton of oil burned. This method of releasing bagasse can provide up to 142,500 tons of bagasse annually in addition to the 7500 tons annual surplus. The Bagasse Index (B.I.) for each of these alternatives must be evaluated.

Alternative 1. In this case the Release Index, $R.I._{b,e}$, is given by

$$R.I._{b,e} = (-S_d)(wf_1) + (C_e)(wf_2)$$

as indicated in Equation IV-5. The savings in surplus bagasse disposal costs applies to the first 7500 tons of bagasse taken by the board plant. The estimated surplus disposal costs to the mill are \$30,000 annually. Thus, by Equation IV-6,

$$S_d = \frac{C_d}{B_s} = \frac{\$30,000}{7500 \text{ tons}} = \$4/\text{ton}$$

The weighting factor wf_1 is determined by the total quantity of bagasse taken by the plant, B_t , as follows:

$$wf_1 = \frac{7500}{B_t}$$

The costs of the mill efficiency improvement program result in a cost per ton of bagasse released, C_e , as follows:

$$C_e = \frac{C_{et}}{B_e} = \frac{DC_e + AI_e + OC_e}{B_e}$$

where

$$DC_e = \frac{\$350,000}{10 \text{ years}} = \$35,000/\text{year}$$

$$AI_e = \$350,000 \times 3\% \text{ (assumed throughout)} = \$10,500$$

$$OC_e = \$5000 \text{ (estimated)}$$

Thus,

$$C_e = \frac{\$51,500}{B_e}$$

The Release Index for bagasse released by this method is thus given by

$$\begin{aligned} R.I._{b,e} &= (-\$4) \left(\frac{7500}{B_t} \right) + \left(\frac{\$51,500}{B_e} \right) \left(\frac{B_e}{B_t} \right) \\ &= \frac{\$21,500}{B_t} \end{aligned}$$

The total cost of bagasse released by this method and delivered to the particle board plant will then be

$$\begin{aligned}
 C_b &= R.I._{b,e} + P_m + (C_{tb})(d_t) \\
 &= \frac{\$21,500}{B_t} + \$1.00 + (\$0.25/\text{mile})(5 \text{ miles}) \\
 &= \frac{\$21,500}{B_t} + \$2.25
 \end{aligned}$$

The Bagasse Index for bagasse released by a program of mill efficiency is then given by

$$B.I._1 = C_b \times Q.I._b$$

where $Q.I._b$ is given in the example as 3 tons of bagasse per ton of board produced. Thus,

$$\begin{aligned}
 B.I._1 &= \left(\frac{\$21,500}{B_t} + \$2.25 \right) (3) \\
 &= \frac{\$64,500}{Q_b} + \$6.75 \quad (V-3)
 \end{aligned}$$

The variation of the Bagasse Index $B.I._1$ with the quantity of board produced annually, Q_b , is shown in Figure V-5.

Alternative 2. In this method of releasing bagasse by the burning of supplemental fuel, the Release Index is

given by

$$R.I._{b,s} = (-S_d)(wf_1) + (C_s)(wf_4)$$

as indicated in Equation IV-5. In the present equation, S_d and wf_1 have the same values as in Alternative 1. The costs per ton of bagasse resulting from the burning of supplemental fuel is given by

$$C_s = \frac{SC_t}{B_{sf}}$$

where

$$SC_t = DC_s + AI_s + OC_s + FC_s$$

$$DC_s = \frac{\$750,000}{15 \text{ years}} = \$50,000/\text{year}$$

$$AI_s = \$750,000 \times 3\% = \$22,500$$

$$OC_s = \$7000 \text{ (estimated)}$$

$$FC_s = \$3.60 \times B_{sf}$$

where the \$3.60 in the equation for FC_s is an assumed fuel replacement cost per ton of bagasse released. Thus, C_s becomes

$$C_s = \frac{\$79,500 + (\$3.60)(B_{sf})}{B_{sf}}$$

The Release Index for bagasse released by the burning of supplemental fuel thus becomes

$$\begin{aligned} R.I._{b,s} &= (-\$4) \left(\frac{7500}{B_t} \right) + \left(\frac{\$79,500 + (\$3.60)(B_{sf})}{B_{sf}} \right) \left(\frac{B_{sf}}{B_t} \right) \\ &= \frac{\$49,500 + (\$3.60)(B_{sf})}{B_t} \end{aligned}$$

The Bagasse Index is then given by

$$\begin{aligned} B.I._2 &= C_s \times Q.I._b \\ &= \frac{\$148,500 + (\$10.80)(3Q_b - 7500)}{Q_b} + \$6.75 \end{aligned}$$

(Equation V-4)

in which $(3Q_b - 7500)$ has been substitute for B_{sf} . The resultant variation of this Bagasse Index with Q_b is shown in Figure V-5.

In addition to the two alternative bagasse release modes which have been determined above, ParBoard Company must also evaluate two alternative modes of obtaining resin. The first mode of obtaining resin is the direct importation

of prepared resin. In this case the Resin Index is given by

$$R.I._1 = C_{ir} \times Q_r = \$70/\text{ton of board} \quad (V-5)$$

since C_{ir} is given in the example as \$0.35/lb and Q_r is assumed to be the usual 10% (or 200 pounds) per ton of board.

In the case of resin produced at the particle board plant, the cost of resin per pound is given by Equation IV-33 as follows:

$$C_{pr} = M_r + \frac{DC_r + AI_r + OC_r}{R_a}$$

where

$$M_r = \$0.16 \text{ (cost of raw materials per pound of resin produced)}$$

$$DC_r = \frac{\$585,000}{15 \text{ years}} = \$39,000$$

$$AI_r = \$585,000 \times 3\% = \$17,550$$

$$OC_r = \$6000 \text{ (estimated)}$$

Thus,

$$C_{pr} = \$0.16 + \frac{\$65,550}{R_a}$$

The Resin Index for resin obtained by the local production of resin at the particle board plant is thus given by

$$R.I._2 = (\$0.16 + \frac{\$65,550}{R_a}) \times (200)$$

Substituting $Q_b = R_a/200$, we obtain the Resin Index as a function of the quantity of board produced annually:

$$R.I._2 = \$32.00 + \frac{\$65,550}{Q_b} \quad (V-6)$$

The Resin Indices derived for both methods of obtaining resin are indicated in Figure V-6.

On the basis of two alternate bagasse release modes and two alternate means of obtaining resin, there are four different possible Supply Indices. These four alternative Supply Indices are as follows:

$$S.I._1 = B.I._1 + R.I._1 + A.I. \quad (V-7)$$

$$S.I._2 = B.I._1 + R.I._2 + A.I. \quad (V-8)$$

$$S.I._3 = B.I._2 + R.I._1 + A.I. \quad (V-9)$$

$$S.I._4 = B.I._2 + R.I._2 + A.I. \quad (V-10)$$

where the Additive Index is assumed to be fixed at \$5/ton of board produced. These four alternative Supply Indices are shown as functions of the quantity of board produced annually by the ParBoard plant in Figure V-7.

B.3 Operations Index

The Operations Index is defined by

$$O.I. = L.I. + E.I. + M.I.M.I. \quad (IV-35)$$

The Labor Index (L.I.) is given directly by

$$L.I. = \frac{C_1}{Q_b} \quad (IV-36)$$

The total annual payroll (C_1) for ParBoard Company is calculated in Table V-2. If extra shifts are added at the 1/3 and 2/3 capacity levels (12,000 and 24,000 tons of board annually), The Labor Index will vary with the quantity of board produced annually as shown in Figure V-8.

The Energy Index for the ParBoard plant will be determined by

$$E.I. = (F_c)(C_{1f}) + (E_b)(C_{1e}) \quad (IV-37)$$

It is assumed here that an evaluation of the production system planned for the ParBoard plant and of the local conditions has yielded the following data:

$$F_c = 30 \text{ lbs fuel oil per ton of board}$$

$$C_{1f} = \$48.00/\text{ton fuel oil} = \$0.024/\text{lb}$$

$$E_b = 450 \text{ KWH/ton of board}$$

$$C_{1e} = \$0.012/\text{KWH if purchased from the utility system}$$

The Energy Index based on the purchase of electricity from the local utility system will thus be given by the constant value

$$E.I._1 = \$6.12/\text{ton of board} \quad (V-11)$$

In the case of electricity which is generated at the particle board plant, we find the following:

$$F_c = 100 \text{ lbs/ton of board (assumed)}$$

$$C_{1e} = \frac{DC_{el} + AI_{el} + OC_{el}}{Q_b}$$

where

$$DC_{el} = \frac{\$600,000}{20 \text{ years}} = \$30,000$$

$$AI_{el} = \$600,000 \times 3\% = \$18,000$$

$$OC_{el} = \$6000 \text{ (estimated)}$$

Thus,

$$C_{1e} = \frac{\$54,000}{Q_b}$$

The Energy Index for a particle board plant producing its own electricity is thus given by

$$\begin{aligned} E.I._2 &= (100) (\$0.024) + \frac{\$54,000}{Q_b} \\ &= \$2.40 + \frac{\$54,000}{Q_b} \end{aligned} \quad (V-12)$$

The Energy Indices for the two possible modes of obtaining electricity are shown in Figure V-9.

The insurance and miscellaneous costs at the ParBoard plant are assumed to be a fixed \$50,000 per year. Maintenance costs are assumed to be approximately \$3/ton of board produced. Hence, the Maintenance, Insurance, and Miscellaneous Index for the ParBoard plant is given by

$$M.I.M.I. = \$3.00 + \frac{\$50,000}{Q_b} \quad (V-13)$$

The Operations Index for the ParBoard plant has two possible forms, based on the two alternative means of obtaining electricity for the plant. The two alternative Operations Indices are defined as follows:

$$O.I._1 = L.I. + E.I._1 + M.I.M.I. \quad (V-14)$$

$$O.I._2 = L.I. + E.I._2 + M.I.M.I. \quad (V-15)$$

The variation of these Operations Indices with the quantity

of board produced annually is shown in Figure V-10.

B.4 Debt Service Index

The maximum value of the annual debt service at the ParBoard plant will occur in the first year of the plant's operation, at which time the required debt service will be \$560,000, based on the financial arrangements given in the example. Using this first year debt service as the maximum value, the Debt Service Index will be given by (a maximum value of):

$$\text{D.S.I.} = \frac{\$560,000}{Q_b} \quad (\text{V-16})$$

Figure V-11 shows the variation of the Debt Service Index with the quantity of board produced annually by the ParBoard plant, based on this first year value of the annual debt service.

B.5 Depreciation Index

The Depreciation Index for the ParBoard plant is determined by the initial value of the equipment and buildings (\$8,000,000) and the depreciation period and rate which reflects the actual deterioration of the equipment and buildings. It is assumed here that a 10-year straight line depreciation is a realistic depreciation rate for the

ParBoard plant as a whole. On this basis, The Depreciation Index is given directly by

$$D.I. = \frac{\$800,000}{Q_b} \quad (V-17)$$

Figure V-12 shows the variation of the Depreciation Index with the annual production at the ParBoard plant.

B.6 Profit Index

In the simplified hypothetical example of ParBoard Company, there are a total of eight alternative modes of production, each one of which produces its own Profit Index function. The equations for the eight alternate Profit Index functions are as follows:

$$P.I._1 = M.I. - (S.I._1 + O.I._1 + D.S.I. + D.I.) \quad (V-18)$$

$$P.I._2 = M.I. - (S.I._1 + O.I._2 + D.S.I. + D.I.) \quad (V-19)$$

$$P.I._3 = M.I. - (S.I._2 + O.I._1 + D.S.I. + D.I.) \quad (V-20)$$

$$P.I._4 = M.I. - (S.I._2 + O.I._2 + D.S.I. + D.I.) \quad (V-21)$$

$$P.I._5 = M.I. - (S.I._3 + O.I._1 + D.S.I. + D.I.) \quad (V-22)$$

$$P.I._6 = M.I. - (S.I._3 + O.I._2 + D.S.I. + D.I.) \quad (V-23)$$

$$P.I._7 = M.I. - (S.I._4 + O.I._1 + D.S.I. + D.I.) \quad (V-24)$$

$$P.I._8 = M.I. - (S.I._4 + O.I._2 + D.S.I. + D.I.) \quad (V-25)$$

These eight Profit Indices are shown in Figure V-13.

On the basis of the Profit Index functions of Figure V-13, the optimum (that is, the most profitable) production mode will be the one represented by P.I.₄, which is based on the release of bagasse by the improvement of mill efficiency and the production of resin at the plant. The generation of electricity at the board plant which is also included in P.I.₄ offers only a slight increase in profitability over the same production mode based on the purchase of electricity from the utility system (P.I.₃).

There is a limit, however, on the amount of board which can be produced annually by the production modes represented by P.I.₃ and P.I.₄. Any production mode at the ParBoard plant based on the use of bagasse released by the program of mill efficiency improvement will be limited to the production of 22,500 tons of board annually, which is the amount of board which can be produced from the 67,500 tons of bagasse available through this release mode. If a greater production level is desired, it will be necessary to release bagasse by the burning of supplemental fuel. In this event, P.I.₈ (based on the production of resin at the plant and the generation of electricity at the plant) will prove the most profitable mode of operation. Again, the purchase of electricity from the utility system (P.I.₇) will only slightly affect the profitability of this production mode.

* BAGASSE PARTICLE BOARD INVESTMENT ANALYSIS

L	QB.K=QB.J+DT	
A	FD.K=((0.61)*(QB.K)+5.4)/QB.K	(Equation V-1)
A	DMI.K=228-(0.49)*(QB.K)-4.3	
A	EMI.K=250-(0.98)*(QB.K)+13.5	
A	MI.K=(DMI.K)*(SWITCH(1,FD.K,CHECK.K))+(EMI.K)	
X	*(SWITCH(0,FE.K,CHECK.K))	(V-2)
A	CHECK.K=(SQRT(FE2.K))+FE.K	
A	FE.K=1-FD.K	
A	FE2.K=(FE.K)*(FE.K)	
A	BI1.K=(64.5/QB.K)+6.75	(V-3)
A	BI2.K=(148.5+(10.8)(3*QB.K-7.5))/QB.K+6.75	(V-4)
A	RI1.K=K1	(V-5)
C	K1=70	
A	RI2.K=32+(65.55/QB.K)	(V-6)
C	AI=5	
A	SI1.K=BI1.K+RI1.K+AI	(V-7)
A	SI2.K=BI1.K+RI2.K+AI	(V-8)
A	SI3.K=BI2.K+RI1.K+AI	(V-9)
A	SI4.K=BI2.K+RI2.K+AI	(V-10)
A	LI.K=(94+72.7+72.7*STEP(1,12))+72.7	
X	*STEP(i,24))/QB.K	
A	EI1.K=K2	(V-11)
C	K2=6.1	
A	EI2.K=2.4+(54/QB.K)	(V-12)
A	MIMI.K=3+(50/QB.K)	(V-13)
A	OI1.K=LI.K+EI1.K+MIMI.K	(V-14)
A	OI2.K=LI.K+EI2.K+MIMI.K	(V-15)
A	DSI.K=560/QB.K	(V-16)
A	DI.K=800/QB.K	(V-17)

TABLE V-1: DYNAMO II PROGRAM USED IN INVESTMENT ANALYSIS
OF PARBOARD COMPANY OPERATIONS (see next page)

A	PI1.K=MI.K-SI1.K-OI1.K-DSI.K-DI.K	(V-18)
A	PI2.K=MI.K-SI1.K-OI2.K-DSI.K-DI.K	(V-19)
A	PI3.K=MI.K-SI2.K-OI1.K-DSI.K-DI.K	(V-20)
A	PI4.K=MI.K-SI2.K-OI2.K-DSI.K-DI.K	(V-21)
A	PI5.K=MI.K-SI3.K-OI1.K-DSI.K-DI.K	(V-22)
A	PI6.K=MI.K-SI3.K-OI2.K-DSI.K-DI.K	(V-23)
A	PI7.K=MI.K-SI4.K-OI1.K-DSI.K-DI.K	(V-24)
A	PI8.K=MI.K-SI4.K-OI2.K-DSI.K-DI.K	(V-25)
N	QB=1	
PLOT	QB=Q(0,50)	
PLOT	FD=F(0,1)	(Figure V-3)
PLOT	MI=M(150,250)	(Figure V-4)
PLOT	BI1=E,BI2=S(0,75)	(Figure V-5)
PLOT	RI1=I,RI2=P(0.150)	(Figure V-6)
PLOT	SI1=A,SI2=B,SI3=C,SI4=D(0,150)	(Figure V-7)
PLOT	LI=L(0,50)	(Figure V-8)
PLOT	EI1=U,EI2=P(0,25)	(Figure V-9)
PLOT	OI1=A,OI2=B(0,50)	(Figure V-10)
PLOT	DSI=S(0,150)	(Figure V-11)
PLOT	DI=D(0,150)	(Figure V-12)
PLOT	PI1=A,PI2=B,PI3=C,PI4=D,PI5=E,	
X	PI6=F,PI7=G,PI8=H(-50,125)	(Figure V-13)
SPEC	DT=1/LENGTH=36/PLTPER=1	
RUN	PARBOARD COMPANY OF AZUCARIA	

TABLE V-1 (continued): DYNAMO II PROGRAM USED IN INVESTMENT
ANALYSIS OF PARBOARD COMPANY OPERATIONS

SHIFT PAYROLL

CATEGORY	NUMBER WORKERS	DAILY WAGE	WORKDAYS PER YEAR	SHIFT PAYROLL
Unskilled	7	\$4.00	360	\$10,080
Semi-skilled	7	6.00	360	15,120
Skilled	6	12.00	360	25,920
Supervisors	3	20.00	360	<u>21,600</u>
Total Shift Payroll				\$72,720

OVERHEAD PAYROLL

General Manager	\$27,500
Three Engineers	60,000
Clerical	<u>6,480</u>
Total	\$93,980

TOTAL ANNUAL PAYROLL

$$\text{Total Annual Payroll} = \$93,980 + n(\$72,720)$$

where n = number of shifts worked

TABLE V-2: CALCULATION OF TOTAL ANNUAL PAYROLL FOR PARBOARD
COMPANY OPERATIONS

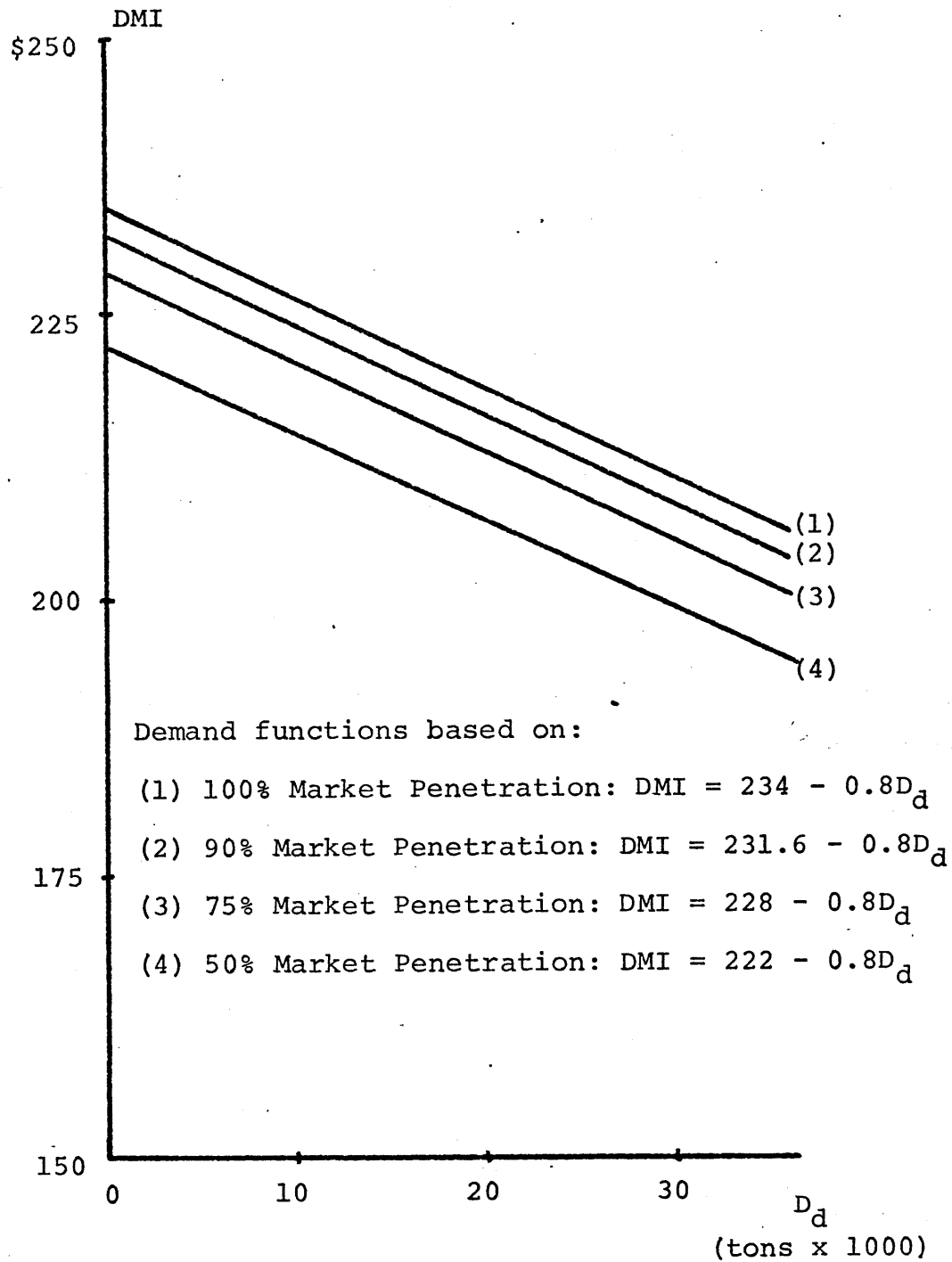


FIGURE V-1: DOMESTIC MARKET DEMAND FUNCTIONS FOR BAGASSE PARTICLE BOARDS IN AZUCARIA

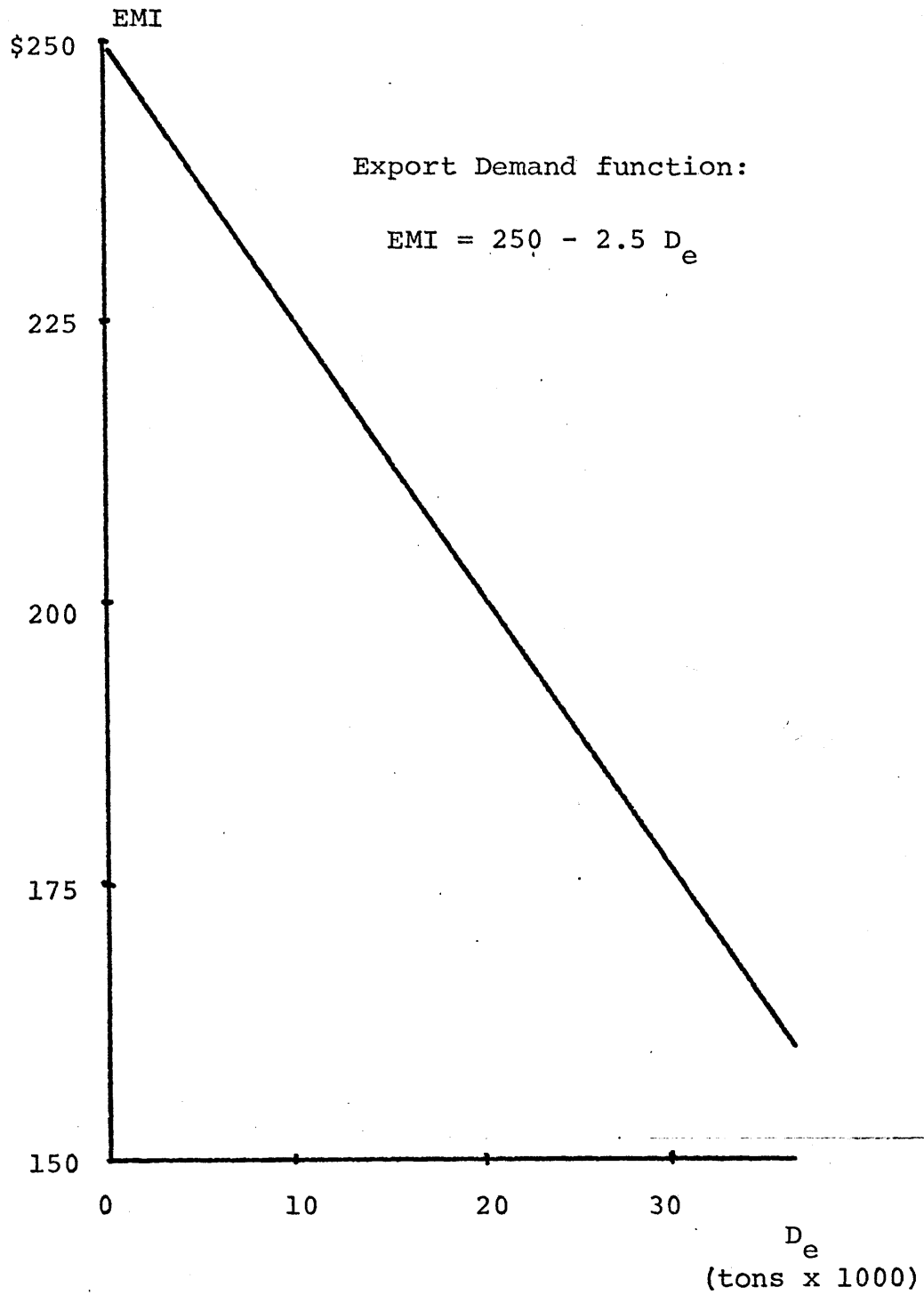


FIGURE V-2: EXPORT MARKET DEMAND FUNCTION FOR PARTICLE
BOARDS PRODUCED IN AZUCARIA.

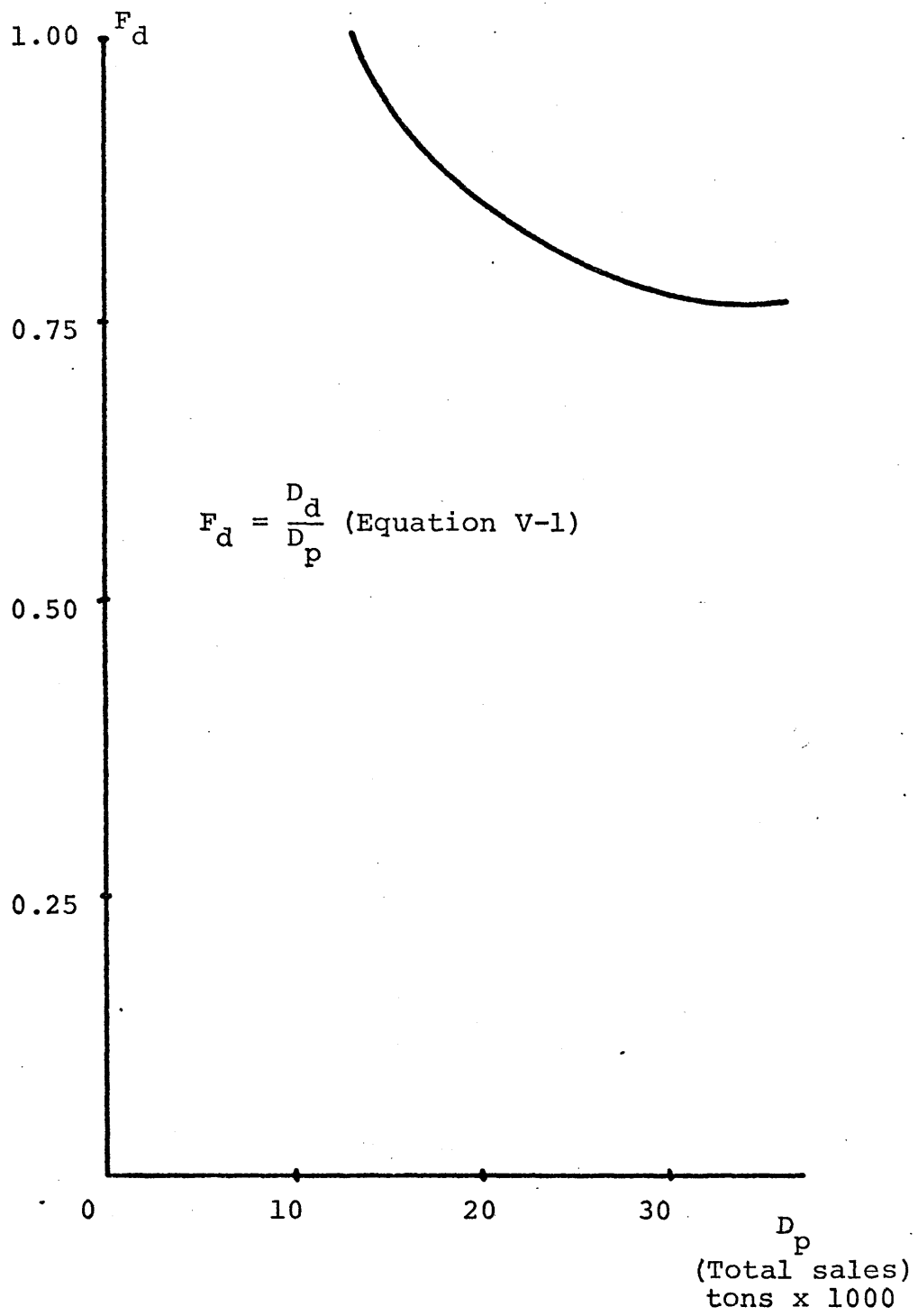


FIGURE V-3: F_d AS A FUNCTION OF D_p (TOTAL SALES)

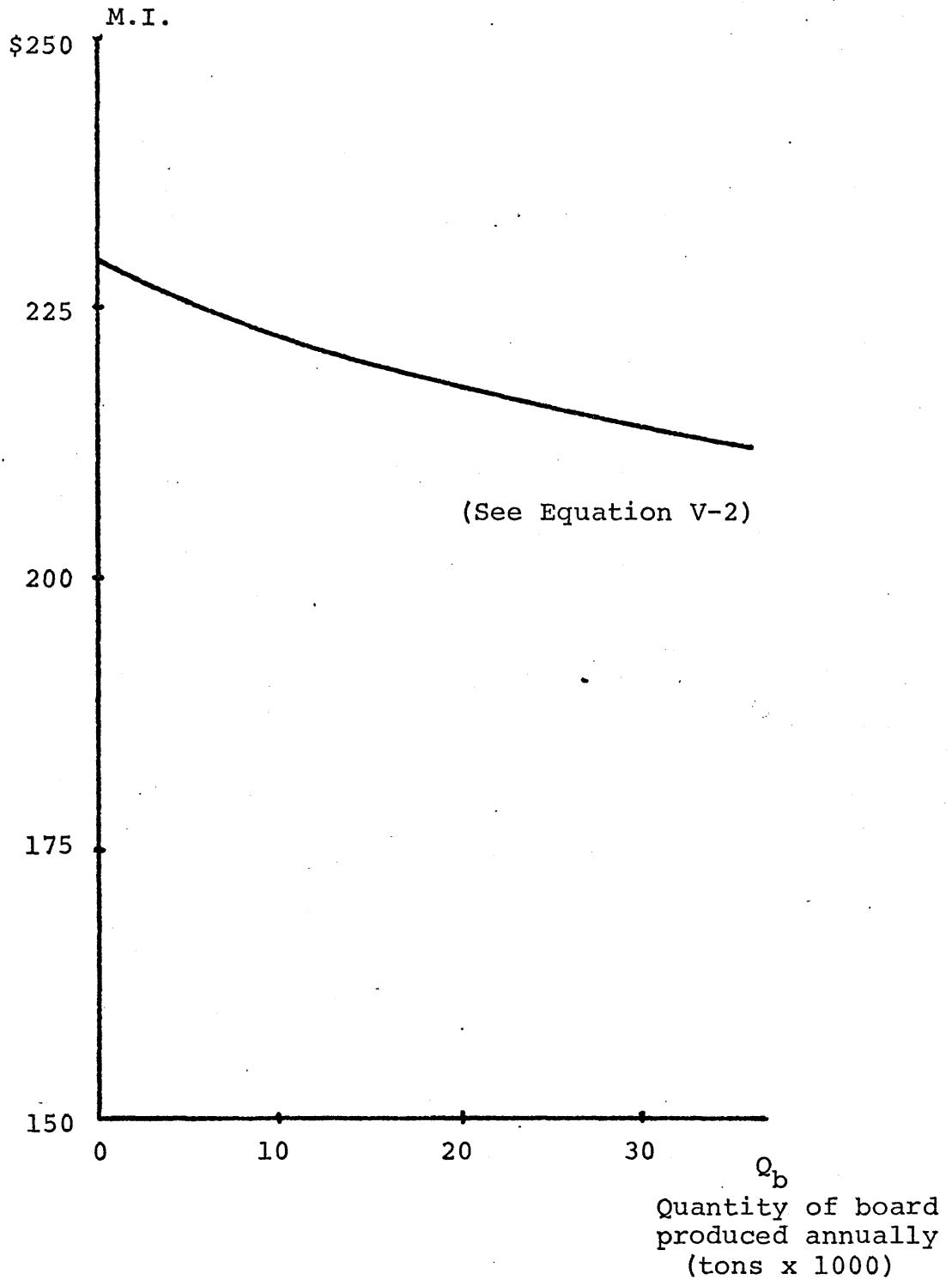


FIGURE V-4: MARKET INDEX (M.I.) AS A FUNCTION OF QUANTITY OF PARBOARD PRODUCED ANNUALLY

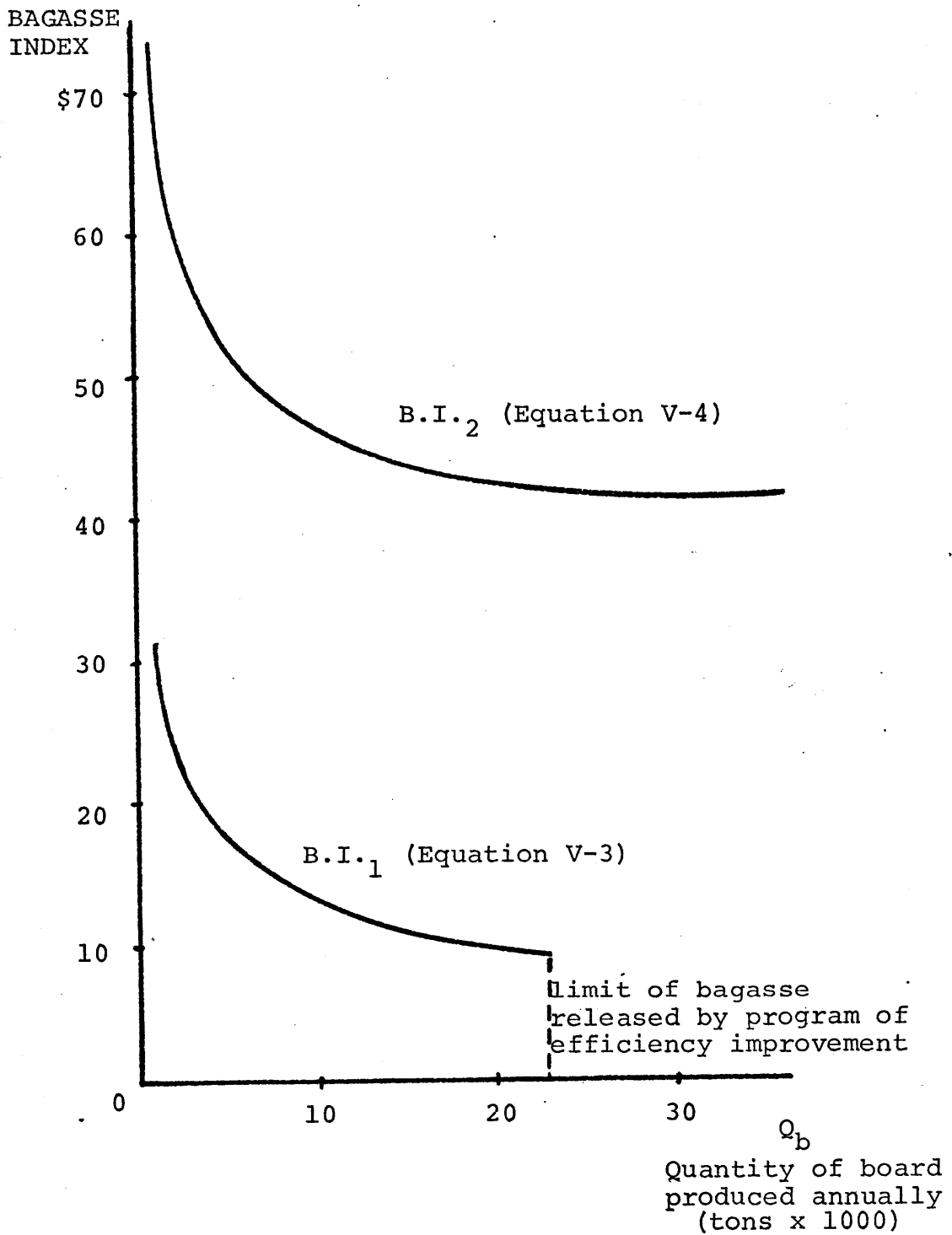


FIGURE V-5: BAGASSE INDICES AS FUNCTIONS OF QUANTITY OF PARBOARD PRODUCED ANNUALLY

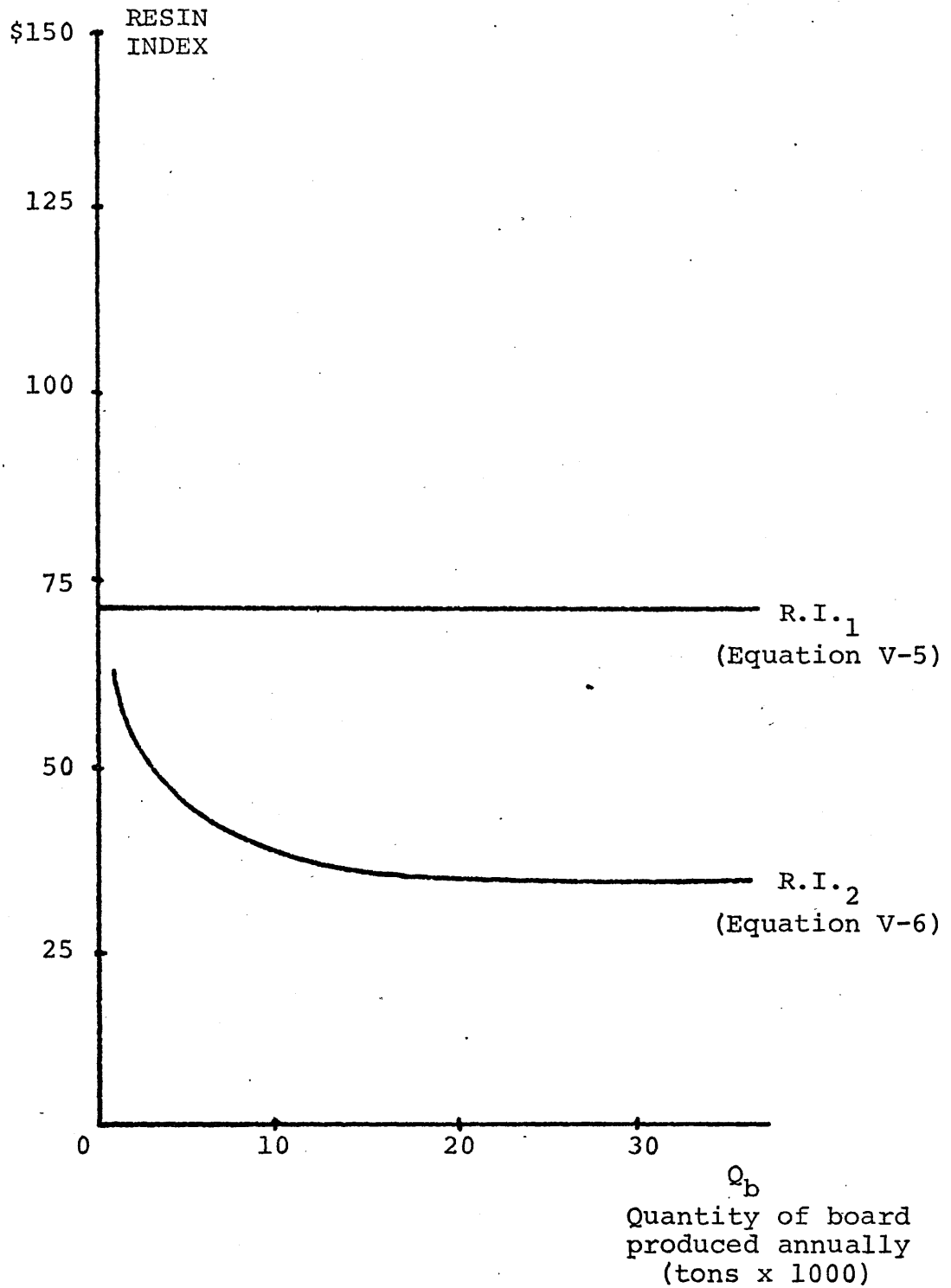


FIGURE V-6: RESIN INDICES AS FUNCTIONS OF QUANTITY OF PARBOARD PRODUCED ANNUALLY

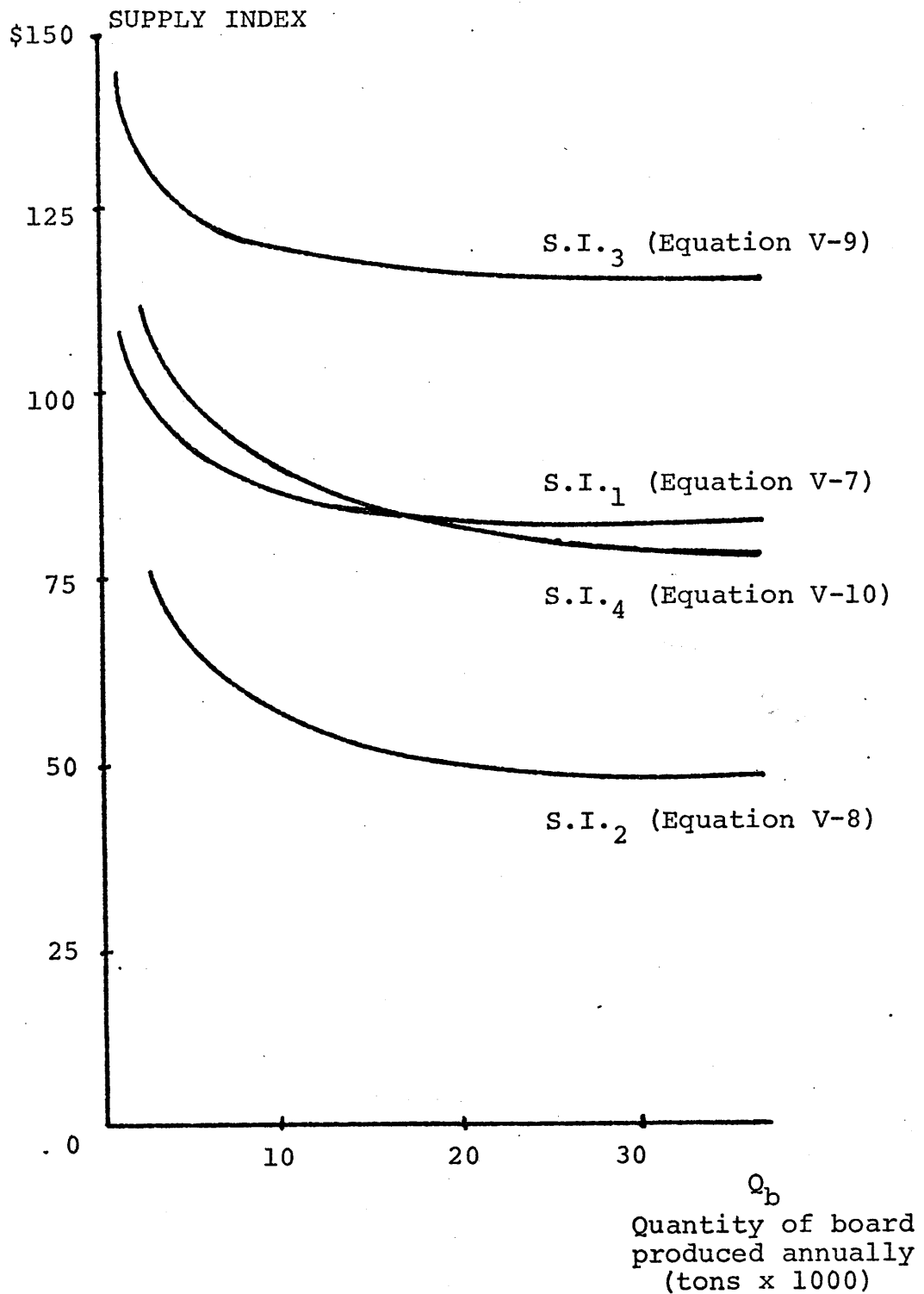


FIGURE V-7: SUPPLY INDICES AS FUNCTIONS OF QUANTITY OF PARBOARD PRODUCED ANNUALLY

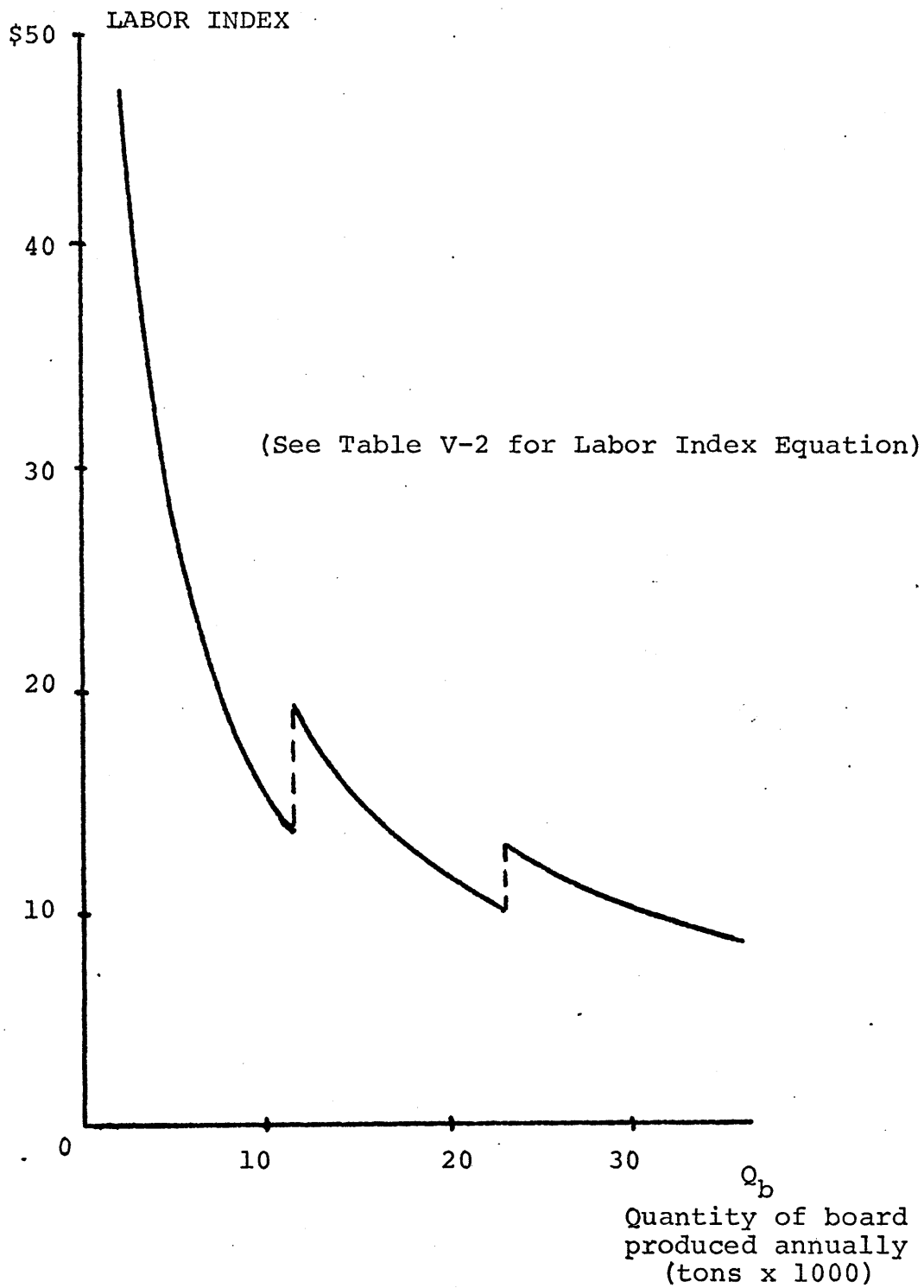


FIGURE V-8: LABOR INDEX AS FUNCTION OF QUANTITY OF PARBOARD PRODUCED ANNUALLY

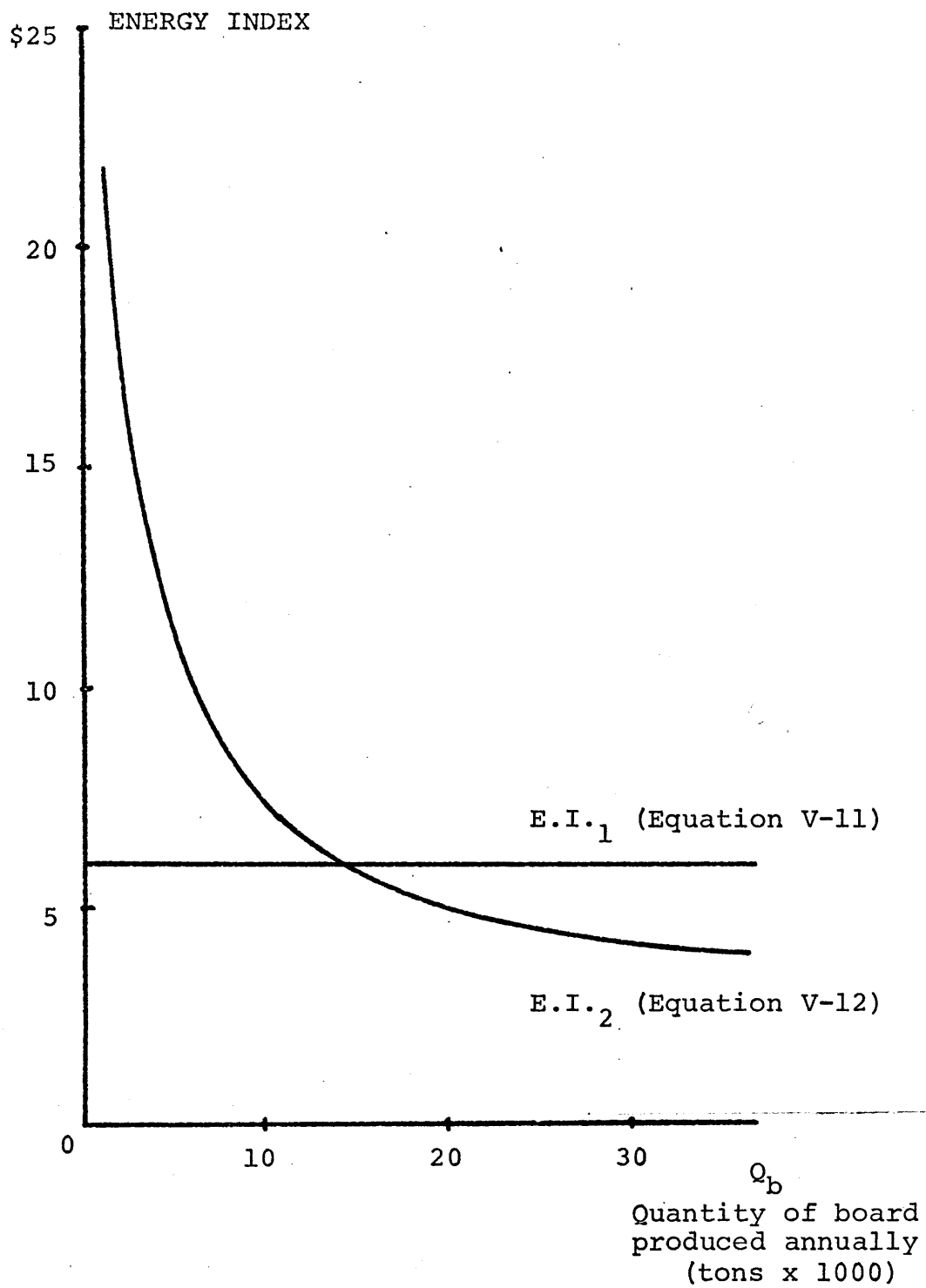


FIGURE V-9: ENERGY INDICES AS FUNCTIONS OF QUANTITY OF PARBOARD PRODUCED ANNUALLY

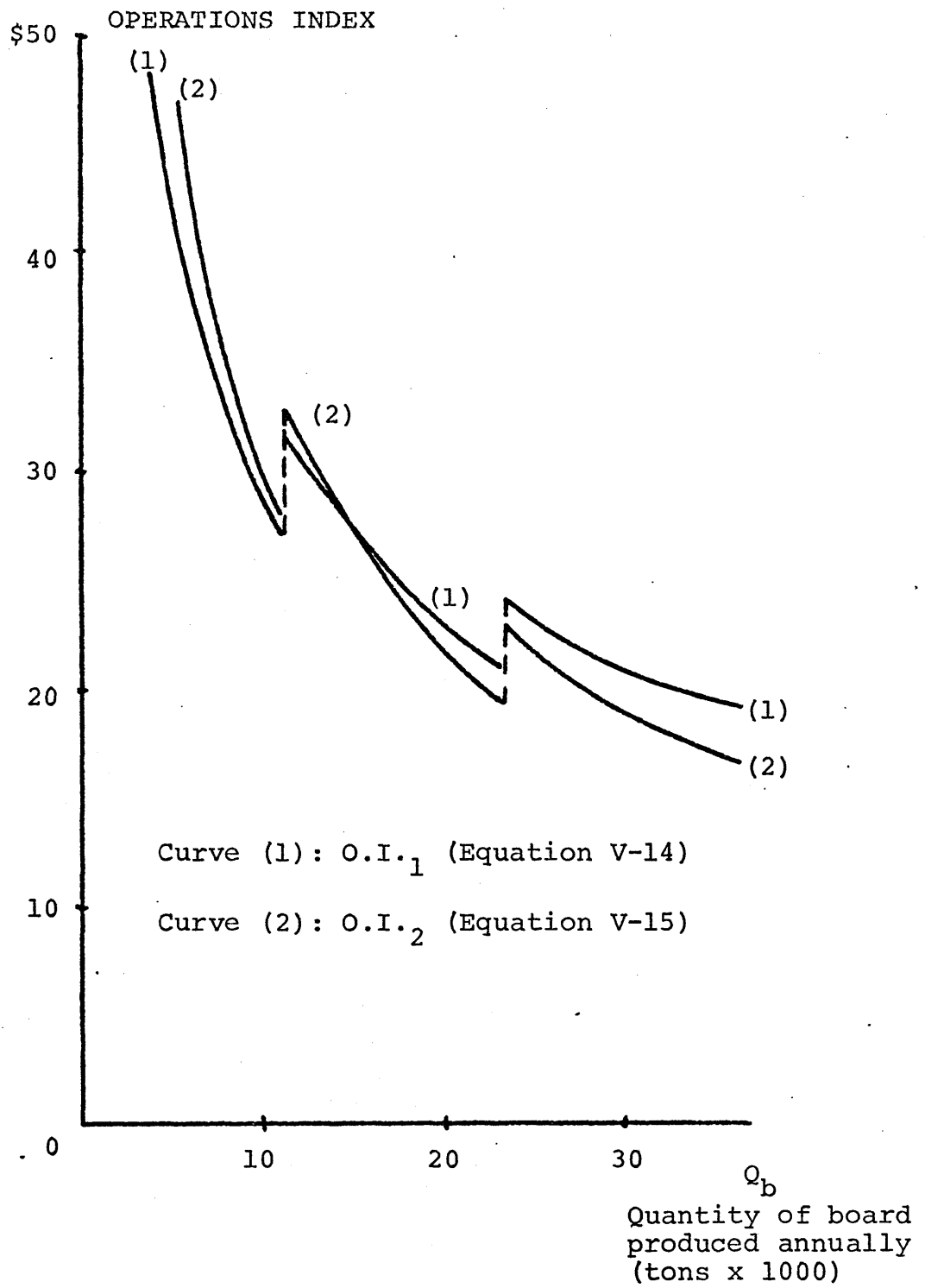


FIGURE V-10: OPERATIONS INDICES AS FUNCTIONS OF QUANTITY OF PARBOARD PRODUCED ANNUALLY

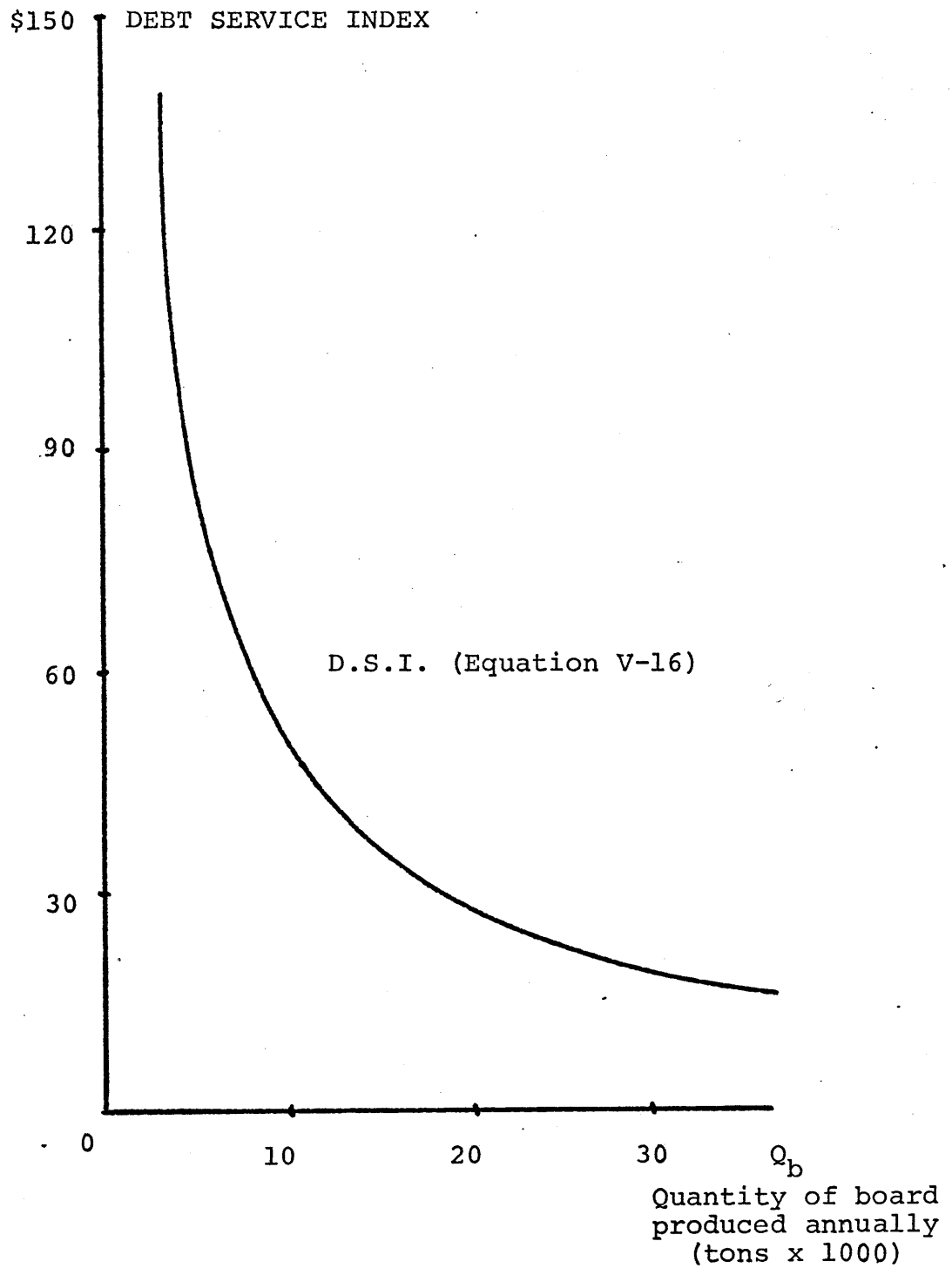


FIGURE V-11: DEBT SERVICE INDEX AS FUNCTION OF QUANTITY
OF PARBOARD PRODUCED ANNUALLY

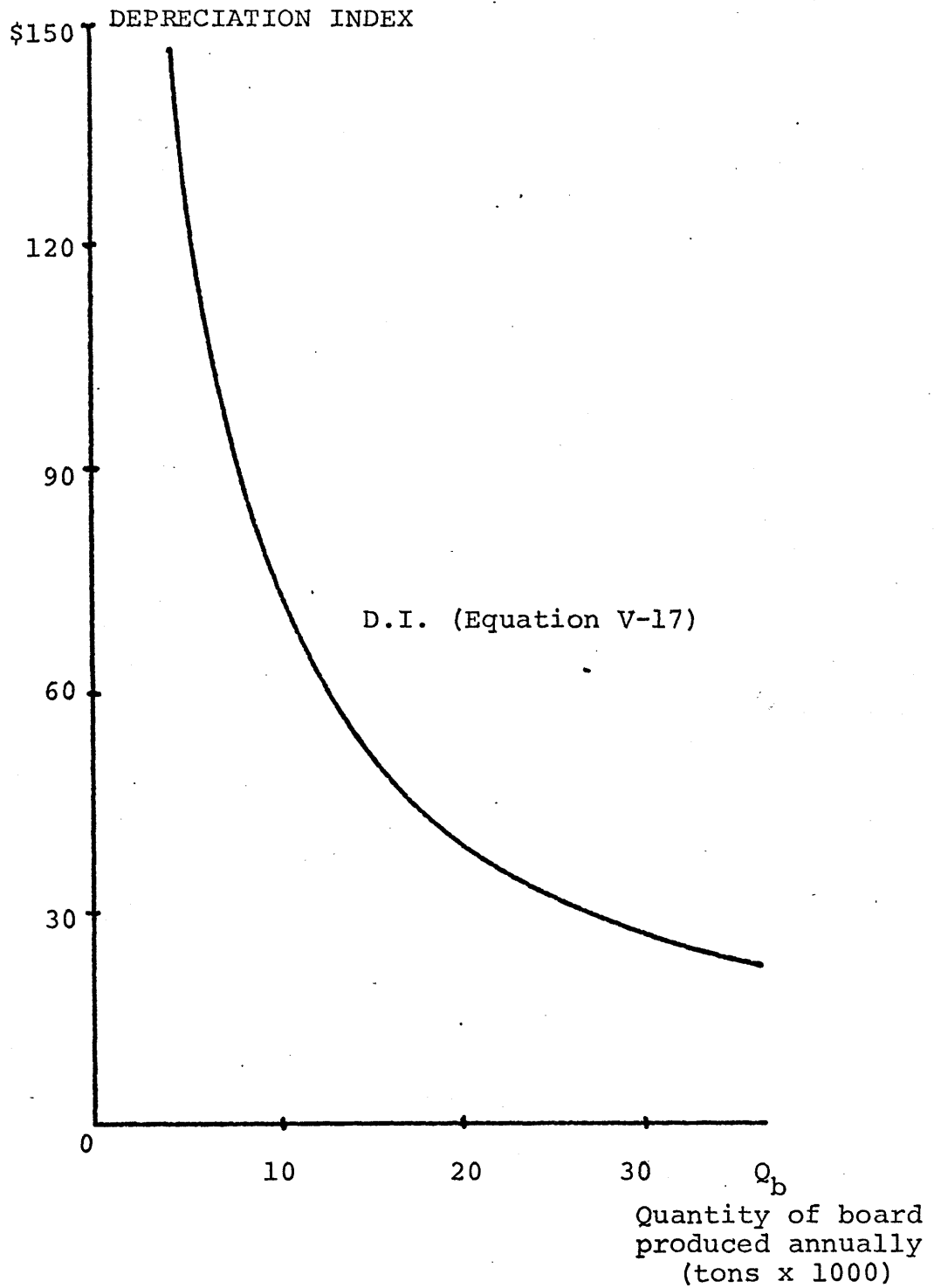


FIGURE V-12: DEPRECIATION INDEX AS FUNCTION OF QUANTITY
OF PARBOARD PRODUCED ANNUALLY

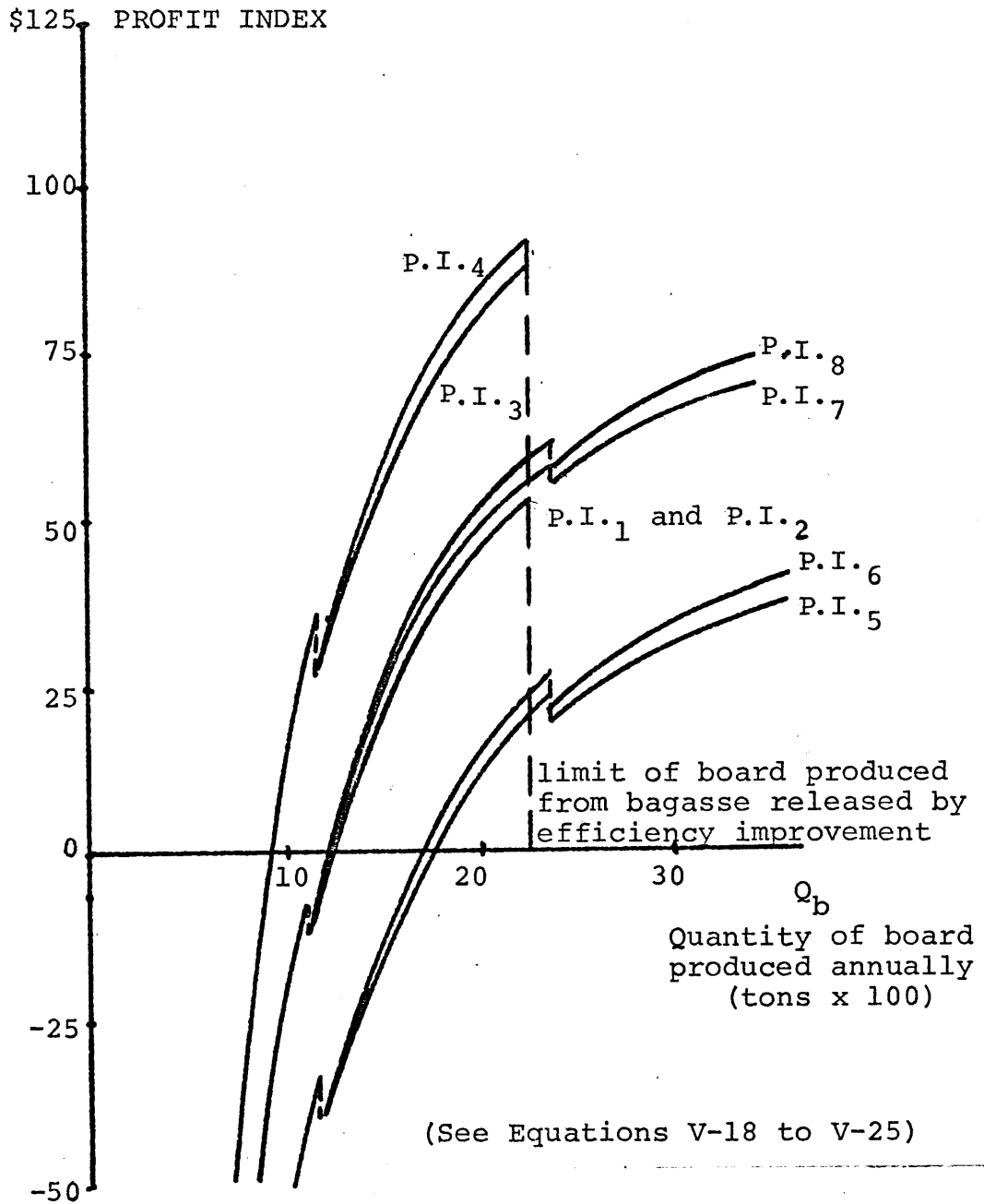


FIGURE V-13: PROFIT INDICES AS FUNCTIONS OF QUANTITY OF PARBOARD PRODUCED ANNUALLY

VI. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

FOR FURTHER RESEARCH

Sugar cane bagasse represents a sizeable and readily accessible source of natural fibers in many regions of the world. Many developing countries, in particular, have significant natural resources in the bagasse fibers produced annually by their sugar industries. The development of by-product uses for sugar cane bagasse should therefore be of considerable interest to both the sugar-producing developing countries and their domestic sugar industries. The diversification of their operations, moreover, is often desired by sugar industries seeking to counteract the fluctuations in their income resulting from changing prices for sugar in the open world markets.

Three types of building materials are currently being produced from bagasse fibers: softboard, hardboard, and particle board. Of these three building materials, bagasse particle board has superior properties which make it highly suitable for use as a lightweight, structural building panel. This general type of panel is, in turn, well suited to the type of construction being carried on and planned in many parts of the world, particularly in many developing regions. The usefulness and adaptability of lightweight panels such as bagasse particle board is indicated by the rapid increase in the per capita consumption of these panels in all parts

of the world.

The bagasse used in the production of particle board and other by-products may in some cases be obtained as a surplus from sugar mills where large surpluses of bagasse are common. In most cases, however, it will be necessary to release the bagasse from its present use as fuel in order to obtain quantities of bagasse sufficient to sustain a moderate- or large-scale by-product operation. Bagasse may then be released by the improvement of mill efficiency or by the burning of supplemental or alternate fuels at the sugar mill. The major portion of the cost of the bagasse will be determined by the costs incurred in releasing the bagasse by these methods.

Bagasse used in particle board manufacture must be relatively free of carbon particles, fine silts, and excessive residual sugar. A variety of methods for storing bagasse are available; the storage of large quantities of bagasse in either the fresh or depithed state will usually be necessary owing to the seasonality of sugar cane milling versus the year-round operation usually planned for particle board plants.

The true bagasse fibers must be separated from the pith component of bagasse -- an operation usually known as depithing -- before the fibers can be used in the production of particle boards. The bagasse fibers are mixed with urea or

phenolic resins, depending on whether the particle board is intended for interior or exterior use. The mixture of fibers, resin, and any additives is pressed into boards which are subsequently trimmed and finished to form the final product.

Investment analysis of the bagasse particle board production system shows that the profitability of such operations depends heavily on the scale of production. Plants at lower levels of production (10,000 tons per year or less) are usually not able to realize the economies possible in the production of their own resins, the generation of their own electricity, and the reduction of debt service and depreciation charges per ton of particle board produced. If the plant has invested directly in or otherwise committed itself to bear the costs of a program to improve a sugar mill's efficiency or of the conversion of the mill's boiler to accept alternate or supplemental fuels, the costs of bagasse at lower levels of production may also prove uneconomic.

The investment analysis model elaborated in this thesis provides the framework for the evaluation of alternative investment strategies and production modes proposed for a possible bagasse particle board operation. The analysis methodology requires that cost estimates of many factors included in the analysis be made on the basis of local con-

ditions under which the proposed plant would operate. On the basis of these specific costs, the various Indices for market price, supply costs, operating costs, debt service, and depreciation charges can be determined and evaluated over the full range of possible production levels. The optimum mode of production at any given level of production can be determined by an evaluation of the Profit Indices for the alternative modes of production.

There are two directions which future research on bagasse particle boards might take and in which this study might serve as an integral part.

First, specific and detailed information of production equipment performances and costs is needed. Such information, if incorporated into the investment analysis framework elaborated in this thesis, would provide a better understanding of the general appropriateness of the possible modes of production under various conditions and at various levels of production.

Second, another area of needed research is a more comprehensive comparison of bagasse particle board with other building materials under diverse economic, geographic, climatic, and other conditions. Such research would hopefully go beyond the simple criterion of the profitability of production used in the investment analysis of this thesis,

and would include an evaluation of the proper role of bagasse particle board production in the national development priorities of developing and other countries. Such a study must investigate the macro-economic benefits and other effects of bagasse particle board production. Such a study would be a natural complement to the micro-economic approach used in this thesis.

BIBLIOGRAPHY

- Anonymous. "Dry Process Bagasse Treatment Developed by Tablopan Board Plant," Sugar y Azucar Yearbook 1968, pages 86-87.
- Association of Indian Trade and Industry. Financial Trends in the Sugar Industry (Bombay, 1957).
- Atchison, Joseph E. "Bagasse Becoming a Major Raw Material for the Manufacture of Pulp and Paper -- Background, Present Status, and Future Possibilities," Proceedings of the International Society of Sugarcane Technologists, Eleventh Congress, pages 1185-1205. Elsevier Publishing Company (Amsterdam, 1963).
- . "Experiences in Developing Building and Operating Bagasse Pulp and Paper Mills," Proceedings of the International Society of Sugarcane Technologists, Twelfth Congress, pages 1827-1843. Elsevier Publishing Company (Amsterdam, 1967).
- Barnes, A. C. The Sugar Cane. Interscience Publishers Inc. (New York, 1964).
- Bersch, John. Personal communication. July 1971.
- Bhagwati, J., and R. Bharadwaj. Human Capital and the Indian Pattern of Foreign Trade. Massachusetts Institute of Technology, Department of Economics, Working Paper Number 70 (Cambridge, July 1970).
- Cellulose Development Corporation Ltd. and John Thompson Water Tube Boilers Ltd. Saving of Bagasse for Paper-making -- Thermal Considerations. United Nations Food and Agricultural Organization, Publication Number ST/ECLA/Conf.3/L.5.3 (1 October 1954).

- Cleasby, D. G. "A Review of Industrial and Agricultural Diversification in the South African Sugar Industry," Proceedings of the International Society of Sugarcane Technologists, Thirteenth Congress, pages 233-252. Elsevier Publishing Company (Amsterdam, 1969).
- Gottlieb, S. "New Vertical Kiln Process for Cement Manufacture." United Nations Publication Number E/Conf.39/D/137 (Geneva, 1962).
- Gupta, S. C., S. L. Saxena, S. K. Ghosh, and P. N. R. Rao. "Possibilities of Saving Bagasse in India for the Paper and Pulp Industries Through Maximum Fuel and Steam Economy Measures," Proceedings of the International Society of Sugarcane Technologists, Twelfth Congress, pages 1844-1856. Elsevier Publishing Company (Amsterdam, 1967).
- Hawaiian Sugar Planters' Association. Period Summary of Factory Results -- Final 1970. (Honolulu, 1971).
- Heritage, Clark C. "The Role of the Forest Products Industry in Economic Development." United Nations Publication Number E/Conf.39/D/178 (Geneva, 1962).
- Hugot, Emile. Handbook of Cane Sugar Engineering. Elsevier Publishing Company (Amsterdam, 1960).
- Hyde, R., B. Old, and E. Pepper. "Direct Reduction of Iron and Steel in the Less Developed Areas." United Nations Publication Number E/Conf.39/D/154 (Geneva, 1962).
- Interafrican Conference on Housing and Urbanization (Second Session). Housing and Urbanization. Scientific Council for Africa South of the Sahara, Publication Number 47 (Nairobi, 1959).

International Sugar Organization. Sugar Year Book, 1965.
(London, 1965).

----- . Sugar Year Book, 1968. (London, 1968).

Keller, Arthur G. "The Parsons and Whittemore 'Horkel' Process for Mechanical Depithing of Sugar Cane Bagasse." Reprinted from The Sugar Journal (December 1957).

----- . "Economical Bagasse Separation." Reprinted from The Sugar Journal (March, 1956).

Lafuma, Henri. "Le Probleme de la Cimenterie au Regard des Besoins de la Construction dans les Pays en Voie de Developpement." United Nations Publication Number E/Conf.39/D/22 (Geneva, 1962).

Langrenney, Fr., and Emile Hugot. "The Bagapan Particle Board," Proceedings of the International Society of Sugarcane Technologists, Thirteenth Congress, pages 1891-1899. Elsevier Publishing Company (Amsterdam, 1969).

Lathrop, Elbert C. Economic Factors to be Considered in the Use of Sugarcane Bagasse as a Raw Material for Paper and Board Manufacture. United States Department of Agriculture, Agricultural Research Service (November 1954).

-----, T. R. Naffziger, and H. I. Mahon. Methods for Separating Pith-bearing Plants into Fiber and Pith. United States Department of Agriculture, Agricultural Research Service (March 1955).

Lengel, Donald E. "Investigations to Determine Optimum Methods of Producing Bagasse-Fibre Boards in the Softboard, Particle Board, and Hardboard Density Ranges," Proceedings of the International Society of Sugarcane Technologists, Eleventh Congress, pages 1156-1173. Elsevier Publishing Co. (Amsterdam, 1963).

Lu, Chien-Jan, Tsai-Wei Hung, and Chao-Moi Hwang. "Heat Balance Determination and Heat Utilization in the Sugarcane Mill," Proceedings of the International Society of Sugarcane Technologists, Thirteenth Congress, pages 1615-1627. Elsevier Publishing Company (Amsterdam, 1969).

Moss, G. "Building Materials in the Territory of Papua and New Guinea," Proceedings: Third Annual Australian Building Research Conference (Melbourne, 1967).

Nee, C. I., and W. C. Hsieh. "Feasibility Study on Furfural and Structural Board from Bagasse," Proceedings of the International Society of Sugarcane Technologists, Thirteenth Congress, pages 1881-1890. Elsevier Publishing Company (Amsterdam, 1969).

Organization for Economic Cooperation and Development. The Trend in the Fibre Building Board Market in Europe 1955-1960. (Paris, 1961).

Organization of American States. Marketing Problems of Sugar at the Hemisphere and World Levels. (Washington, 1964).

Paturau, J. Maurice. By-Products of the Cane Sugar Industry. Elsevier Publishing Company (Amsterdam, 1969).

Pearson, D. S. Industrial Development in East Africa. Oxford University Press (Addis Abba, 1969).

Ribadeau-Dumas, J. "l'Industrie de l'Aluminum dans la Republique Federale de Cameroun." United Nations Publication Number E/Conf.39/D/31 (Geneva. 1962).

Ruckstuhl, K. "A Program for Overall Improvement in Bagasse Mill Efficiency," Sugar y Azucar (Volume 6, Number 4) April 1971.

Ruckstuhl, K. "The Problems and Achievements of the World's Largest Bagasse Board Plant," Sugar y Azucar (Volume 7, Number 1) January 1972, pages 14-16.

----- . Personal Communication. March 1972.

Spencer, Guilford L., and George P. Meade. Cane Sugar Handbook. John Wiley and Sons, Inc. (New York, 1955).

Standard Building Products Ltd. The Standard Building Products Story. (Kingston, Jamaica) Undated.

Tao, H. C. "The Manufacture of Fiber Board from Bagasse," Sugar y Azucar Yearbook 1968, pages 79 and 82-83.

United Nations. Statistical Yearbook 1967. (New York, 1968).

----- . United Nations Sugar Conference 1958: Summary of Proceedings. (Geneva, 1958).

United Nations Economic Commission for Asia and the Far East. Economic Factors in Multi-storied construction -- A Case Study. United Nations Publication Number E/CN.11/I&NR/HBWP.8/C.5.

United Nations Food and Agricultural Organization. 1968 Yearbook of Forest Products. (Rome, 1968).

United Nations Industrial Development Organization. Building Materials Industry. United Nations (New York, 1969).

----- . Construction Industry. United Nations (New York, 1969).

----- . Estimation of Managerial and Technical Requirements in Selected Industries. United Nations (New York, 1968).

----- . Production Techniques for the Use of Wood in Housing Under Conditions Prevailing in Developing Countries. United Nations (New York, 1970).

----- . Industrialization and Productivity, Bulletin
Number 17. United Nations (New York, 1970).

Wu, Hsi-Sheng. "The Manufacture of Hardboard from Bagasse," Proceedings of the International Society of Sugarcane Technologists, Eleventh Congress, pages 1174-1184. Elsevier Publishing Company (Amsterdam, 1963).

APPENDIX. MILL OPERATING SYSTEM

The purpose of this appendix is to provide the general reader with an overview of the basic sugar mill operating system, with particular reference to those aspects of the mill operating system which affect and are affected by the associated production of bagasse building materials and other bagasse by-products. The operating system of the typical cane sugar mill has four principal divisions as shown in Figure A-1. In essence, the sugar cane produced by the field operations arrives at the sugar mill, where milling the cane produces raw juice and bagasse. The raw juice is then processed into raw sugar and molasses; in some mills the raw sugar is further processed into refined sugar, as indicated by the dotted lines in Figure A-1. The bagasse, meanwhile, is sent to the power generating station, where it is burned to generate steam which is used in the milling and processing operations. Surplus bagasse is either converted into waste heat or disposed of in some other manner.

Each of the four basic divisions of the mill operating system are examined more closely below. Power generation in particular, is discussed in some detail, since the release of bagasse for by-product utilization depends on a clear understanding of this area. The last part of this

section discusses in detail the release of bagasse for by-product uses.

A. Field Operations

Field operations involve the cultivation, harvesting, and transporting of the sugar cane. As mentioned earlier, the fiber content of the many varieties of sugar cane varies from 9% to 16%, and thus the variety of cane being cultivated has considerable effect on the total quantity and fibrous content of the bagasse produced. In general, the variety of cane being cultivated in any location has usually been carefully selected on the basis of the specific physical and nutritive properties of the soil, the available water supply, the desired harvesting age of the cane, the resistance of the cane to disease and insect attack, and other factors, as well as its sugar yield. Consequently, any modifications in field operations which involve changes in cultivation--say, for example, a change to cane with higher fiber or sugar content--must take place under stringent horticultural restraints.

Furthermore, changes in cultivation may have considerable impact on the overall economics of both sugar and bagasse production in any mill. Again, for example, a shift to cane with higher fiber content would have considerable impact on the consumption of power per ton of

cane milled and on the wearing rate of the milling equipment. Of all the possible changes in cultivation, however, the most critical are those which involve a change in sugar content or extraction levels. For example, a drop of one percent in the sugar content or extraction levels in a mill producing 100,000 tons of sugar per year would mean a loss of \$100,000 ($1\% \times 100,000 \text{ tons sugar} \times \100 per ton) in typical revenues from sugar sales. Reductions in revenue of such magnitude must be carefully weighed against the advantages to be gained.

Sugar cane is a seasonal crop. Its harvesting, therefore, takes place only during certain parts of the year. The harvesting season varies greatly from one part of the world to another, lasting 75 to 90 days in Louisiana, 120 to 150 days in Florida and the West Indies, and 11 months in Hawaii and Peru, with other parts of the world falling within this range. The harvesting of sugar cane consists of three operations: (1) cutting the cane; (2) removing the trash (leaves and tops) from the stalks; (3) conveying the cane to a collecting point. These operations are accomplished in different areas by various methods ranging from completely manual to completely mechanized.

The cutting of sugar cane may be done by manual laborers machetes and cutting cane stalks one at a time, as is common in Cuba. Cane may also be cut by special field machines using rotary or reciprocating blades which cut the cane slightly

above ground level, as is frequently found in Australia. Cane may also be "cut" by means of a bull-dozer with a specially-designed toothed blade which is pushed through the cane field at about one to three inches below ground level, thereby severing the cane slightly above its roots. This method of cutting cane is used primarily in Hawaii, where the harvesting of cane is completely mechanized.

In the case of cane which has been cut manually, the removal of trash is also accomplished manually, either by the laborer who has cut the cane or by a trimmer who follows the cutter through the cane field. A more common practice in areas where labor costs are significant is to remove a large part of the trash from the cane by burning the cane field just before harvesting. The cane field fire burns away much of the trash but leaves the tough stalk and its sugar content essentially intact.

Sugar cane that has been cut and trimmed manually in the field is then either bundled and carried to a central loading point or placed on a field wagon, which may be either motorized or animal drawn. In highly mechanized operations, the cut cane is bull-dozed or otherwise moved into large piles. Field cranes are then used to load the cane into truck trailers or special railroad cars. Whether transported by primitive or modern methods, the cane must reach the mill and be milled promptly, since the cane will become "sour" (that is, the

sugar will begin to invert) in a matter of a few days.

B. Milling

When cane arrives from the field, it is loaded onto large conveyors in such a manner as to insure a steady, even flow of cane into the milling area of the sugar mill. Figure A-2 diagrams this and subsequent steps in the milling operation. If the cane arrives from the field relatively free of dirt and trash, it may require only a light spraying with water before entering the mill; this is usually the case with cane that has been cut and trimmed by hand. Cane arriving from mechanized field operations such as those in the Hawaiian Islands, however, will contain significant amounts of dirt, rocks, and partially-burnt leafy trash. Trash which is partially burnt (carbonized) must be removed as completely as possible before entering the mill, since particles of carbonized trash are virtually impossible to remove from the rest of the bagasse once the two have been mixed together. The presence of particles of carbon is objectionable both in the processing of sugar and in the manufacture of many bagasse by-products, since the particles of carbon may cause discoloration in both the sugar and the by-products.

In addition to the removal of trash, dirt must be washed away and rocks mechanically sorted out before the cane enters the milling area. The elimination of dirt and rocks is impor-

tant in reducing the wear on the milling equipment and in minimizing the level of dirt in the raw juice and the bagasse. Removal of the dirt from the bagasse is feasible but may be costly.

The cane on the conveyor entering the mill is leveled by a rotating spoked leveler and then enters the preparation stage. Three machines -- knives, crushers, and shredders -- may be used in various combinations to reduce the cane stalks to smaller fragmented pieces before the cane stalks enter the mill rollers. Figure A-2 shows the common combination of knives and crusher rollers in tandem.

The fragmented cane then enters the first of a series of three-roller mills which crush the cane into progressively smaller pieces and squeeze out the sugar-laden juices. Extraction of the sugar from the cane reaches 94% to 97% of the sugar content in efficient sugar mills, but can be as low as 85% or less in mills with poor efficiency. The level of sugar extraction in a given mill is of some importance to bagasse by-products manufacture, since any sugar not extracted from the cane in the mill is left in the bagasse. Finally, the size distribution of the bagasse fiber bundles will vary according to the condition of the mill rollers, the applied milling pressure, the rate of milling, and several other factors.

In the sugar mills which do not utilize bagasse in by-

product manufacture, bagasse passes directly from the roller mills to the bagasse furnace where it is burned as fuel for the operation of the mill. The burning of bagasse is discussed in some detail in Part D (Power Generation).

C. Processing of Sugar

The raw juice which is extracted from the cane by the roller mills is then sent to the sugar house where it is processed into raw sugar. This processing involves four steps: (1) clarification of the heated raw juice by the addition of lime and filtration; (2) the further heating of the juice in multiple-effect evaporators to boil the juice down to a sirup; (3) the cooling of this sirup in vacuum pans into a mixture of molasses and sugar crystals known as massecuite; (4) the separation of the sugar crystals from the molasses in a centrifugal separator. The sugar produced by this processing is known as raw sugar or "plantation raw." Some mills are also equipped for the further processing of this raw sugar into refined sugar.

The processing of sugar in sugar mills ~~is of interest~~ in this study by virtue of the fact that the heating of the raw juices requires a large part of the heat generated at the mill by the burning of the bagasse and/or other fuels. Table A-1 shows that 70% to 78% of the heat energy consumed by the typical sugar mill is consumed in the boiling opera-

tion. Thus, as will be shown in Part E (Freeing of Bagasse for Utilization in By-Products), the efficient use of heat in the boiling operation can result in large-scale savings of bagasse for by-product uses.

D. Power Generation

The bagasse output of the mill is normally sent to the boiler house where it is burned in special bagasse furnaces to provide power for the entire mill operating system. This power is distributed throughout the mill by steam or by electricity generated by steam. The use of bagasse as a fuel and the consumption of power within the mill must be examined in some detail, since the possible release of bagasse for by-product utilization will depend on these two operations.

D.1 Fuel Value of Bagasse

The heat energy which can be practically obtained in any given sugar mill is a function primarily of the heat value of the bagasse and of the efficiency of the boiler in which the bagasse is burned. The heat value which can be obtained from burning bagasse under ideal conditions is called the Net Calorific Value (NCV). The NCV of dry bagasse shows little variation from one variety of sugar cane to another. Table A-2 indicates the limited variation of the NCV for dry bagasse derived from several varieties of cane in widely

separated parts of the world. Significant variations in the NCV of bagasse are observed, however, for the varying levels of moisture content and, to a lesser extent, of the sugar content found in fresh bagasse, which is the condition in which bagasse is normally burned in the mill's boiler. Various formulae for the determination of the NCV of bagasse in the fresh state have been devised and used throughout the sugar industry. The most widely used of these formulae are used in Figure A-3 to show the variation in the NCV of bagasse as a function of moisture content. As can be seen from the figure, the various formulae give essentially equivalent values of NCV at any given moisture content.

The moisture content of bagasse, and thus the NCV of the bagasse, does show considerable variation from sugar mill to sugar mill. The range of this variation is indicated in Table A-3, which shows the range of the moisture content, sugar content, and NCV of bagasse produced by sugar mills in South Africa, Jamaica, and Hawaii. Since the total heat energy which can be obtained in any sugar mill has obvious dollars and cents value, the moisture content of bagasse produced in any given mill will be a key factor in the economics of saving bagasse for by-product utilization.

D.2 The Bagasse Furnace

The second factor -- in addition to the moisture content

of the bagasse -- which determines the heat energy obtained by burning bagasse is the efficiency of the bagasse furnace. The efficiency of the bagasse furnace is a function primarily of the heat lost in the stack (exhaust) gases and secondarily of the heat losses resulting from unburnt fuel, radiation, and other causes which are usually minor. The heat loss in the stack gases is, in turn, determined by the temperature and volume of the stack gases. The volume of the stack gases is directly related to the volume of air entering the combustion area of the furnace, which is usually expressed as a percentage in excess of that amount of air theoretically required for complete combustion. In essence, then, the efficiency of a bagasse furnace will be a function of the temperature of the stack gases and the percentage of excess air.

Figure A-4 shows the variation in furnace efficiency with the change in the percentage of excess air for stack temperatures of 450^o, 500^o, 550^o, and 600^o F. (Losses of efficiency due to unburnt fuel, radiation, and other minor factors are not included in the expressed nominal furnace efficiencies.) These stack temperatures are typical of older, less efficient bagasse furnaces. Bagasse furnaces which have been installed in recent years usually have lower stack temperatures and lower levels of excess air than the older furnaces. Table A-4 shows the overall efficiency ratings (based on NCV) of four types of modern bagasse furnaces in common use.

The total heat which is actually obtainable for the generation of steam in the boiler of the furnace is, in summary, a function of the moisture content of the bagasse, the temperature of the stack gases leaving the furnace, and the percentage of excess air entering the furnace. Table A-5 shows the range of the net heat obtainable in a bagasse boiler as a function of the moisture content of the bagasse and the percentage of excess air, for an assumed stack temperature of 500° F. The large range of the values of the net heat obtainable in the boiler is both notable and critical in its potential impact on the heat balance of the mill. A mill, for example, which is burning bagasse with a moisture content of 40% in a furnace with 50% excess air has available 3572 BTU's per pound of bagasse burned (see Table A-5), which is 178% of the heat available to a mill burning bagasse at the other end of the spectrum (54% moisture content, 200% excess air, and a yield of 2057 BTU's per pound of bagasse burned). Clearly, such possible variations in the net heat obtained from bagasse in any given mill will make a determination of the existing heat balance in the mill a prerequisite in the establishment of the economics of the freeing of its bagasse for by-product utilization.

D.3 Power Distribution

The heat obtained from the bagasse boiler is used to

generate steam which is used directly in the processing of the raw juice and in supplying the power which is used in the mechanical handling and milling of the cane. The mechanical power requirements may be met by steam delivered directly to steam engines in the mill, or in the case of electrified mills, the steam is converted into electrical energy in steam turbines (ideally 1 KWH = 3413 BTU's = 860 Kcal). The power consumption of a sugar mill typically follows a relatively fixed pattern, as indicated by the distribution of power consumption by operations shown in Table A-1. A more detailed breakdown of power consumption in five Taiwan Sugar Company mills is shown in Table A-6. This table also shows the absolute power consumption of each operation in terms thousands of BTU's per ton of cane milled (KBTU/TC). Total heat consumption at these factories varies from 1197.9 KBTU/TC to 1756.0 KBTU/TC.

E. Freeing of Bagasse for Utilization in By-Products

If the use of bagasse for the manufacture of some by-product is being considered, it will be necessary to examine both the possible methods and the economics of releasing bagasse from its present use as fuel -- unless, of course, the sugar mill is producing a surplus of bagasse adequate for the demands of the proposed by-product utilization. Should an adequate surplus of bagasse exist, then the economics of

the bagasse release simply include a determination of the savings resulting from a reduction or elimination of the surplus disposal expenses borne by the mill. In many cases, however, it will be necessary to release large additional quantities of bagasse if the mill is to engage in or supply a bagasse by-product manufacturing operation, such as bagasse particle board. It is necessary, therefore, to examine in detail the two basic methods of releasing bagasse and to consider briefly the economics of each release method. The first method for releasing bagasse is based on the improvement of thermal efficiencies within the mill operating system; the second method involves a conversion to the burning of alternate or supplemental fuels in place of bagasse.

E.1 Improvement of Thermal Efficiency

A sugar mill may be viewed as a complex mechanical system consuming energy, principally in the form of heat, and producing work, principally in the form of transforming sugar cane into bagasse and raw juices into raw sugar and molasses. The usual equilibrium level of energy consumption for a given amount of work produced is known as the heat balance of the mill, since all energy consumed in the mill is in the form of either direct heat energy or electrical energy generated by heat energy. Almost invariably within a mill which is not currently using bagasse for by-products, there will exist

numerous opportunities for the improvement of the heat balance -- that is, for the lowering of the energy consumption for a given output of work or product. If the energy required per given output of work can be reduced, then less bagasse will be needed to generate energy in the bagasse boiler, and a certain amount of bagasse is thus released for other uses. The extent of the bagasse which can be released by this method depends on the existing heat balance of a given mill and on the specific measures undertaken to improve mill efficiency.

In general, if a sugar mill is staffed by competent engineers and operators, its staff will have a sound knowledge of the heat balance of the mill. The heat consumptions of the various stations in the mill operating system, the net heat obtained from the bagasse boiler, and the approximate heat losses throughout the mill will be known, monitored frequently, and used daily in the operation of the mill. Figure A-5 shows an arrangement of typical heat balance data in the form of a nomograph used to determine the excess bagasse which will result from mill operations under certain variable conditions. This nomograph is based on and was used in the operation of the Cartavio Sugar Mill in Peru, and reflects possible day-to-day variations in the heat balance (the amount of steam generated per pound of cane milled, the percentage of fiber in the cane, and the quantity of refined sugar produced per day).

For simplicity in considering the possible release of bagasse, the heat balance of the mill is most conveniently expressed in terms of a "macro" or aggregated value such as "KBTU/ton of cane milled" or "tons bagasse required/ton of cane milled." Such an aggregated value essentially lumps together all the individual heat balance data into one easily understood figure. The heat balance data in Table A-6 includes an aggregated value for each mill, expressed in terms of KBTU/ton of cane milled. This aggregated value can be converted directly into an aggregated value in terms of bagasse required/ton of cane milled, as follows. Assume the average net heat obtainable in the mill's boiler is 3087 BTU/pound of bagasse burned (corresponding to a bagasse moisture content of 49%, an excess air percentage of 50%, and a stack temperature of 500°F, as shown in Table A-5). The new value then becomes

$$\frac{1,586,800 \text{ BTU/ton of cane milled}}{3087 \text{ BTU/lb bagasse} \times 2000 \text{ lbs/ton}} = 0.255 \text{ tons bagasse per ton of cane milled}$$

On the basis of such an aggregated value and the known quantity of cane milled, it is possible to calculate the actual amount of bagasse one can expect to be released by adapting measures designed to improve the thermal efficiency.

The possible improvements in thermal efficiency in a sugar mill fall into four basic categories (in order of importance): (1) thermal economies effected at the processing station and the milling station; (2) use of pre-heaters and economisers in the boiler; (3) control of the moisture content of the bagasse; and (4) control of heat losses through radiation and "blow-off." A full discussion of the theoretical and technical aspects of these measures is beyond the scope of this discussion. It will suffice here simply to describe the basic improvement and to give the approximate percentage improvement in thermal efficiency to be expected.

Various methods of tapping and recycling exhaust steam from the processing station have been devised. The exact nature of the best arrangement and of the benefit to be derived depends on the particular existing equipment and layout of the processing station of the mill under consideration. In general, improvements of 9-15% in overall thermal efficiency of the mill are possible with this method.¹ Milling station power consumption can be reduced by up to 40% by the use of higher pressure and superheated steam in the prime movers of the mill (usually these are the steam engines).² Since this station of the mill typically consumes 10-12% of the heat required in the mill (Table A-1, overall efficiency improvements of 4-5% can be

expected at this station. Thus, modifications to the processing and milling stations can lead to overall efficiency improvements of 13-20%.

Preheaters are devices installed in the exhaust area of furnaces. Heat is transferred from the hot exhaust gases to air which is forced through the preheating unit. This preheated air is then introduced into the combustion area of the furnace, thus increasing the number of BTU's obtained from the combustion area of the furnace. Economizers are similar to preheaters, except that water is circulated through the economizers. This preheated water is then introduced into the heating tubes of the boiler and is converted to steam. The preheated water obviously requires fewer BTU's to convert to steam than does ordinary unheated feed water. The introduction of either or both of these devices into the bagasse boiler can effect improvements in the overall thermal efficiency of the mill of 10-15%.³

The effect of moisture content on the NCV of bagasse has already been discussed; hence, the importance of minimizing the bagasse moisture content should be clear. One of the determining factors in the moisture content of bagasse is the amount of water added to the bagasse as it is being milled. (See Figure III-2.) A 40% reduction in the water added to the bagasse in the milling process can

result in a 5% overall improvement in the net heat obtained from the bagasse boiler.⁴ Thus the overall thermal efficiency of the mill would also increase by 5%.

Finally, heat losses due to radiation from steam pipes and "blow-off" (that is, release of steam into the atmosphere) from various equipment may range from 1-4% in a typical sugar mill.⁵ These losses may be considerably higher in some mills. Effective control of these heat losses by lagging of pipes and elimination of "blow-off" can therefore improve overall thermal efficiency by at least 1-4%.

On the basis of these improvements, overall thermal efficiency in a typical sugar mill can be increased by 37-44%. Thus, if a mill is currently in close heat balance with its bagasse supply--that is, if the mill's total heat requirements equal or closely approximate the net heat obtainable from its bagasse output--then the adoption of a thorough program of improving thermal efficiencies in the mill could result in the release of 37-44% (approximately) of the mill's total bagasse output. Table A-7 shows an even greater range of potential bagasse release through the improvement of thermal efficiency in several Indian sugar mills.

One final consideration in regard to this method of releasing bagasse for by-product utilization relates to

the minimum quantity of bagasse required for a by-product use at a feasible scale of production. Say, for example, that a bagasse particle board plant is desired, and a daily volume of 100 tons of board is deemed the minimum feasible scale of production. Assuming that one ton of board requires three tons of bagasse, then 300 tons of bagasse are required daily by the board plant. If the sugar mill supplying the bagasse to the plant has a six-months grinding season vs. year-round operation of the board plant, then the mill must be prepared to supply the plant with 600 tons of bagasse daily during its grinding season. If the mill intends to release this amount of bagasse through effecting a 40% improvement on overall thermal efficiency, then its total daily bagasse output during the grinding season must be at least 1500 tons (1500 tons x 40% = 600 tons). If one further assumes a typical 0.25 tons of bagasse produced per ton of cane milled, then 6000 tons of cane (6000 tons cane x 0.25 tons bagasse/ton of cane = 1500 tons bagasse) must be milled daily during the grinding season.

In point of fact, extremely few sugar mills have daily grinding capacities as high as 6000 tons of cane. Consequently, to supply a bagasse by-product manufacturing operation requiring 300 tons of bagasse per day, and to do solely on the basis of releasing bagasse by the improve-

ment of thermal efficiency, it will be necessary for two or more mills to act collectively in supplying the bagasse. Alternatively, the improvement of thermal efficiency may be used in conjunction with the burning of supplemental or alternate fuels to reduce the overall operating cost and thereby lower the cost of the bagasse released. The burning of supplemental or alternate fuels is an important-- indeed, the principal--method of releasing bagasse when large amounts of the bagasse are required. For smaller amounts of bagasse, however, the improvement of thermal efficiency may be more than adequate to meet demands.

Unfortunately, few generalizations can be drawn, as to the economics of improving thermal efficiency, since the costs of such improvements and the benefits to be derived are so highly specific to the particular circumstances of each mill. A very approximate range of costs for an overall improvement in thermal efficiency of 25-40% might be \$250,000 to \$500,000, depending on the size of the mill and many other factors.

E.2. Supplemental and Alternate Fuels

If the large-scale release of bagasse for by-product utilization is contemplated, the burning of supplemental or alternate fuels in place of bagasse will usually be necessary. There are two stages in this change-over to

the burning of other fuels, both of which have their own technical and economic considerations.

The first stage in the change-over to supplemental or alternate fuels is the conversion of the existing bagasse-fired boiler to meet the particular requirements of the new fuel. If the boiler is being converted to burn wood, the required modifications are not extensive. Virtually all furnace conversions being currently contemplated, however, are for the burning of fuel oil, natural gas, or coal, all of which are superior in performance to wood or bagasse. In the case of these preferred fuels, extensive boiler modifications are necessary, and in some cases installation of a complete new unit will be the most economical measure. Costs of the conversion will vary considerable with location, the type of existing equipment, the exact fuel desired, etc., but a major new installation will range from \$250,000 to \$1,000,000.

The second stage in the change-over process is the operation of the new boiler. In general, the performance of fuel oil and natural gas boilers is much superior to that of a bagasse boiler in many respects. The net heat output of the boiler, for example, can be controlled much more closely in oil or gas furnaces, since the amount of fuel fed to the boiler can be regulated more closely and easily and since the conversion of those fuels to heat is

virtually instantaneous. Thus the net heat produced by the boiler can readily be adjusted to meet the varying demands of the mill operating system. Also, bagasse-- unlike oil or gas--leaves an ash residue which must be removed from the furnace frequently and disposed of. In short, conversion to oil or gas will make the operation of the sugar mill more efficient, simpler, and cleaner.

The economics of burning supplemental or alternate fuels is relatively straightforward. The first step is to establish the equivalent fuel value (EFV) of the mill's bagasse in terms of the new fuel being considered. The EFV is that amount of fuel which, when burned in an appropriate furnace, will give an amount of net heat equal to that obtained by burning a unit amount of bagasse in a bagasse furnace. A general equation for the EFV of bagasse is given below:

$$EFV_{\text{bagasse}} = \frac{NCV_{\text{bagasse}} \times \text{Bagasse Boiler Efficiency}}{NCV_{\text{new fuel}} \times \text{New Fuel Boiler Efficiency}}$$

The determination of the values for bagasse NCV and boiler efficiencies have already been discussed. Typical values of NCV and boiler efficiency for alternate fuels--fuel oil, natural gas, coal, and wood--are given in Table A-8. Thus, the EFV of bagasse in terms of fuel oil, for example, will

be

$$\text{EFV}_{\text{bagasse}} = \frac{2340 \text{ kcal/kg} \times 60\% \text{ B.E.}}{10,000 \text{ kcal/kg} \times 75\% \text{ B.E.}} = 0.187 \text{ Fuel Oil}$$

where it is assumed that

NCV of bagasse at 49% moisture content = 2340 kcal/kg

Bagasse boiler efficiency = 60%

NCV of fuel oil = 10,000 kcal/kg

Fuel oil boiler efficiency = 75%

Typical EFV's of bagasse are given in Table A-8 for natural gas, coal, and wood, as well as fuel oil. These values are only approximate, however, since the actual EFV will depend on the exact NCV of the bagasse and other fuel under specific local conditions and on the exact efficiencies of the boilers to be used with each fuel.

The fuel cost of burning alternate or supplemental fuels to release bagasse can be expressed in terms of the cost/ton of bagasse released, as follows:

$$\text{Fuel Cost} = \text{EFV}_{\text{bagasse}} \times P_{\text{new fuel}}$$

where

$$P_{\text{new fuel}} = \text{local unit price of new fuel}$$

The distinction between supplemental and alternate fuels is simply a matter of whether the fuel is burned along with a portion of the bagasse produced by the mill

(supplemental) or whether the new fuel is burned exclusively by the mill (alternate). The total operating costs of burning alternate and supplemental fuels are examined in more detail in the investment analysis in Section IV.

<u>OPERATION</u>	<u>ENERGY CONSUMPTION</u> <u>(% OF TOTAL)</u>
Boiling	70-78
Condensation	9.7-13
Mechanical power	10-12
Heat losses	1.2-3.3
Other	0.1-7.3

TABLE A-1: TYPICAL DISTRIBUTION OF POWER CONSUMPTION IN MILL

Source: C-J. Lu et.al., "Heat Balance Determination and Heat Utilization in the Sugarcane Mill."

<u>AREA</u>	<u>NET CALORIFIC VALUE</u>	
	<u>BTU/lb</u>	<u>KCAL/kg</u>
Queensland, 1935	7547	4292
South Africa, 1936	7623	4335
Hawaii, 1934	7690	4372
Cuba, 1944	7814	4441
Puerto Rico, 1944	7640	4244
Mean Value	7663	4357

TABLE A-2: NET CALORIFIC VALUE (NCV) OF DRY BAGASSE FROM
VARIOUS REGIONS

Source: E. Hugot, Handbook of Cane Sugar Engineering, p. 678.

AREA	MOISTURE CONTENT (%)			SUGAR CONTENT (%)		NET CALORIFIC VALUE		
	LOWEST	MEAN	HIGHEST	LOWEST	HIGHEST	LOWEST	MEAN	HIGHEST
South Africa, ¹ 1951-1952	44.68	--	53.41	2.58	3.32	2944	3163	3744
South Africa, ¹ 1961-1962	49.44	--	54.82	2.60	2.88	2867	3067	3327
Jamaica, 1960 ¹	45.18	--	51.81	2.20	3.03	3034	--	3692
Hawaii, 1970 ^{2&3}	43.20	47.8	50.60	1.00	2.80	3250	3500	3880

TABLE A-3: MOISTURE CONTENT, SUGAR CONTENT, AND NET CALORIFIC VALUE OF BAGASSE FROM SUGAR MILLS IN SELECTED REGIONS.

Sources, by notes:

¹A.C. Barnes, The Sugar Cane, page 366.

²Hawaiian Sugar Planters' Association, Period Summary of Factory Results -- Final 1970.

³Net calorific value calculated by formula.

<u>CHARACTERISTIC</u>	<u>TYPE OF BAGASSE FURNACE</u>			
	<u>STEPGRATE</u>	<u>HORSESHOE</u>	<u>WARD</u>	<u>SPREADER-STOKER</u>
Heat losses (% NCV)				
Stack gases	16.2	15.9	13.4	12.7
Unburnt fuel	4.9	3.1	2.5	2.5
Radiation and other	7.3	4.9	3.1	3.1
Total heat losses	28.4	23.9	19.0	18.3
Furnace efficiency (%)	71.6	76.1	81.0	81.7
Percentage excess air	80%	70%	40%	30%
Stack temperature (°F)	356	356	356	356

TABLE A-4: CHARACTERISTICS OF MODERN BAGASSE FURNACES.

Source: J. Paturau, By-Products of the Cane Sugar Industry, page 31.

BAGASSE MOISTURE CONTENT (%)	NET HEAT OBTAINABLE IN BAGASSE FURNACE (BTU/lb)				
	PERCENTAGE EXCESS AIR				
	0%	50%	100%	150%	200%
40	3747	3572	3400	3225	3054
41	3664	3494	3321	3151	2985
42	3579	3412	3244	3077	2902
43	3494	3329	3167	3004	2840
44	3400	3249	3089	2928	2769
45	3326	3169	3012	2854	2697
46	3241	3087	2933	2778	2624
47	3160	3007	2856	2704	2553
48	3077	2928	2779	2631	2482
49	2993	2851	2700	2557	2409
50	2910	2767	2624	2481	2338
51	2829	2689	2548	2416	2275
52	2744	2607	2469	2332	2194
53	2664	2528	2393	2259	2124
54	2582	2450	2319	2188	2057

TABLE A-5: NET HEAT OBTAINABLE IN BAGASSE FURNACE AS A FUNCTION OF BAGASSE
MOISTURE CONTENT AND PERCENTAGE EXCESS AIR AT 500° STACK TEMPERATURE

Source: Spencer and Meade, Cane Sugar Handbook, page 67.

HEAT CONSUMPTION

OPERATION	MILL A		MILL M		MILL N		MILL O		MILL P	
	KBTU/TC	%	KBTU/TC	%	KBTU/TC	%	KBTU/TC	%	KBTU/TC	%
Turbogenerator	74.5	6.2	78.1	6.4	40.0	2.5	61.0	3.7	48.0	2.8
Milling	52.8	4.4	42.0	3.5	68.0	4.3	28.5	1.8	77.9	4.4
Pumps	17.1	1.4	16.3	1.3	59.5	3.7	53.1	3.2	49.3	2.8
Power subtotal	144.4	12.0	136.3	11.2	167.5	10.5	142.6	8.7	175.2	10.0
Evaporation	552.4	46.1	472.4	38.9	510.4	32.1	626.2	38.1	680.7	38.7
Vacuum pan	316.8	26.5	391.7	32.3	608.6	38.4	584.9	35.6	665.1	37.9
Boiling subtotal	869.2	72.6	864.1	71.2	1119.0	70.5	1211.1	73.7	1345.8	76.6
Condensate	157.6	13.2	149.5	12.3	153.5	9.7	166.8	10.2	185.7	10.6
Loss	26.7	2.2	15.8	1.3	31.2	2.0	54.8	3.3	25.8	1.5
Other	--	--	48.2	4.0	115.6	7.3	67.7	4.1	23.5	1.3
Total heat	1197.9	100%	1213.9	100%	1586.8	100%	1643.0	100%	1756.0	100%
Grinding capacity, tons cane/day	2000		1500		3200		1200		3600	

TABLE A-6: DISTRIBUTION OF HEAT CONSUMPTION IN FIVE TAIWAN SUGAR COMPANY MILLS

Source: C-J. Lu et.al., "Heat Balance Determination and Heat Utilization in the Sugarcane Mill."

BOILER EFFICIENCY, NCV BASIS (%)	BAGASSE REQUIRED AS FUEL (AS % OF CANE MILLED, BY WEIGHT)			
	CANE WITH HIGH FIBER CONTENT		CANE WITH LOW FIBER CONTENT	
	MILL AT HIGHEST EFFICIENCY AND BAGASSE AT 46% MOISTURE	MILL AT LOW EFFICIENCY AND BAGASSE AT 50% MOISTURE	MILL AT HIGHEST EFFICIENCY AND BAGASSE AT 46% MOISTURE	MILL AT LOW EFFICIENCY AND BAGASSE AT 50% MOISTURE
83	14.9	--	15.7	--
79	15.5	23.3	16.3	24.7
74	16.8	25.3	17.8	26.8
67	18.1	27.6	19.1	29.3
60	--	30.4	--	32.4

TABLE A-7: BAGASSE REQUIRED AS FUEL AT VARIOUS LEVELS OF THERMAL
EFFICIENCY IN SELECTED INDIAN SUGAR MILLS (THEORETICAL)

Source: S. Gupta et.al., "Possibilities for Saving Bagasse in India Through Maximum Fuel and Steam Economy Measures."

FUEL	NET CALORIFIC VALUE		BOILER EFFICIENCY (NCV BASIS)	EQUIVALENT FUEL VALUE OF BAGASSE (EFV _{bagasse})
	BTU/lb	KCAL/kg		
Fuel oil	16,600	9,300	90%	0.18
Natural gas	20,000	11,200	89%	0.15
Coal (bituminous)	11,600	6,500	85%	0.28
Wood (air-dried)	6,400	3,600	82%	0.55

TABLE A-8: NET CALORIFIC VALUE, BOILER EFFICIENCY, AND
EQUIVALENT FUEL VALUE OF BAGASSE FOR FOUR FUELS.

Source: J. Paturau, By-Products of the Cane Sugar Industry,
pages 31-32.

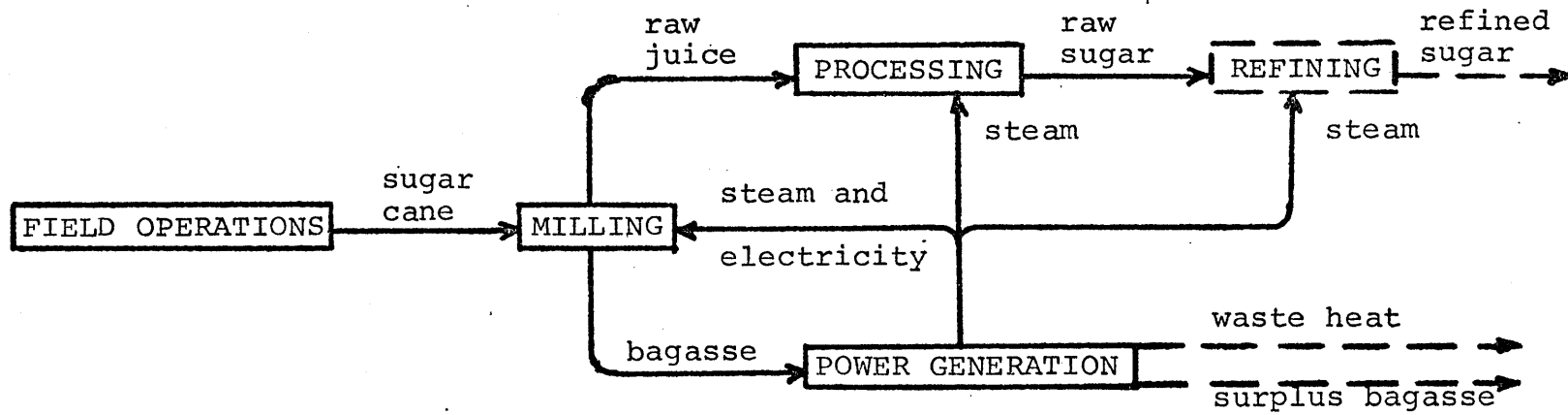


FIGURE A-1: PRINCIPAL DIVISIONS OF MILL OPERATING SYSTEM

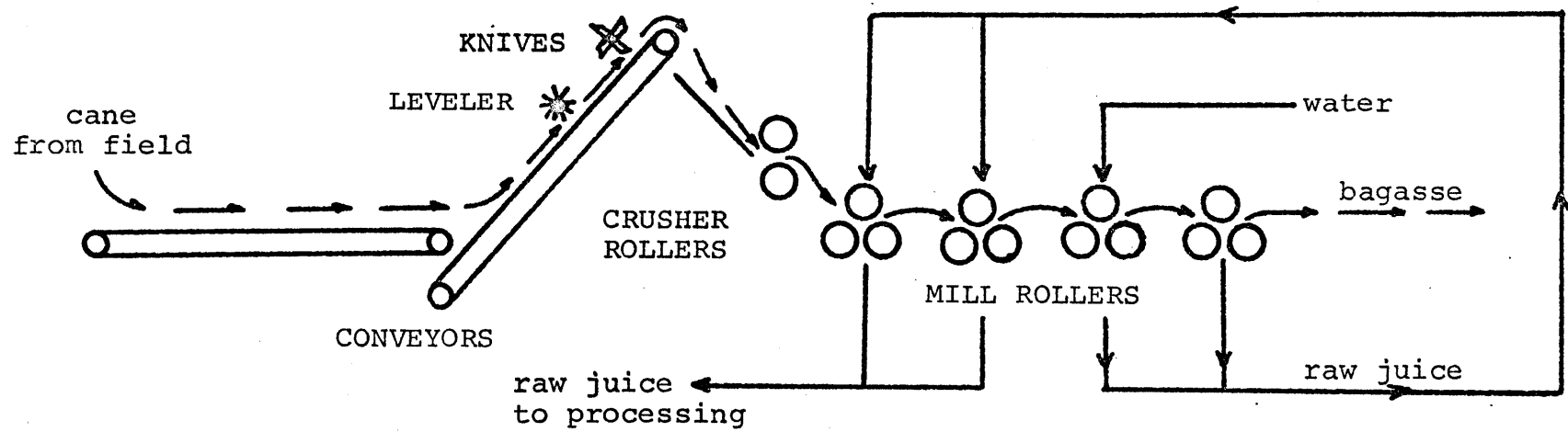
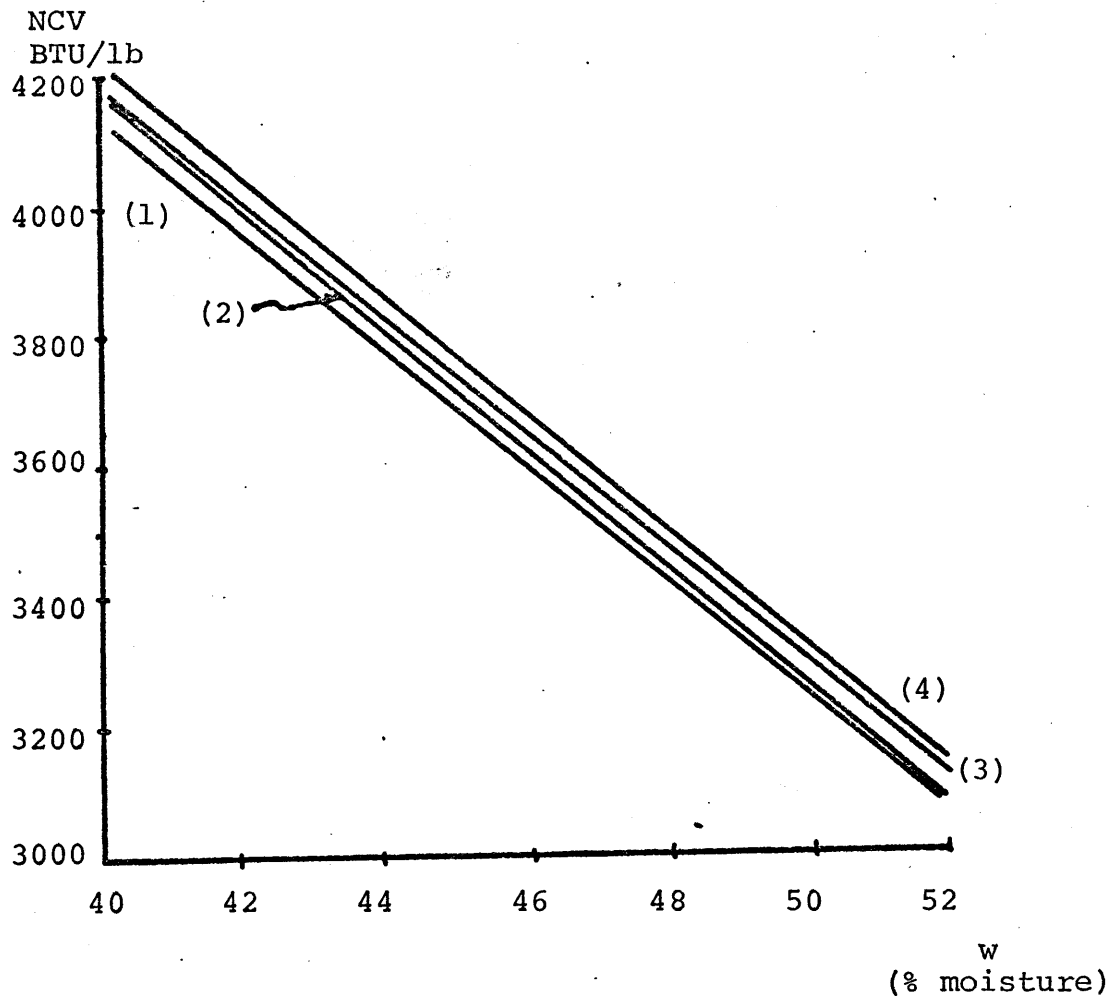


FIGURE A-2: TYPICAL MILLING OPERATION



NCV Curves:

$$(1) \text{ NCV} = (7650 - 13.5s - 87.3w) \text{ BTU/lb}$$

$$(2) \text{ NCV} = (7650 - 18s - 86.4w) \text{ BTU/lb}$$

$$(3) \text{ NCV} = (7712 - 14.4s - 87.6w) \text{ BTU/lb}$$

$$(4) \text{ NCV} = (7783 - 22s - 88.27w) \text{ BTU/lb}$$

Note: Sugar Content (s) assumed to be 2%.

FIGURE A-3: NET CALORIFIC VALUE (NCV) OF BAGASSE AS A FUNCTION OF MOISTURE CONTENT.

(See next page for reference notes.)

Reference Notes for Figure A-3

Curve 1: E. Hugot, Handbook of Cane Sugar Engineering, page 679.

Curve 2: A. Barnes, The Sugar Cane, page 366.

Curve 3: S. Gupta, "Possibilities of Saving Bagasse in India for the Paper and Pulp Industries Through Maximum Fuel and Steam Economy Measures."

Curve 4: J. Paturau, By-Products of the Cane Sugar Industry, page 30.

FIGURE A-3 (continued): NET CALORIFIC VALUE (NCV) OF BAGASSE AS A FUNCTION OF MOISTURE CONTENT.

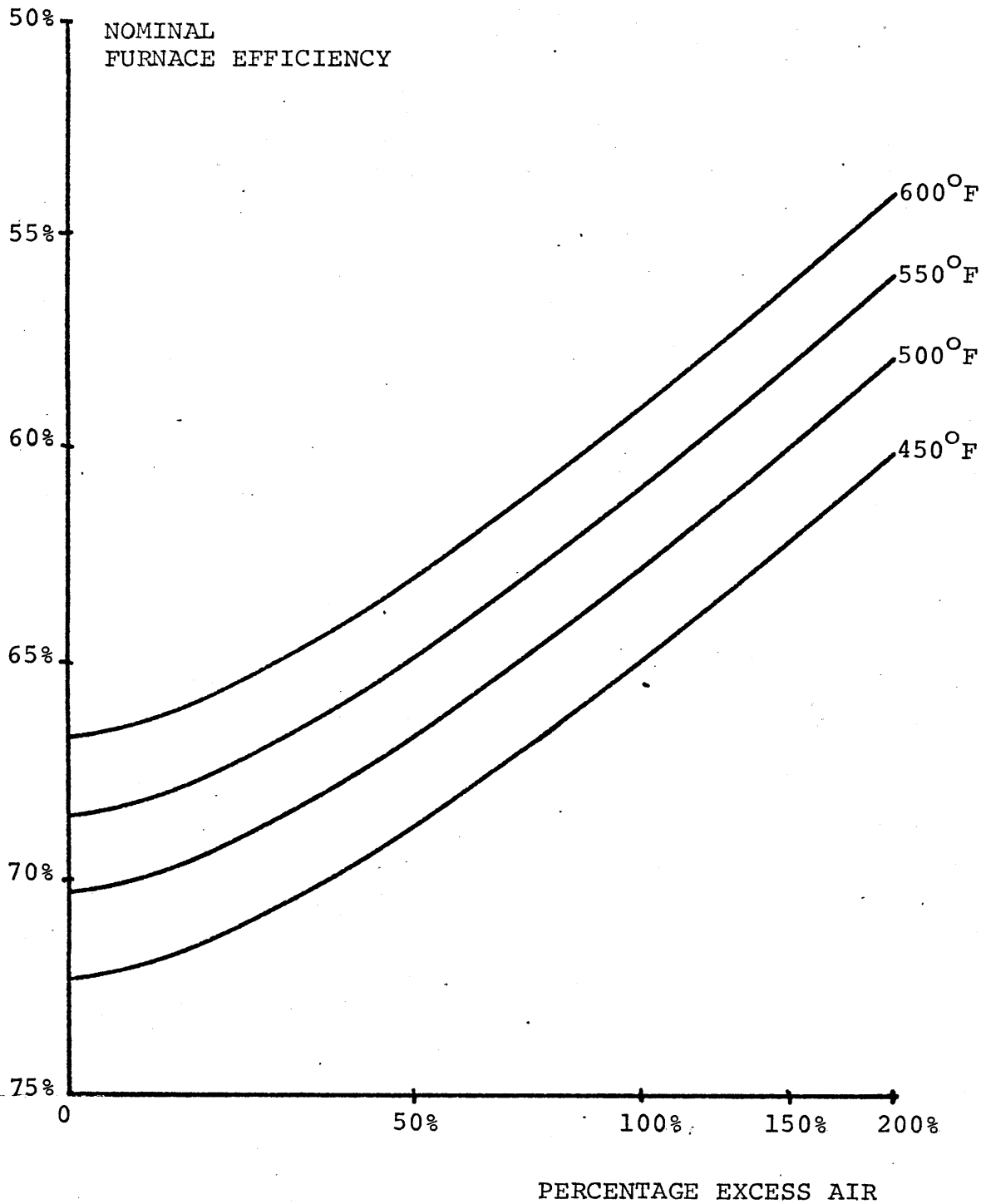


FIGURE A-4: NOMINAL FURNACE EFFICIENCIES AS FUNCTIONS OF THE PERCENTAGE EXCESS AIR, FOR STACK TEMPERATURES OF 450°F, 500°F, 550°F, and 600°F.

Source: Spencer and Meade, Cane Sugar Handbook, page 67.

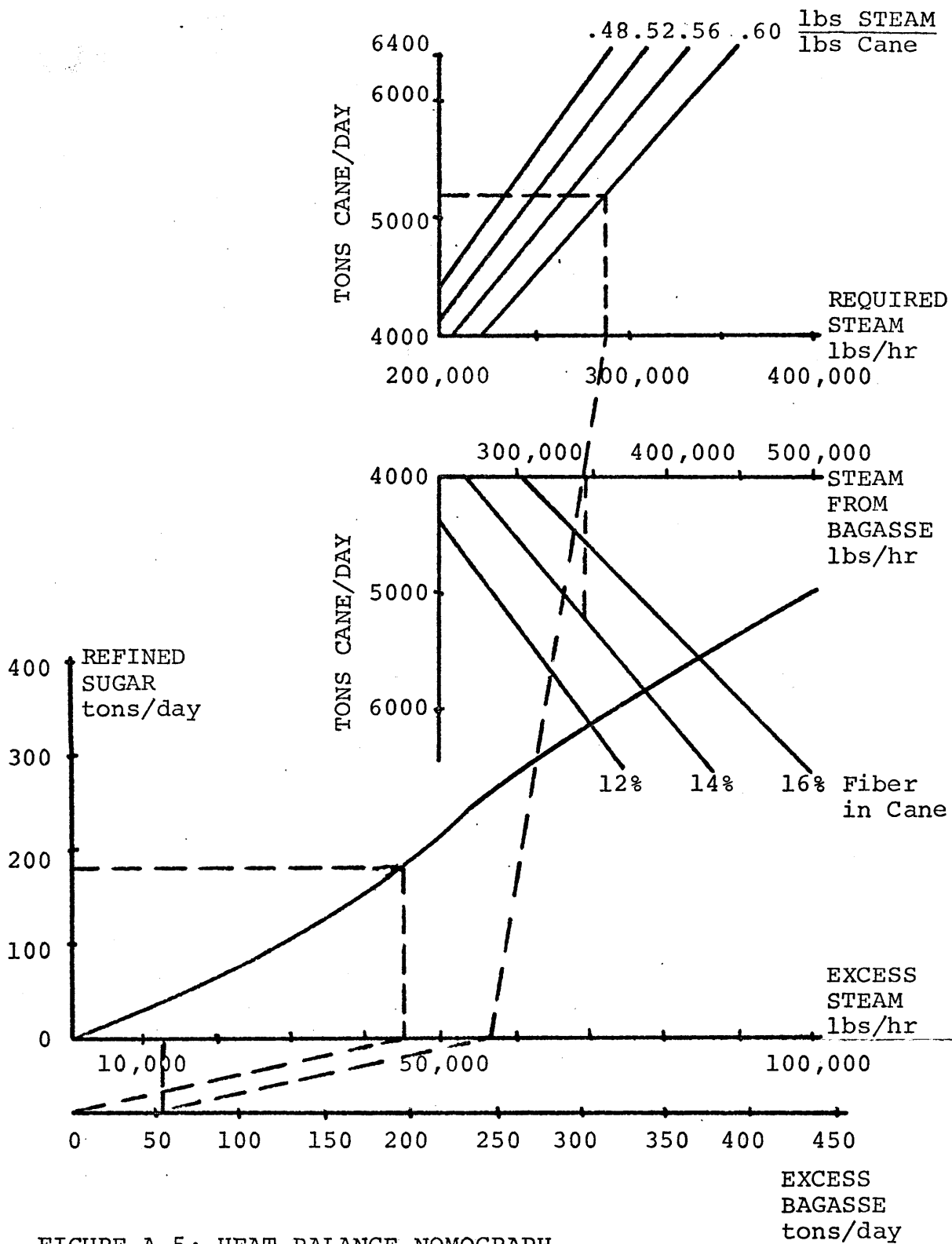


FIGURE A-5: HEAT BALANCE NOMOGRAPH

Source: Mr. John Bersch, personal communication.

NOTES -- APPENDIX

- ¹Cellulose Development Corporation Ltd. and John Thompson Water Tube Boilers Ltd., Saving of Bagasse for Papermaking -- Thermal Considerations (unnumbered).
- ²S. Gupta et. al., "Possibilities of Saving Bagasse in India for the Pulp and Paper Industries through Maximum Fuel and Steam Economy Measures."
- ³Cellulose Development Corporation Ltd. and John Thompson Water Tube Boilers Ltd., loc.cit.
- ⁴Idem.
- ⁵C-J. Lu et. al., "Heat Balance Determination and Heat Utilization in the Sugarcane Mill."