ENERGY COGENERATION AND WASTE HEAT RECOVERY IN A RICE MILL OF PERU

-A CASE STUDY-

By

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PREFACE

The inspiration for this study originated in 1979 when the author worked as a methods analyst in Ingenio Guadalupe Rice Mill, Peru. In a report to the management of the company, Mr. Ramon Yep, the plant manager, and the author recommended consideration of burning of rice husk to generate energy.

Since the oil embargo in the mid 1970s, the utilization of refuse derived fuels has received increased emphasis in industry, government and academia. The rice husk, considered for years an agricultural waste and a nuisance, arises as a renewable and economical alternative to traditional fuels.

This study examines questions of the rice husk combustion, the potential for cogeneration, the power requirements, the steam required for paraboiling and solvent extraction milling in a rice mill of Peru. It focuses on developing suitable technologies for waste heat recovery and cogeneration in a rice mill. Also, it considers the economic evaluation of some alternative projects likely to be implemented as a source of power and heat for the mill plant. Portions of this study were developed while the author was on a research trip in the northwestern region of Peru in 1982.

The author is pleased to present this study as a small contribution to the solution of the energy options and the food problem of his country: Peru. Its applications can be useful in any place in the world where rice is harvested, especially in the Third World Countries, where this golden and tough grain is the stalple grain.

J. B. W. K.

ACKNOWLEDGMENTS

I am indebted to the management and personnel of the Ingenio Guadalupe Rice Mill for providing from their archives the material pertaining to the rice mill process and its energy requirements.

I am grateful to the companies, the contractors and the engineers who gave me much valuable information.

To my good friends Eduardo and Pam Martinez, I express my thanks, for having been my hosts, perhaps at times with a bit of coersion.

I am especially beholden to Dr. Wayne C. Turner, for all I have learned from him. His advice and his understanding permitted the completion of this study.

Robert (Bob) S. Wilson, my cosmopolitan host, obligingly read all the manuscript and made invaluable suggestion for its improvement. To Bob, I owe my gratitude.

I am deeply indebted to my family. Their infinite patience, understanding, humor and love gave me the courage to make my dreams come true.

Jorge B. Wong-Kcomt

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CHAPTER 1

INTRODUCTION

Rice provides the principal food for about half of the world population. During 1975 the World Total Production was 353.5 million metric tons. In Peru, 125,000 Ha. (312,500 acres) were harvested during the crop year of 1977; the production for this year was 580,000 M.T. of Paddy (unhulled rice). Thus, the average yield of those crops was about 4,640 Kg/Ha (4,092 lb/acre). This yield was the highest in South America and close to that obtained by the USA the same year, (4,995 Kg/Ha). Even so, the Peruvians barely were able to fulfill their consumption requirements. The degree of sufficiency, i.e., the ratio between per capita production and per capita consumption, for that year was about 0.94. Hence, the deficit had to be imported. [7]

As in many developing countries, rice is the main meal for the Peruvians. Its continuous shortage and an incorrect agricultural management have contributed to a recession accompanied with inflation rates over 100%. Food is regarded by many world leaders as the most important problem confronting both agriculturists and engineers in the next century. It is probably most serious in those countries that are not oil exporters. For these reasons, most of this paper deals with "getting energy out of a food by-product."

Because of the magnitude of these problems, it is clear that the food required will have to be produced in the countries which need it. Also, it will be necessary to design a rational energy policy. The improvement of the productivity of food production systems is imperative. It can be accomplished by increasing the production capacity and/or reducing the production costs. If a study of both the food and energy problems results in a coherent solution, we would be overcoming one of the biggest challenges for the near future. [13]

Rice is unique among the cereals in being able to germinate and thrive in water. Consequently, water is a precious resource in the rice growing countries. Until the last decade energy that was used in pumping water, farming rice fields and post-harvesting processing was not a serious consideration among the myriad of costs involved in rice production. But, after the oil embargo in 1973, Peru as well as other rice producing countries were affected by the energy crises. The cost of fuel increased 50 times the original price in two years (1974-1976). Before 1972, the labor costs in rice milling were about 22 percent of the total costs and energy cost was 7 percent. In 1983 the cost of energy was 32 percent and labor 13 percent of the total production cost.

It is evident that any effort to improve the energy usage of the rice milling industry in Peru will bring to both the government enterprises and the milling industry significant savings in dollars and BTUs. However, the main benefit may arise to the public: the high prices of rice which include a large share of energy expense will be more manageable if this energy cost can be controlled.

Rice milling constitutes an energy intensive activity. Despite the smaller size of the rice milling facilities in Peru its energy consumption per output unit is superior to those ratios encountered in the USA. About 28 KWH are used in Peru and 26 KWH in the USA to obtain a metric ton of finished rice.

A significant Energy Conservation Opportunity (ECO) can be found in the recovery of energy from the combustion of rice hulls. In the USA, some rice mills are utilizing rice hulls to generate energy, while some others are considering it.

In Peru, there are a few mills that use the husk as fuel (less than 5% of the total production capacity). These mills utilize old boilers and reciprocating piston engines (locomobiles) from the beginning of this century. Most of these facilities are connected to the mill shaft load by using countershafts, flat pulleys and flat belts. Evidently, the energy transmission efficiency and the thermal efficiency as well leave a lot to be desired.

Except for some few mills that produce husk-ash as a low priced by-product, most of the mills do not use the hulls to generate energy nor to sell them as a raw material, since further processing is not performed. The husk is considered as waste matter and its disposal constitutes a serious environmental problem. In the 75 or more countries where rice is produced the challenge of utilization or disposal of *hulls, within* the framework of its economical structure has now a different approach. Such a nuisance can be converted in an attractive investment opportunity, as we will see later.

The much higher energy utilization that can be obtained from the newest Waste-to-Energy technology permits us to consider rice hulls as an economic, renewable and efficient source of energy.

CHAPTER 2

OBJECTIVE OF THE STUDY

In general, it is the intention of this project to find suitable technological alternatives to the energy requirements of a typical rice mill of Peru and to determine their economical feasibility. The enormous potential for energy cogeneration, i.e., the coincident generation of heat and power -electrical or mechanical-, the opportunity of recovering the husk ash, and the skyrocketing prices of fossil fuels in Peru, make it possible to consider this study.

This study will examine the economics of waste heat recovery and cogeneration for a specific rice mill. Then a comprehensive sensitivity analysis will be performed to fully examine the possiblity. Data will be taken from the Ingenio Guadalupe Rice Mill in northwestern Peru.

There are many reasons to cogenerate in the rice milling industry; they include:

A. The rice hulls contain enough energy to supply the energy requirements of a rice mill. The hulls account for about one-fifth the weight of paddy and have a heating value about one-third of that of Fuel Oil No 2. Based on a 24-hour operation of a rice mill milling one ton of paddy per hour, the husk produced represents a calorific value of 1,500 Kg of diesel fuel per day (1,700 liters or 375 gallons).[12]

B. It has been estimated that the power development to run a rice mill utilizes about 80% of the total hulls produced for a medium size facility (7.5 to 15 M.T./hour of Paddy). The calorific value of husk is such to produce 2.5 Kg and more of steam from 1 Kg of husk. Excess energy may be sold to a utility.[9]

C. Another way of using rice husk -so far not fully developed- is the gasification to obtain producer gas used use in internal combustion engines.[9]

D. Additionally the steam can be used in the following process:

-To dry paddy (increasing husk heating value).
-To produce paraboiled rice.
-To perform solvent extractive milling.
-To be used in canning process.
-To produce breakfast rice cereals.

E. The ash -which contains 96% Silica- a result of hulls combustion can be used as/for:

-An insulator, with R values similar to glass-wool.
-Glass production.
-Semiconductor manufacturing.
-Calcium silicide, a powerful reducing agent used in explosives and as deoxidizing agent in steel manufacturing.
-Cement can be made by combining hulls with lime. Similar characteristics to Portland cement can be attained.
-Water purificator by filtration, adsorption or coagulation.
-Rubber compounding.
-Silicon carbide and silicon nitrite for abrasives or refractories.

CHAPTER 3

DESCRIPTION OF THE OPERATIONS OF A TYPICAL RICE MILL IN PERU

The product structure, the milling operations and the equipment of a typical rice mill of the northwestern region of Peru are described below:

3.1 PRODUCT STRUCTURE.-

Rice comes from the big combines or field thrashers rough and yellow because each grain is enclosed in a little straw covering or hull. The process to separate these hulls is known as hulling. The rice kernel enclosed by the hulls as it leaves the thresher is known as as rough rice or paddy. It weights about 45 pounds per bushel (0.58 Kg/liter). Rough rice is used for seed, but is milled for food. Damaged or low quality rice is used for livestock feed. When milled, rough rice yields about 65% whole and 12% broken kernels, 2 to 3% polish and 20% hulls. When somewhat undermilled the yields of head rice range from 66% to 70 %. Since in Peru the minimum required yield by the Ministry of Agriculture is 68%, the rice classified as "current" is not completely polished.

Our description will rest on the current-type rice since it accounts for most of the production capacity.

Table 1 shows the composition of the three different qualities of long-grain-rice, which is the only one consumed in Peru.

Table 1

COMPOSITION BY SUB-PRODUCTS OF LONG-GRAIN-RICE (%)*

QUALITIES	CURRENT	SUPERIOR	EXTRA
Hulls	20	20	20
Bran	11	12	13
Polish	1	2	3
Whole grain	53	58	62
Broken grain	15	8	2
Share of total	92	6	2

*Source: Ministry of Agriculture of Peru, "Reglamento de Comercializacion de Arroz", 1979.

It can be noted that rice is a product of an analytical process, i.e.,product and by-products separate from the main stream of the process as the material flows throughout the mill plant. This feature is depicted in Figure 1.

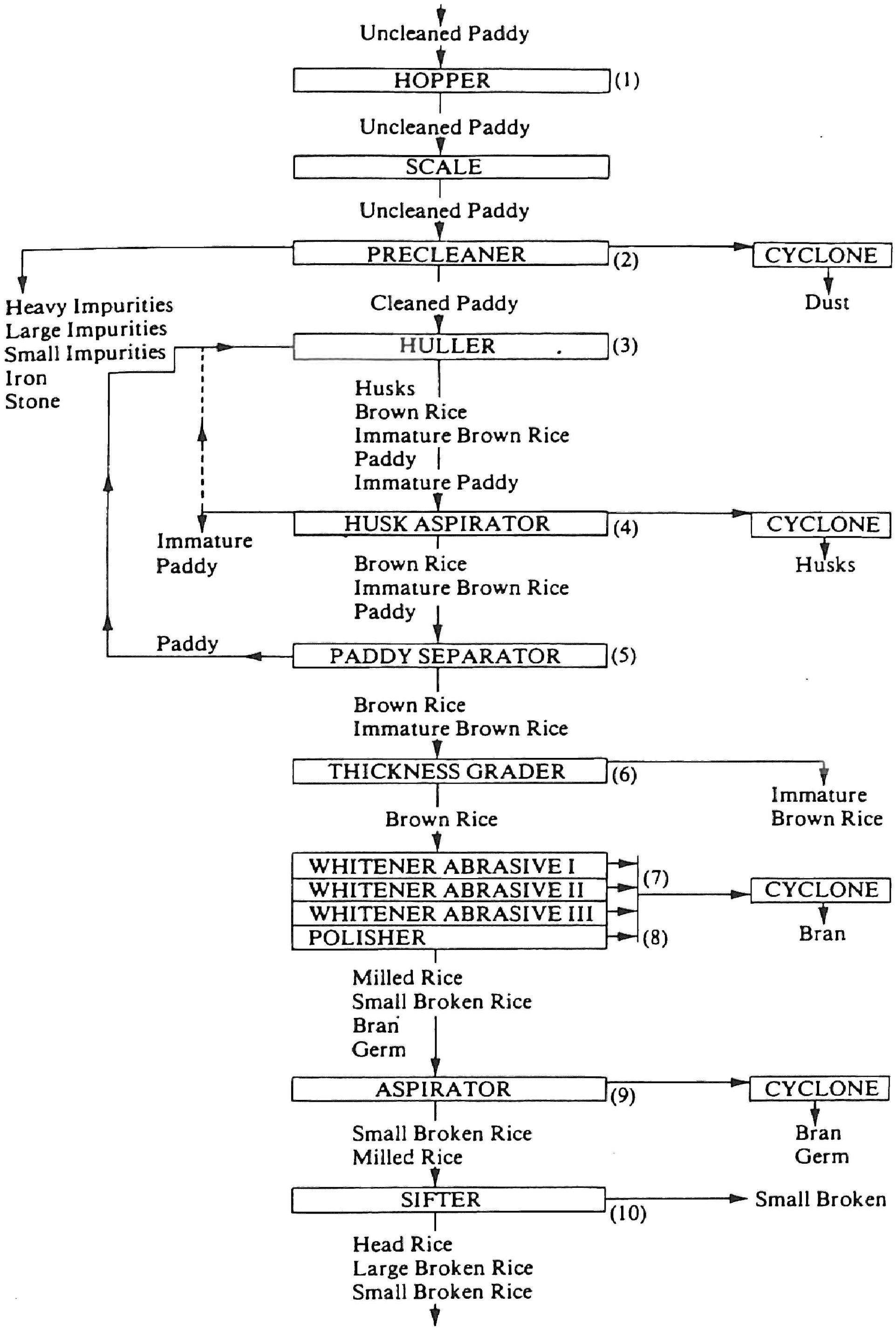


Figure 1. Flow chart of the complete milling process.

3.2. OPERATIONS AND EQUIPMENT IN A RICE MILL.-

Rice is sent to a mill to remove the hulls and to make it ready for cooking. Many of the mills in Peru are small and have a production capacity no larger than 1.5 M.T. per hour of milled rice. On the other hand there are mills which are rather complex with several elevators, bins and drying towers combined with actual milling facilities. These mills can have capacities of 10 to 50 M.T. per hour. However, most of the mills have a capacity of 3.5 to 6 M.T. of milled rice. These medium size mills account about 74% of the total milling capacity of Peru (560 M.T. milled rice per hour).[2]

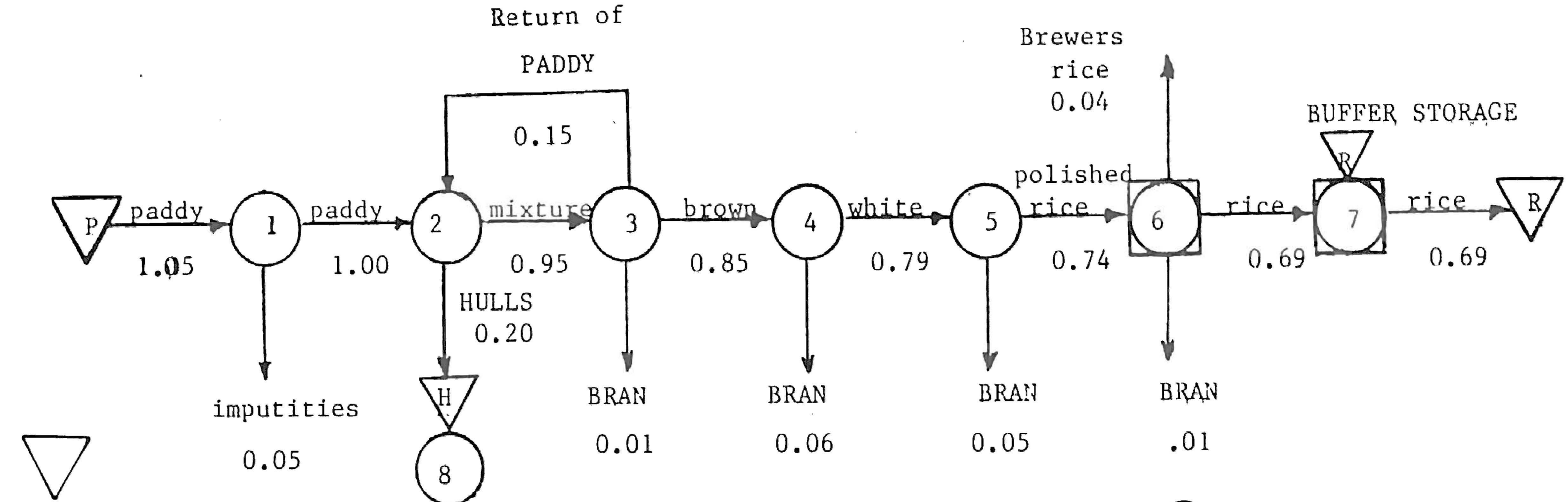
The rice milling process has the following operations:

1. Preparation,
2. Hulling,
3. Separation,
4. Milling or Pearling,
5. Polishing or whitening,
6. Screening or sorting,
7. Packaging, and
8. Husk burning

Figure 2 shows a general flowchart of the rice mill and its operations by using time-motion standard symbols. This description has been based upon the plant of Ingenio Guadalupe a typical rice mill of the Northwest of Peru. This mill has a capacity of 7,250 Kg/hr of paddy, i.e., 5000 Kg of polished rice with a yield of 69%.

FIGURE 2. PROCESS FLOW CHART AND MATERIAL BALANCE

(A UNITARY MODEL, INPUT FLOW RATE = 100%)

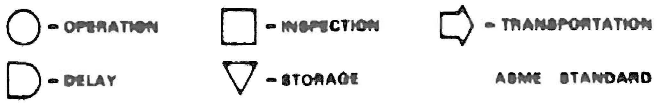


STORAGES

P	paddy
R	rice
H	hulls

No	OPERATION
1	PREPARATION
2	HULLING
3	SEPARATION
4	MILLING
5	POLISHING
6	SORTING
7	PACKING
8	HUSK BURNING

FLOW PROCESS SYMBOLS



Paddy is poured into a hopper at the receiving end of the mill; From there, it passes either direct or by means of an elevator to a dryer -if necessary- or to the cleaner monitor. The cleaned paddy passes in front of a magnet to extract any ferrous metal and is then lifted by an elevator and delivered to the huller. The product from the huller -consisting of hulled rice, husk, a little paddy, some rough bran, and small points- passes to an attached chamber that is a husk-winnowing aspirator. This sieve recovers the bran and broken points and discharges them to the bran aspirator duct. Hulls are aspirated to the furnaces.

The result of winnowing is a mixture of hulled rice and paddy. These produces are separated in a specific-weight separator or paddy table, the resulting paddy is sent back to the huller by an elevator and hulled rice is collected in order to be sent to the milling area.

Shelled rice or brown rice passes up an elevator and is delivered to the whitening cones. The resultant bran is automatically collected and delivered to the bran cyclone through the bran duct. The milled rice is elevated to the polisher where more bran is obtained. Finally, the rice passes to the shaking tables or graders. The whole rice with its broken-grain percentage is elevated to an in-process-buffer silo. Excess broken grains and brewers rice from the sorting are bagged independently.

At the in-process silo, finished rice is packed in plastic bags with gross weight of 50 Kg each. The bags are then delivered to the warehouse by railroad cars.

This rice mill carefully designed the plant layout to allow for full working of all machines with the greatest possible continuity, while minimizing energy used in handling and movement of grain from one operation to another . This consideration -based upon the IDEAL concept, for production systems design- allows significant savings in conveying energy.[17,23]

Buffer storages provide safety stock and are used before critical operations that require a minimum of in-process rice and after machines that are subjected to breakdowns. These buffers increase the work-in-process but decouple the operations and smooth the main stream flow.[22]

CHAPTER 4

FORMULATION OF THE PROBLEM

It is desired to design a rice husk fired cogeneration system for a rice mill and to evaluate its economical feasibility. Here and thereafter we will refer to the plant of this rice mill as "the mill" and to the cogeneration system as "the system". When a specific cogeneration alternative is proposed and evaluated for the mill it is assumed that the actual plant will suffer some changes in both operations and performance. Consequently, when a specific alternative for energy cogeneration and its respective alteration to the mill are formulated, the whole system composed of the cogeneration proposal and the modified mill is to be called an "alternative solution." The state of the actual system and the desired state are to be evaluated in this chapter.

4.1. ACTUAL SYSTEM STATE

The operations within the rice mill have been described completely in the previous chapter. In order to find the flow rate or specific production capacity of an operation, the total input capacity of the mill, (7.150 M.T./hr) should be multiplied by the conversion factor which is the unitary flow rate stated in the model depicted in Fig. 2. Therefore, the actual production of rice hulls is 1,430 Kg/hr. This amount can be increased up to 2,500 Kg/hr, since hulls may be purchased from small mills of the region at negligible prices, only transportation and storage costs are relevant.

The variation of the rice flow rate has been approximately fitted to a uniform distribution with a range of .92 times the mean to 1.08 times the mean (+/- 8%). However for any of the recommended combustion alternatives a buffer storage is to be included in order to attain a smooth and deterministic flow of hulls to the combustion device. [22]

Energy to the mill, offices and a workshop are supplied by a Caterpillar diesel generator of 200 KWH -220 VAC/3ph-. The actual demand has been calculated as 180 Kw. All the shaft power is supplied by electric motors. The plant has a work - shift of 12 hours during the day and insignificant artificial illumination is utilized. The actual operating shift hours for the mill are 10 hr/day.

Six cylindrical furnaces of adobe construction are the burning facilities to obtain ash. Their measurements are: 12 meters high with an inside diameter of 5 meters , for a total capacity of 1,400 cubic meters. These furnaces can be used as buffer storage of hulls for any alternative solution. This consideration will require that the location of the cogeneration system be constrained to a nearby area.

4.2. DESIRED SYSTEM STATE

A cogeneration plant, with suitable heat recovery devices, that uses rice husk as the primary fuel and a process that utilizes either superheated or saturated steam to dry paddy are the basic components of any desired alternative solution. In addition, a system to collect ash is to be considered.

An alternative solution may include any of the following elements:

1. A material handling system to collect the rice hulls from the hulling work stations and to transport them to a buffer storage and/or to the burning facility.

2. A buffer storage in order to decouple the system of the mill and to offer reliable supply of fuel.

3. A combustion device that is likely to be a furnace or stoker together with a boiler.

4. A boiler that should produce steam with quality suitable to be used in a steam turbine.

5. A steam turbine that should match both the plant electricity demand and the process steam requirements.

6. An electric generator suitable for the mill electrical demand.

7. An ash collector that effectively recovers the ash from the flue gases.

8. A dryer that is suitable for the moisture content of the paddy processed in the mill. The dryer may use as heating fluid either steam or flue gases.

9. An additional process -such as paraboiling or milling by solvent extraction- may be included in the recommended solution if the steam supply is sufficient and it is demonstrated to be economically feasible.

10. Any additional device that supports the performance of the elements mentioned above or enhances the energy treatment systems and heat recovery equipment may be included under this category.

CHAPTER 5

ANALYSIS OF THE PROBLEM

In this chapter we are to study the facts of the mill and data of energy available to the system. First, the energy requirements of the actual plant are to be determined. Second, an analysis of hulls combustion is performed in order to obtain the energy potential of hulls. Finally, the power and steam generation capacity are to be estimated.

In order to approach the problem in a consistent and orderly way, the the following subproblems are discussed:

STEP 1. Determine the Energy Requirements of a rice mill.
    A) Energy Requirements of the actual plant.
    B) Farmers Rice Mill Energy Facts.
    C) Cogeneration Potential.
STEP 2. Examine Combustion of rice hull.
    A) Properties of rice hulls.
    B) Rice-Hulls Combustion Model.
STEP 3. Steam Generation Analysis.
    A) Preliminary Steam generation estimation.
    B) Available Power Capacity.
    C) Available Energy for Electricity.
    D) Available Energy for Process.

5.1. ENERGY REQUIREMENTS OF A RICE MILL PLANT.-

The energy requirements of the mill in Peru are to be determined in this section. For comparison purposes the energy requirements outline of Farmers Rice Mill & Co. plant of Lake Charles, La. is to be included as well. Farmers Rice Mill is a cooperative that is evaluating its cogeneration potential and plans to sell electricity to utilities in the State of Texas.[5] Sections 5.1.1 and 5.1.2 present the data for the 2 plants. Section 5.1.3 examines the cogeneration potential.

5.1.1. Energy Requirements of the actual plant.-

<u>INGENIO GUADALUPE RICE MILL</u>

1. PRODUCTION CAPACITY.- 7.15 M.T. of paddy/hr
   @ 70% yield: 5.0 M.T./hr of head rice

2. POWER DEMAND.- 180 Kw (peak average).

3. INSTALLED CAPACITY: 35 weeks/year, 6 days/week,
   12 hours/day: 2520 hrs/year
   @ 7.15 M.T./hr : 18,000 M.T./year [paddy]

4. FUEL CONSUMPTION.- 13.75 gallons/hr for diesel generator.
   @2,500 hr/year: 34,650 gal/year

5. FUEL PRICE.- $0.86/gallon fuel oil No.2, 13.1 kwh/gal.:

$0.0212/kwh

6. FUEL COSTS .- @ 1,500 hr/yr, 13.75 gal /hr, $0.86/gal.:

$17,737.5/year

During the study a turbocharger was added to the diesel generator, improving its efficiency and giving a lower fuel consumption (11.86 gal/hr). Thus, the cost of fuel is:

@ 180 KW and 11.86 gal/hr = $15,325/year

7. FUEL CONSUMPTION PER INPUT UNIT (Diesel generator).-

A. (11.88gal/hr)/(7.15 MT/hr) = 1.6615 gal/M.T. of paddy

B. (1.6615 gal/MT) (19,750 BTU/lb) (7 lb/gal) = 230 KBTU/MT

C. (200 kw) (1 hr/ 7.15 MT) = 27.97 kwh/ M.T. of paddy

8. OVERALL EFFICIENCY [oe].-

oe = output energy/input energy

Fuel Oil No. 2: 19750 BTU/lb HHV

output energy = (180 kw) (3412 BTU/kw) = 614,160 BTU

input energy = (13.75 gal) (19750 BTU/lb) (7 lb/gal)

= 1,900,937.5 BTU

oe = 32.3%

5.1.2. Farmers Rice Mill & Co Energy Facts.-

1. PRODUCTION CAPACITY.-

250 Tons hulls/day = 10.416 ton/hr

@ 20% husk yield: 52.083 ton paddy/hour

about 7.3 times the capacity of Ingenio Guadalupe.

2. POWER DEMAND.- 1.5 MW.

3. OPERATION.- 24hr/day (assumed).

4. ENERGY COST AND ENERGY CONSUMPTION.-

   Overall Revenues - Net profit = Electricity Costs

   3.3 Millions - 2.8 Millions = 0.5 million/year

   (\$500,000) / (\$.04/kwh) = 12.5×10^{6} kwh/year

   Assuming oe: 31.4 % = 13.583×10^{10} BTU/year

5. ENERGY PRICE.- \$.04/kwh

6. POWER PLANT CAPACITY.- 115,000 lb steam/hr

   @ 10.416 ton husk/hr

7. ENERGY CONSUMPTION PER INPUT UNIT.-

   (1500 kw)(1/1250 day/ton)(.9072 ton/1 MT)(24 hr/day)

   = 26.127 kwh/M.T. of paddy.

As is indicated in the data and calculations above, there is a similar overall efficiency of energy generation at Ingenio Guadalupe (32.3%, diesel generator) and in Farmers Mill (31.4%, husk combustion/turbogenerator). However, the energy utilization of the Louisiana mill is sligthly better (energy input unit: 26.13 kwh/M.T.- paddy-) than the energy consumption in the mill of Peru, (28 Kwh/ M.T. of paddy). Note: Farmers Mill has as about 7 times the capacity of its Peruvian counterpart.

5.1.3. Cogeneration Potential.-

The potential for cogeneration is further evaluated by calculating the theoretical heating capacity of the Farmers Rice Mill and estimating the ratio of attainable energy to consumption. This index is an indicator of the availability of energy in hulls.

1. HEAT VALUE OF RICE HULLS.- As a rule of thumb the estimate of the higher heating value [HHV] of dry hulls is

$$1/3 \text{ of HHV Fuel Oil No. } 2$$

$$1/3\ (19{,}500 \text{ BTU/lb}) = 6{,}500 \text{ BTU/lb}$$

The HV with 10% moisture and 2% of soil has been found to be 5,700 BTU/lb.[8]

2. FUEL CHARGEABLE TO POWER .- FCP is the amount of thermal energy (BTUs) required to generate a unit of electrical energy (kwh) [21]. For hulls with 10% of moisture we have:

a. Heating capacity, Hc. (Assumed a husk NHV= 6 KBtu/lb).

$$(2000 \text{ lb/ton})\ (250 \text{ tons/day})\ (1 \text{ day/24h})\ (6000 \text{ Btu/lb}) =$$

$$Hc = 125 \times 10^{6} \text{ BTU/hr}$$

b. Rated Power, RP: 11.5 MW

c. Fuel Charged to Power.- $FCP = Hc/RP$

$$(125 \times 100 \text{ KBTU/hr})/(11.5 \text{ MW}) = 10.8 \text{ KBTU/kwh}$$

3. ATTAINABLE ELECTRICAL ENERGY PER GROSS INPUT:

Assuming a net heating value (NHV) of 6,000 BTU/lb,

(6.0 KBTU/lb) (.2 lb hulls/lb paddy) (1 kwh/10.8 KBTU) =

= .1104 kwh/lb of paddy .

= 243.4 KWH/M.T. of paddy.

4. REQUIRED ENERGY PER GROSS INPUT UNIT.- (Section 5.1.2-7).

= 26.127 KWH/M.T. of paddy.

5. RATIO OBTAINABLE ENERGY TO REQUIRED ENERGY.-

= 243.4 /26.127 = 9.315

It can be implied that a cogeneration system that utilizes rice hulls as fuel, can attain as much as 9 times the amount of energy required to perform the milling process.

6. OVERALL SYSTEM EFFICIENCY.-

= 3,412/10,870 = 31.4%

5.2. COMBUSTION OF RICE HULLS.-

In the past, burning rice hulls has been one of the solutions for rice hulls disposal. However, use or disposal has frequently proved difficult because of the tough, bulky and abrasive structure of this material. On the other hand, environmental regulations have limited the combustion of both rice straw and rice husk in open fields near urban settlements. All this is a result of the high content of inorganic matter, mainly silica (SiO_2) in the hulls. In addition, hulls have low nutritive properties, resistance to weathering, great bulk and high ash content.

The general characteristics described above tell us about the constraints likely to be found in rice hulls combustion. For instance, their low nutritive value make them not useful as a feed component. Next, their resistance to weathering implies that husk can be stored with minimum protection. But, their great bulk requires significant storage volume. Finally, the ash has been found to be the most cumbersome problem in flue gas emissions. However, the probability of utilizing flue gases, mixed with air for drying paddy, and the potential market for rice husk ash make desirable the installation of an effective ash recovery element within the combustion system.

5.2.1. Properities of Rice Hulls.-

Most of this section has been adapted from Houston.[10]

Physical Properties.-

This section is to describe physical properties of rice hulls , such as color, size and shape; moisture content, hardiness and abrasiveness; density, fuel value and thermal conductivity are to be studied as well.

Color, Size and Shape.-

Most Peruvian rice varieties are straw or golden color. Hulls have a length about 6 to 10 mm. Their width varies from one third to one fifth of their length. Hulls removed in milling often separates into complete lemma and palea , which then turn as boat-shaped particles with dimensions similar to those cited.

Moisture Content, Hardiness and Abrasiveness.-

As with other organic materials, hulls absorb or loose moisture and then tend to come into equilibrium with the relative humidity of the surrounding air. Karan and Adams[11] have found equilibrium moisture contents at 25 degrees Cent. that are shown in table 2.

TABLE 2

<u>EQUILIBRIUM MOISTURE OF RICE HULLS</u>

	Relative Humidity, %								
	10	20	30	40	50	60	70	80	90
a) %	3.7	5.4	1.8	8.1	9.5	10.8	11.8	12.9	15.3
b) %	3.7	5.4	6.8	7.9	9.1	10.8	10.8	11.6	14.0

Water content, a) Naturally dried Rexoro variety
b) Artificially dried mixed variety

These moisture contents fall consistently below those of milled, brown or rough rice. The differences of several percent are undoubtedly due to the absence in hulls of any quantitity of starch and sugars, which have relatively high equilibrium values, and to the presence of considerable silica.

Since the relative humidity in the North-Coastal region of Peru varies between 50% to 70% it can be estimated that the moisture content is about one tenth of the husk weigth.

The high concentration of opaline silica in the outer surface would not change the moisture in this layer but would establish the effective hardiness at approximately 5,5 to 6.5 Mohs scale, reported for opal. The hardiness of approximately 6.5 to 7 in the ash is in accord with the value for cristobalite. These values compare with grade 7 for quartz as in sand. As the Mohs hardiness values are measured as relative scratch resistance, they also suggest relative abrasiveness. When the moderate hardiness noted is coupled with large proportion of angular fragments as in hulls and ash, wearing on surfaces that have contact with these particles is a critical consideration.

It has been found high wearing of materials handling equipment due to the abrasive characteristics of paddy, hulls and ash; especially in duct work, fan blades and elevator buckets. Therefore the design and maintenance of these parts should be considered highly relevant in determining their costs.

Densities.-

Although the true density of hulls have been reported as 0.735 gr/cc., their great bulk is an apparent or bulk density of 0.1 gr/cc. These values correspond to 46 and 6.24 lb/cu ft. respectively, in commercial terms. Other sources report bulk densities ranging from 6 to 10 lb/cu ft. depending on the moisture content and accomodation factors, Hulls can be compressed to 25 lb per cu ft. [3] When ground to various fineness bulk densities range from 12 to 25 lb/cu ft.[14] Bulk densities of ash is reported as 0.1 to 0.2 gr/cc or 6 to 12 lb/cu ft.[1,20]

Fuel Value and Thermal Conductivity.-

As mentioned in Section 5.1.3 the heating value of dry hulls is equivalent to one-third of the higher heating value (HHV) of Fuel Oil No. 2.

$$1/3\ (19{,}500\ \text{BTU/lb}) = 6{,}500\ \text{BTU/lb paddy}$$

Heating values ranging from 5 KBTU/lb to 6.5 KBTU/lb have been reported . [6,15,19] Fieger, et al. [15] reported the heat of combustion determined in an oxygen bomb as 6,274 BTU/lb; this would be a maximum value for certain kind of rice. However it is necessary to perform a calorimetric analysis in a representative sample of the hulls likely to be encountered in the mill. Hulls have been reported to burn at 800° to 1,000° C,(1472°-1832° F).[20]

Thermal conductivity may be expressed as K values ,which is the inverse of R insulation values, (BTU/sg ft -hr-in-° F). Fieger and co-workers [15] determined K values for ground, unground and treated hulls under controlled experimental conditions. These values and some of other insulating materials are presented in Appendix A-2. Ahsan Ullah, et. al. reported a k value of 0.271, [1].

Chemical Properties.-

The hulls are composed by carbohydrates, crude protein, lipids, ligning, and cutin; vitamins, organic acids and inorganic components, [14]. The composition of rice hulls is given in table 3.

TABLE 3

COMPOSITION OF RICE HULLS (DRY BASIS %)

Cellulose	Pentosas	Ligning	Ash	Others
40	19	20	18	3

Source: Karan and Adams [11].

5.2.2. Rice Hulls Combustion Model.-

In order to determine a Combustion Model , the following ultimate analysis has been performed in hulls of the mill:

	C	H	O	N	Si	S
%	37.5	5.5	39.5	0.5	17.0	0

For comparison and linear regression purposes a table with the Ultimate Analysis of Selected Fuels is included in Appendix B. The data presented in such a table have been plotted in figure 3; a least squares line shows the carbon content to range from 4.9 % to 51.2%. The equation obtained after fitting such line is:

$$y = 188.0x - 131.5 \quad \text{or} \quad HHV^{*} = 1.88\ C - 131.5 \quad [*]$$

Where y is HHV* and x is C, i.e., the percentage of carbon content. The coefficient of correlation of this empirically observed relation is $r = 0.98$. The coefficient of determination is $r^2 = 0.96$. These coefficients give an acceptable confidence to the model.

For hulls with 37.5 % of carbon, as in the mill, we have:

$$HHV^{*} = 188.0 \times 37.5 - 131.5 = 6{,}918.5 \text{ BTU/lb}$$

This would be the highest heating value of our MODEL FUEL. The MODEL heating capacity of the mill [Ht] would be :

$$Ht = Ph \times HHV^{*}$$

$$\text{or } (3150 \text{ lb/hr})\ (6{,}918 \text{ BTU/lb}) = 21.81 \text{ MBTU/hr}$$

where Ph is the husk production rate of the mill.

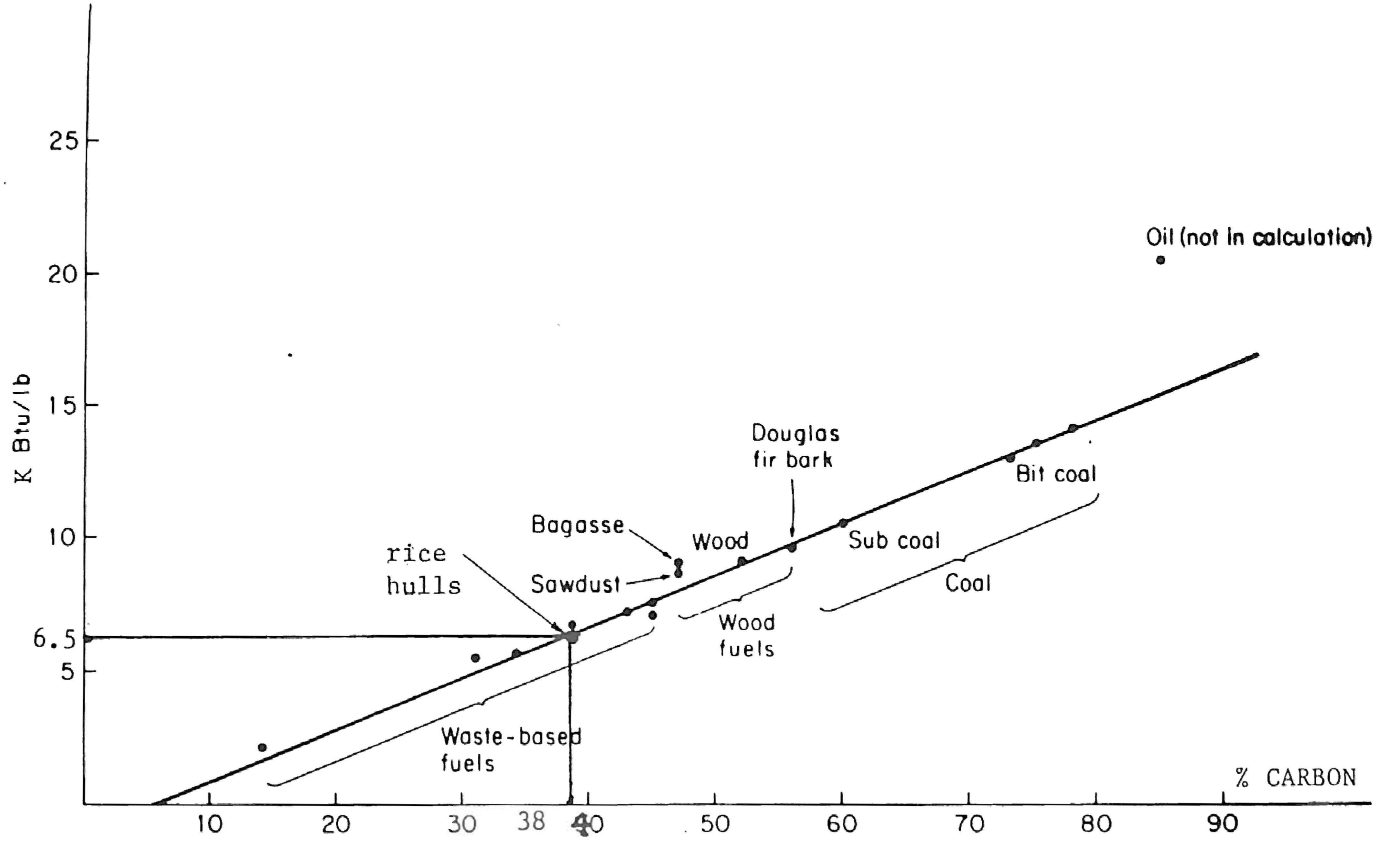


Figure 3. *Carbon content and heating value for selected combustible fuels.*

However, the operating time of the mill is 32 weeks per year, 6 days per week, and 12 hours per day. Therefore the actual heating potential (AHP) for a continuous operation throughout the year, for a 26.3% of time-op-efficiency, is:

$$\text{AHP} = (21.81 \text{ MBTU/hr})\ (.263) = 5.736 \text{ MBTU/hr}$$

A preliminary estimation of the available heat to the boiler with 80% efficiency using a fuel with 9% moisture is to be examined. Tillman Rossi and Kitto [20] developed the following expression from equation (*), when a moisture content (MC) is included, to obtain the Net Heating Value (NHV):

$$\begin{aligned} \text{NHV} &= (1.88\text{ C} - 131.5)\ (1 - \text{MC}/100) \qquad (**) \\ &= (1.88 \times 37.5 - 131.5)\ (1 - 9/100) \\ &= 6226.65 \text{ btu/HR} \quad \text{(green basis)} \end{aligned}$$

Thus, the actual heating capacity (AHC) for a Model Firing System that burns husk at the same rate that these hulls are actually produced, (Pr, hulls = 3,150 lb/hr) would be:

$$\begin{aligned} \text{AHC} &= (\text{NHV})\ (\text{Pr, hulls}) \\ &= (6226 \text{ BTU/hr})\ (3150 \text{ lb/hr}) \\ &= 19.614 \text{ MBTU/hr} \end{aligned}$$

Due to improved drying capabilities, because of a proposed drying system, the managment of the mill estimates a 35% increase in the total production per year, which is the slack capacity of the plant. Therefore the production rate of husk should be increased accordingly ; for 7,150 kg/hr of paddy and 20% yield of husk, we have:

(1.35) (7,150) (.2) = 1930 Kg/ hr (4,250 lb/hr)husk

We consider two burning rates that involve two cases:

Case 1. For a continuous operation all year around, the projected POWER available, burning 1,230 lb of hulls/hour, is:

PHC1 = (AHC) (n) (1 + % of add. hulls)
= 19.61 MBTU/hr (.291) (1.35)
= 7.7 KBTU/hr

Where n is the operating efficiency of the mill: 2520 hr year / total hr per year, 0.291.

Case 2. For a simultaneous operation of both rice mill and cogeneration system, i.e., the power plant works only when the mill is producing, the POWER would be:

PHC2 = (19.61 MBTU/hr) (1.35)
= 26.47 KBTU/hr

Since PHC1/PHC2 = .29, only 1/3 of the power available in a steady mode can be generated if an all year around operation is selected. PHC1 and PHC2 are the theoretical power values.

5.3 STEAM GENERATION ANALYSIS.-

High-quality steam will be used in a single-stage turbine for Case 1 and a multi-stage turbine for Case 2. These non-condensing turbines will exhaust steam for process. For this purpose, superheated steam at 600 psi, 750 deg. F is required . Enthalpy available in this steam is hs = 1379.6 BTU/lb, (A).

5.3.1. Preliminary Steam Generation Estimation.-

1. For a continuous-operation plant during 24 hr/day, 360 days/year. Feedwater conditions for a 100 % return of condensate (assumed after economizer): 35psig, 281 deg. F, hw = 250.21 BTU/lb (B). The boiler has 78% efficiency.

Net heat required = hs - hw from (A) and (B)

= 1379.6 - 250.2

= 1129.4 BTU/lb

Available steam (theoretical):

= (7.7 KBTU/hr) / (1129.4 BTU/hr)

= 6.817 lb/hr (600 psig, 750 deg F)

Available Net steam = Boiler efficiency x Available steam

= (.78) (6,817)

= 5,317 lb/hr

2. For a simultaneous operation , we have 26.47 MBTU/hr available. Thus, the available steam would be:

= (26.47 MBTU/hr0) / (1129.4 BTU/hr)

= 23,437 lb/hr.

Net steam = (.78) (23,437) = 18,280.86 lb/hr.

5.3.2 Available Power Capacity.-

To estimate the overall energy available for shaft power we may use a "broad-brush" approach. But, further calculations should be made to determine electrical energy.

For the first case above, continuous operation of the energy cogeneration plant selling energy to utility, we may use an approximate efficiency of 45% for a non-condensing steam turbine. Also, the following losses can be charged to cogenerate power from a stoker-fired boiler, with economizer and air heater:

Boiler losses	17%
Generator and/or mechanical	2%
Auxiliares and ash	3%
TOTAL LOSSES	22%

See table 7.2 (page 207) and page 205 of Turner [21] for references to efficiency losses.

For a system -boiler with 78 % efficiency (100% - 22%) and 45 % prime mover efficiency , we have an overall efficiency of (.78) (.45) = .35, i.e., n=35%.

The Net Available Power (NAP) for this case is:

$$NAP1 = [(7.7\ KBTU/hr) / (3412\ KW/BTU)]\ (.35)$$
$$= 790\ KW.$$

For a simultaneous operation we have a higher firing rate and improved efficiency in a Multistage-Noncondensing turbine-generator. It is estimated a 60% efficiency for the same exhaust conditions [21]. Therefore, the Turbo-Generator overall efficiency is (.60) (1 - 0.22) = 46.8 %.

The net available electrical power calculaed from the husk production rate is:

$$NAP2 = [(26.47\ KBTU/hr)/(3412\ BTU/kw)]\ (.468)$$
$$= 3,630\ KW.$$

All net available electrical powers computed above are gross indicators of power availability for generation of electrical energy, exclusively. Noticed that, in the first case, the power available is as much as 4 times the power demand of the mill (790/180). In the second case it is possible to generate 18 times the power demand of the mill, (3600/180). A closer look and a more accurate electrical power is evaluated in the next section.

5.3.3. Available Energy for Electrical Power.-

It is assumed that a continuous-operation system shall sell energy to a utility and that a simultaneous cogeneration system is to be for in-plant process energy usage only. For a more accurate evaluation of electrical energy, the system should be evaluated using the thermodynamics of isentropic expansion in a turbine.

A.- STEAM REQUIREMENTS FOR PROCESS.-

At this point, we should set appropriate steam exhaust conditions for the T-G. Thus, it is required to determine the steam requirements for process; two processes are evaluated: Paraboiling and Solvent Extraction Milling (SXM).

Assuming similar conditions for Paraboiling and SXM:

Type of steam	:	Slightly Subcooled
Pressure	:	30 psig
Temperature	:	200 deg. F
Quality	:	97% (3% moisture)
Hs	:	1150 BTU/lb

We consider more two assumptions in computing the steam rate: First, exhaust steam is to be used in paraboiling . This

kind of process is suitable for a cogenaration all year around and simultaneuos operation as well.
Second, exhaust steam is to be used for both paraboiling and solvent extraction. Most of steam is for solvent extraction.

These processes can be feasible with a higher firing rate i.e., only when cogeneration is performed simultaneously with the mill operations.

B. STEAM RATE.-

Having established T-G efficiencies of 45% for case 1 and 60% for case 2, Section 5.3.1, it is possible to calculate a steam rate. The first step requires establishing the amount of energy available for use in the turbo-generator, then to determine what portion of this heat is to be converted to electricity by the T-G. Whatever amount of steam not used in the T-G is still available to process by using a pressure-reducing valve.

By using a Mollier diagram, we can obtain the available energy in an isentropic heat drop:

$$\begin{aligned}\text{Available energy} &= \text{isentropic heat drop}\\ &= \text{inlet enthalpy} - \text{exhaust enthalpy}\end{aligned}$$

This amount is equivalent to the energy released in a constant entrophy exhaustion, [19].

Inlet enthalpy (600 psig & 750 F) = 1380 BTU/lb

Exhaust enthalpy (isentropic drop to 30 psig) = 1150 BTU/lb

Case 1, Available energy = 1380 - 1125 = 230 BTU/lb

Since a subcooled steam of 200 F is required for paraboiling 30 psig steam is set for exhaust conditions.

The steam rate can be calculated for Case 1:

STEAM RATE = (3412 BTU/kwh) / [(230 BTU/lb) (0.45)]
= 32.96 lb/kwh

For case 2 we require saturated steam at 85 psig for solvent extraction of rice oil. The vapor for paraboiling can be obtained by passing the 85 psig saturated steam trough a water jet pressure reduction valve, thus obtaining steam at required conditions of 3% moisture. We have the same inlet enthalpy as in case 1, i.e.:

hi = 1380 BTU/lb @ 600 psig, 750 F
ho = 1185 BTU/lb @ 85 psig, saturated

Case 2, Available energy = 1380 - 1185 = 195 BTU/lb.

For a Non-Condensing- Multistage Turbine we can obtain about 60% efficiency, and a steam rate of:

3412 / [(195) (.60)] = 29.16 lb/kwh

C. ELECTRICAL ENERGY.-

For the first case the steam flow is:

0.78 x 6,817 = 5,317 lb/hr

Thus , the power that can be generated is:

Case 1, 5,317/ 32.96 = 161.3 KW

For the second case, i.e., intermittent cogeneration (only when the mill is running):

0.78 x 23,437 = 18,281 lb/hr of steam

Thus, the system can generate:

Case 2 18,281/29.16 = 626.9 kw

5.3.4 Available Energy to Process.-

CASE 1.- The turbine exhaust conditions is a subcooled steam at 30 psig (1150 BTU/lb). Assuming that this is the inlet condition for the paraboiling process and that exhaust condition is a steam condensate at atmospheric pressure.

Inlet enthalpy to paraboiling vessel	: 1150 BTU/lb
Oulet saturated water at 15 psia	: 180 BTU/lb
Available enthalpy	: 970 BTU/lb

For this case case the energy rate is:

(5317 lb/hr) (970 BTU/lb) = 5.15 MBTU/hr

CASE 2, the same assumptions are made for inlet conditions:

Inlet enthalpy saturated steam @ 85 psig = 1,185 BTU/lb
Oulet enthalpy saturated water @ 15 psig = 180 BTU/lb
Available Enthalpy = 1,005 BTU/lb

The energy rate is:

(18,281 lb/hr) (1005 BTU/lb) = 18.37 MBTU/hr

All the results obtained in computations on sections 5.3.3 and 5.3.4 are summarized in Table 4.

TABLE 4

SUMMARY OF ENERGY AVAILABLE TO POWER AND PROCESS

CASE	ELECTRICAL POWER		PROC-STEAM	TOTAL		ne	u
	Kw	MBTU/hr	MBTU/hr	NET-USE	THEORY	%	
1	161.31	1.56	5.15	6.71	7.7	35	87
2	627.91	4.58	18.37	22.95	26.47	46	86

Where: Proc-Steam is the amount of heat available in process steam; Net use, is the summation of energy available for electricity and steam; Theo, is the theoretical energy available, and ne and u are the efficiencies of electricity generation and overall energy utilization, respectively.

CHAPTER 6

DEVELOPMENT OF ALTERNATIVE SOLUTIONS

As a general rule, better decisions can be made by evaluating as many alternatives as possible. However, several alternatives have been discarded because of evident restrictions. Considerations such as qualification of labor, existence of a maintenance service crew , policies of the company, requirements of the utility, and technical reasons have bounded four viable alternatives. It is evident that an alternative intermediate among the four to be proposed may arise as an attractive alternative; thus, the current financial and technological situation of the rice mill may condition a variation to any of the four alternatives.

For instance, utilities in Peru can not buy electricity at a variable demand capacity, thus a steady supply of a constant number of Kwh -with a certain tolerance- should be guaranted throughout the year in order to obtain a profitable buy-back contract.

Sophisticated combustion equipment is not likely to be utilized because of lack of highly trained boiler operators and maintenance engineers. Pyrolisis, combustors or equipment for direct firing of internal combustion engines are a remote possibility. Also, fluidized bed combustors would require a limestone supply, which is not readily available in the region. However, for this last case husk-ash may be a substitute for limestone. In any alternative all remaining husk should be burned in order to generate valuable ash.

Many companies and consultants have been contacted in order to obtain information about technology suitable for burning rice hulls, steam generation equipment, paraboiling plants, turbo generator sets, and waste heat recovery. Several companies and dealers have supplied quotations of equipment, packages, and turn-key projects. Also, the author has looked for specification and prices of equipment produced in Peru. In addition, several technical and trade literature have been examined for state-of-the art cogeneration technology.

Four alternatives are proposed below. In addition, a brief specification of the selected equipment is listed for each each alternative.

6.1. ALTERNATIVE 1.-

Do nothing i.e. keep the current production rate and the diesel generator. Paddy with excessive moisture may be sun dried.

No equipment is proposed for this alternative.

6.2. ALTERNATIVE 2.-

The existing situation plus a heat recovery system, i.e., a dryer that utilizes the exhaust of the diesel generator to dry paddy with excessive moisture. The exhaust gas and the ambient air are to be mixed for drying.

Selected equipment:

1. Piping and ductwork to transfer exhaust gases to blower of dryer.
2. A damper to regulate flow of hot gases to blower.
3. A plywood bin for batch drying, (3 cu mt).
4. A blower: 12 Kw, 90 cu m/ min; and 16 HP motor.

Note that all this equipment is manufactured in Peru and the installation can be carried out by the mill personnel.

6.3. ALTERNATIVE 3.-

A Cogeneration system with a firing device that burns hulls. This system should be composed of a furnace, a boiler, a turbogenerator and a paraboiling plant. The electricity generated is to be sold to utility. Thus, the actual diesel generator is to be kept for internal supply of electricity. Exhaust steam from the turbine is for paraboiling. This system shall operate all year around. Flue gases of both, diesel-generator and husk-furnace are for drying. Due to improved drying devices, it is possible to increase production capacity by 35 %. Data and results from study of Case 1 in Section 5.3 will be used in this alternative. The selected equipment for this alternative is:

1. A water tube boiler of 6000 lb/hr (750 deg F, 600-psi). This package should include: an economizer, a super heater, feedwater pump and accesories, and water softening accesories.

2. A stoker furnace for 1,500 lb of hulls per hr with an aircooled movable grid for fuel feed. This stoker should include: a primary and secondary forced draft fan, a hoper to colect furnace ash, a cyclone to colect fly ash, a heat exchanger to cool ash bin and preheat air, a feed bin, a belt or screw conveyor for hulls, and a silo to store husk ash.

3. A system for fuel storage (150,000 cu ft) includes: a corrugated steel silo partially covered, a pneumatic system to transport hulls to feed bin, a pnumatic system to transport ash from a colector to an ash silo.

4. The duct work includes: piping from furnace exhaust to dryer blower, appropiate dampers (3) to regulate flue gases and ambient air for drying paddy.

5. A blower of 12 Kw to blow air and flue gases to dryer.

6. A turbo-generator package by Carling:

   A 200 kw turbo generator package (turbine 20-C-300 HP). This turbo-generator includes basic switch gear for monitoring volts, amps., and frequency. The connection to the public network is supplied by the utility.

All the equipment proposed in this alternative, except the turbo-generator package can be purchased in Peru.

6.4. ALTERNATIVE 4.-

A cogeneration system that operates simultaneoulsy with the rice mill. Process steam is utilized in paraboiling and for solvent extraction of oil on the non-parboiled rice. The system shall supply all electrical power to the processes in the plant. Flue gases are for drying and the existing diesel generator can be salvaged. As in Alternative 3 there will be an incremental production of 35%. Information from Case 2 of Section 5.3 is used in this alternative.

The proposed equipment is listed as follows:

1. A Fluidized Bed package by Keeler/Dorr-Oliver,

   Furnace Capacity: 6,000 lb/hr of hulls.
   Water tube boiler: 26,000 lb/hr of steam.
   Fuel feeding system : 6.000 lb/hr.

2. A turbo-generator package by Coppus,

   Generator: 650 Kw, 480 v -3ph- 60 Hz (direct drive)
   Turbine: 1000 HP, 600 psig, 750 deg F (size 23-1)

3. A Transformer: from 480 to 240 vac. (1000 Kw rating) This transformer can be purchased in Peru.

4. The ash handling and storage equipment include: a high efficiency multicyclone colector, a baghouse with pneumatic cleaning, a blower for ash handling, ductwork, and a steel bin. These devices can be purchased in Peru.

5. Blower of 20 Kw for drying in a column dryer (250 cu m/ min). It includes a motor of 30 HP.

6. Switchgear for electrical connection and control alredy exists. Only the installation and wiring costs are relevant.

Note that the drying equipment for Alternatives 3 and 4 have been assigned to an external drying-project. Therefore, the expenditure on the drying equipment is not included in these alternatives.

CHAPTER 7

ANALYSIS OF ALTERNATIVE SOLUTIONS

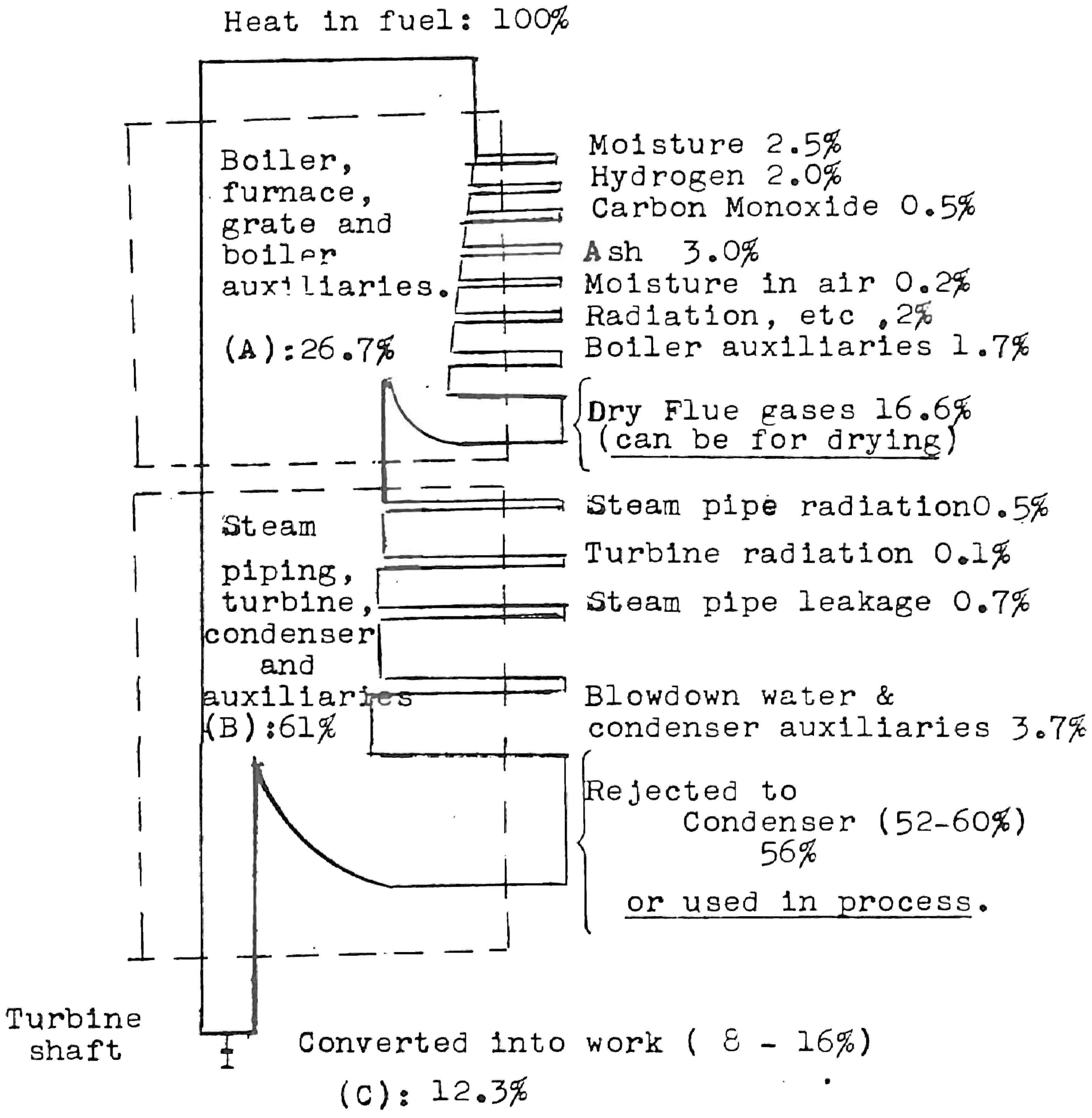
The main purpose of this chapter is to determine the technical viability of each of the four alternatives by evaluating and comparing the available energy from the Waste Heat Recovery proposal and/or the Cogeneration System, with the energy requirements of each proposal.

Every alternative is illustrated by means of a flow diagram, except Alternative 1 (actual situation, do nothing). A graph of the balance of energy flow in a model furnace-boiler-turbine-generator system is shown in Figure 4.

7.1. ALTERNATIVE 1: DO NOTHING.-

7.2. ALTERNATIVE 2: THE ACTUAL SITUATION PLUS WASTE HEAT RECOVERY FOR DRYING.-

This alternative includes the current plant of the rice mill with the proposal of drying rice with the diesel-generator exhaust gases. In this section we are going to determine the drying capabilities of the diesel-generator exhaust gases and the current drying requirements of the mill. This alternative will be technically feasible if the flue gases satisfy the current drying requirements. The diesel-generator consumes 13.75 gl/hr of fuel oil #2. The generator total



Energy Balance: (A) - (B) - (C) : 100%

Figure 4. Energy flow balance in a Furnace-Boiler-Turbine/Generator System.

efficiency is 32% (Section 5.1.1). Losses to the radiator and the surrounding air are estimated to be 30%. A diagram of this proposal is depicted in Figure 5.

7.2.1 Heat availble in diesel-generator exhaust gases.-
The energy available in exhaust gases is (Eex):

$$Eex = Teg - \text{Generator losses}$$

Where Teg is the Total Energy Generated, i.e., the heat content of the fuel oil.

$$Eex = (13.75 \text{ gal/hr}) (19750 \text{ BTU/lb HHV}) (7\text{lb/gal}) (1-.32-.30)$$

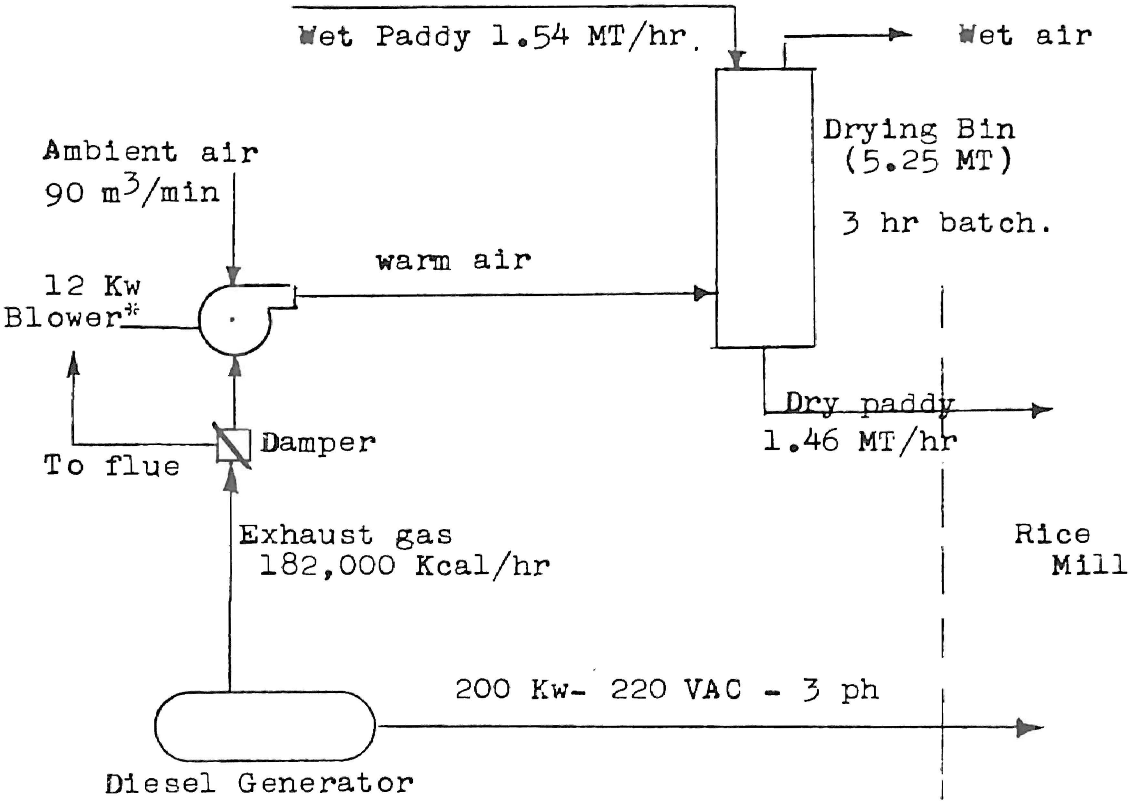
$$= 722{,}356 \text{ BTU/hr} = 182{,}034 \text{ KCl/hr.} \qquad [7.1]$$

7.2.2 Air and heat requirements to dry paddy.-
An air flow of 50 cu m/ min per 1.M.T. of paddy is required for a batch-drying bin [6]. It is assumed that the air has the following conditions:

Type of air i	Outside air i = 1	Heated air i = 2	Wet air i = 3
Temperature (ti, C)	28	43	27.4
Rel. Humidity (RHi)	70%	31%	100 %
g Moisture/Kg air (Wi)	16.7	16.7	16.7
Enthalpy (hi, Kcal/kg)	17.0	20.7	20.7

All values are from the psychrometirc chart. Appendix B.

Thus, the moisture content in paddy should be reduced from



Alternative 2 flow-diagram: Waste Heat Recovery for drying paddy from diesel generator exhaust gas.

- Figure 5 -

22.5 to 14% , and the ambient air temperature (RH1 = 70%) should be increased from 28 to 43 deg C.

Water removal per M.T.of paddy:

Paddy with 22.5% of moisture (wet basis), @ 1000 Kg basis:

Water = 225 Kg   Dry matter = 775 Kg

Paddy with 14.0% of moisture (wet basis), optimal conditions for milling:

paddy wt = dry matter/water = 775 / (1-.14) = 902 Kg.

Water wt = 127 Kg   dry mater = 775 Kg

Water removed: 225 - 127 = 98 Kg water / M.T. of paddy

The mass of drying air required for these conditions are 50 cum/min air flow,(Ma).

Ma = Mass H20 / (W3 - W2)

= 98000 / (23.0 - 16.7)

= 15,500 Kg air / M.T. of paddy.

Net drying heat required:

Q net drying = Ma (h2 - h1)

= 15,500 (20.7 - 17.0)

= 57,600 Kcal / M.T. paddy [7.2]

Assuming a thermal efficiency of nt = 55% ,the total drying capacity available, DCA2 :

DCA2 = (Eex / Q net drying) nt

By using values of equations [7.1] and [7.2] we have:

DCA2 = (182,033 / 57,600) (0.55) = 1.74 M.T paddy/hr

The air requirement will be:

=(50 cum/min-ton) (1.74 M.T /hr)

= 87 cu mt/min or 3,225 cu ft/hr.

7.2.3. Determination of Drying Capacities .-

In general, any paddy with moisture content greater than 16% (wet basis) should be dried. About 21% of the paddy received in the mill has this moisture content. (18.5% w.b. in the average). Thus, the 22% of moisture utilized to compute the dryer capacity is a rather conservative figure in order to assure an appropriate performance in extreme conditions. Hence, the drying requirements of this alternative are:

(0.21) (7150 kg/hr) = 1.5 M.T./hour

Since the dryer capacity (1.7 M.T/hr) is greater than the actual drying requirements (1.5 M.T./hr) , the exhaust gases of the diesel generator are sufficient for this purpose. For a continuous dryer, additional drying air may be obtained from the diesel-generator radiator, if necessary. This drying process can be performed by using a batch drying bin, with a capacity of 2.0 M.T (3.0 cu m.). Drying time would be about 1.3 hours per batch to assure proper moisture content.

7.3. ALTERNATIVE 3: A COGENERATION SYSTEM AND WASTE HEAT RECOVERY FROM FLUE GASES.-

In this alternantive high pressure steam produced by a husk burning stoker-boiler would feed a T-G; the electricity produced by the T-G is sold to a utility. The exhaust gases from the diesel-generator and furnace are used to dry paddy. The exhaust of the turbine is a low pressure steam to be used in the paraboiling plant. The electricity for the mill is supplied by the actual 200 Kw diesel generator. A flow diagram of this proposal is shown in Figure 6.

As mentioned above, this alternative would require the addition of a furnace to burn rice hulls at a rate of 1,240 Kg/hr, a boiler to produce superheated steam (600 psig-750 deg F) at 5,317 lb/hr, and a turbogenerator to generate 160 Kw. Considering that additional husk might be purchased at insignificant cost and that the power capacity have been computed conservatively, the equipment should be oversized in order to absorb fluctutations in demand, say a 20% oversize. Balances of energy will be calculated for the paraboiling and drying processes to assure their viability.

7.3.1. Energy Balance for the Paraboiling Process.-

Since the process steam is going to be used to paraboil 30% of the rice production, it its required to determine to what extent the available steam is sufficient for such a process.

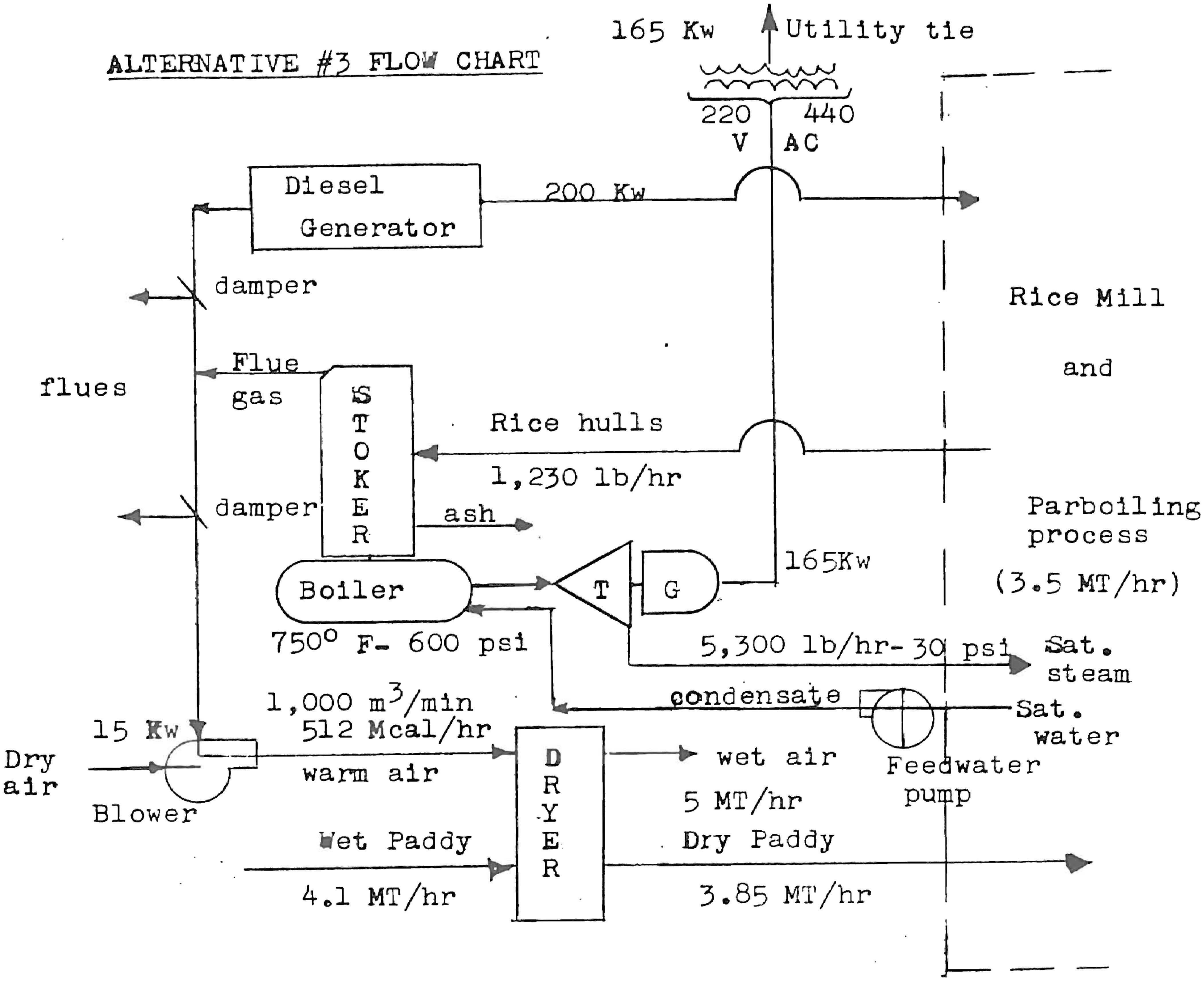


Figure 6. A cogeneration and waste heat recovery system that produces electricity to be sold to a utility and operates all year around. Process steam is for parboiling 30% of the rice production. A non-condensing (backpressure) turbo-generator generates 165 Kw. Electrical power for the mill is from existing diesel-generator. Gases from either spreader-stoker furnace or diesel generator are for drying paddy.

A fuel balance for a paraboiling plant of 1 M.T. of paddy per hour is shown in Table 5.

TABLE 5

FUEL BALANCE FOR A PARABOILING PLANT OF 1 M.T. PER HOUR

Energy and Water requirements		Husk equivalent*
Water	2200 litres	--
Heating Steam	250 Kg (25 psig)	58 Kg/hr
Drying Steam	320 Kg (25 psig)	75
Electricity	20 Kw for pumps	67
	Total husk required :	200 Kg/hr

* at 4.3 Kg steam or 0.3 KWh per Kg of husk.

Suorce: Rice Chemistry & Technology by Houston [10]

This balance has an exact ratio of 200 Kg of husk/ M.T. The demand of 20 kw for the paraboiling process can be readily supplied by the actual diesel-generator. This would benefit the overall effectiveness of the plant because of a higher utilization of the diesel generator. However, some spare power could be obtained from the proposed T-G.

The amount of husk required for 1 M.T/ hour of Paddy is 200 Kg. This is a lower rate than the firing rate of 561.6 Kg of hulls/hr. Nevertheless, the mill may have a demand of paraboiled rice about 30% of the actual production capacity.

Thus, the annual production of paraboiled rice would be:

(1.35) (18,000 MT/year) (.3) = 7,300 M.T./ year

Therefore, the mill have more than enough husk for the paraboiling demand.

The paraboiling production rate may be found by using the steam availability from Section 5.3.1.

Steam requirements per 1 M.T.	570 Kg (1255 lb)
Steam availability	5317 lb/hr

Maximum paraboiling capacity = 5317/1256 = 4.23 M.T. /hr

A standard plant of 3.5 M.T./hr would match the milling capacity of one of the parallel flow-lines of the mill. For this production rate of paraboiling the operation-days at a 10/hr day shift, 6 days/week would be:

(7,200 M.T.) (1.35) (1hr/3.5 MT) (1day/10hr) (1 week/6days)

= 47 weeks or 282 days.

This operating time would assure a high utilization of the equipment, and allow for a maintenance schedule.

7.3.2 Energy Balance for Paddy Drying Process.-

In this subsystem, the exhaust gases from both the diesel generator and husk furnace should be utilized to dry paddy.

The overall drying requirements would be the actual and current requirements (one fifth of the actual production), (Section 5.2) plus an incremental production of 35%, attainable because of improved drying facilities, so:

(0.20 + 0.35) (7.150 M.T./Hr) = 4.075 M.T./hr

Rounding numbers, we need a drying capacity of 4.1 M.T./hr.

Available heat.-

From diesel generator:	182,000 Kcal/hr [*]	(Section 7.2.)
From flue gases:	17 % of NHV	(Figure 4.)
Firing rate:	1230 lb/hr	(Section 5.2)

(.17) (6,225 BTU/lb) (1230 lb/hr) = 1.31 MBTU/hr

= 330,120 Kcal/hr [**]

By adding [*] and [**] we have the total available heat:

TAH = 512,120 Kcal/hr.

Psychometric data for a continuous dryer at 50 deg C (122 deg. F) are shown:

1. The air flow for 1 MT. of paddy should be 200 cu m/ min.
2. The moisture should be reduced from 20% to 14%.
3. The air temperature is raised from 28 to 50 deg C.
4. The outside air relative humidity is 70%.

The water removal per MT of paddy (20% w.b.):

water: 200 Kg dry matter: 800 Kg

Paddy with 14% moisture (w.b.) for optimal milling conditions:

Paddy wt = dry matter / water

= 800 / (1- 0.14) = 930 Kg.

Content of water in paddy after drying is 130 Kg and dry matter is 800 kg. Hence, the water removed is:

200 - 130 = 70 Kg Water/ ton of paddy

The air conditions for a continuous dryer are listed :

	Outside air i=1	Heated air i=2	Air from dryer i=3
ti (deg C)	28	50	27.5
RHi (%)	70	22	100
Wi (g/Kg)	16.7	16.7	23.0
Hi (Kcal/kg)	17.0	22.5	20.7

Where ti is the temperature, RHi is relative humidity, Wi is moisture in grams per Kilo of paddy, and Hi is the enthalpy of air . The type of air is noted by i = 1,2 & 3.

For a water removal (m) of 70 kg/ M.T of paddy and an air flow of 200 cu m/ min, the mass of air (Ma) is:

Ma = m water / (W3 - W1)

= 70 (1000) / (23.0 - 16.7)

= 11,112 Kg air/ M.T. paddy.

The drying heat required is:

$$\begin{aligned} Q\ \text{drying} &= Ma\ (h3 - h1) \\ &= 11{,}112\ (22.5 - 17) \\ &= 61{,}100\ \text{Kcal/ M.T. of paddy.} \end{aligned}$$

Since the total available heat from exhaust is 512,120 Kcal per hour and the drying efficiency is estimated as 60% (only heat). So, there is a net drying capacity (NDC) of:

$$NDC = (THC\ /\ Q\ \text{drying})\ (Nd)$$

Where THC is the total drying capacity and Nd is the efficiency of the dryer.

$$\begin{aligned} NDC &= [(512{,}120)/(61{,}100)]\ (.60) \\ &= 5.03\ \text{M.T./hr.} \end{aligned}$$

Therefore, in this alternative both, the steam generator and the flue gas proposal will be able to supply the energy required by the paraboiling and the drying processes.

7.4. ALTERNATIVE 4: A "SYNCHRONOUS" COGENERATION SYSTEM AND SOLVENT EXTRACTION MILLING (SXM) PROCESS.-

This alternative proposes a simultaneous operation of the mill and the system; in addition, it proposes a plant for solvent extraction of rice oil. In this case the operating characteristics are different; the electrical and thermal energy demands will be higher than in Alternative 3.

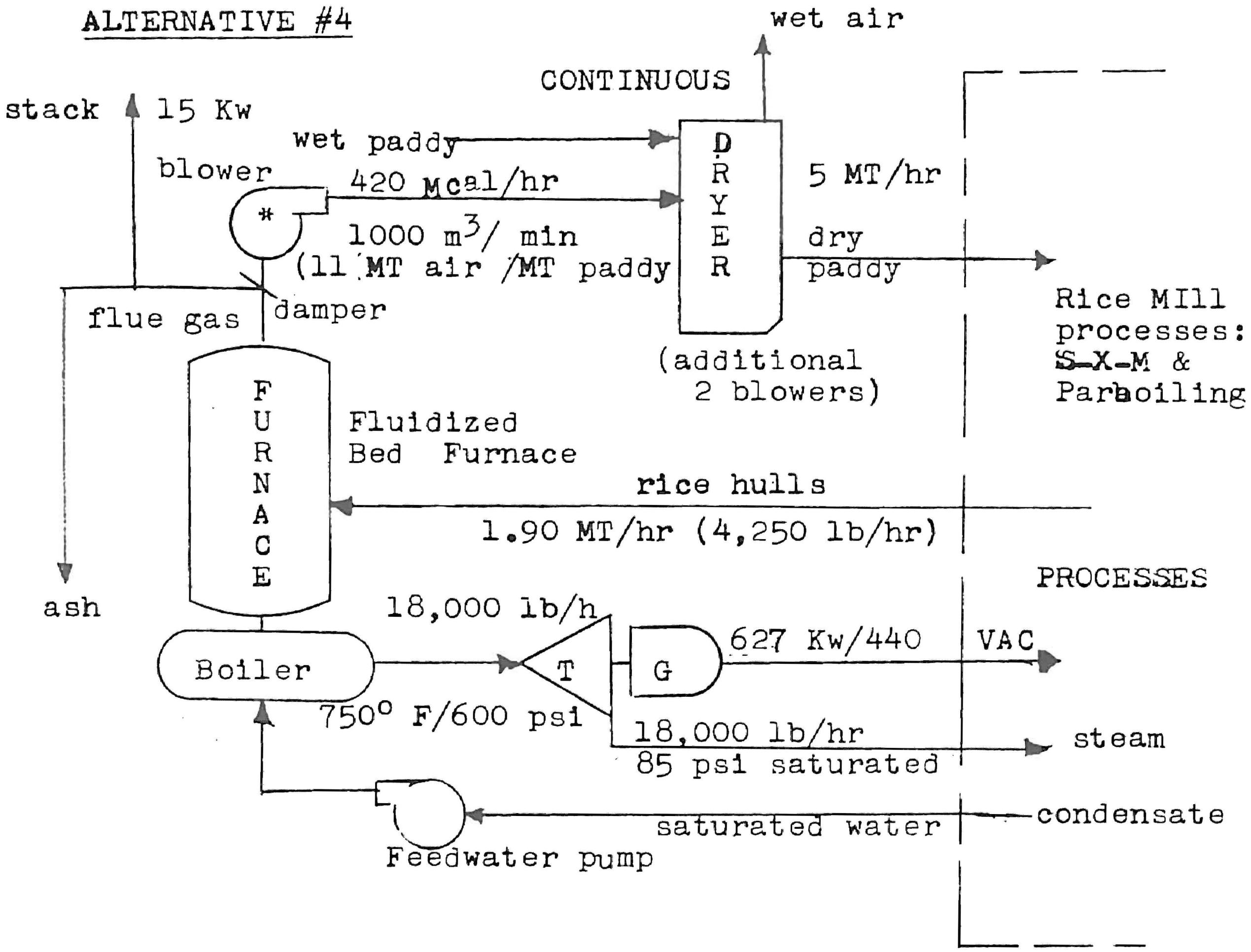


Figure 7. Flow diagram for Alternative 4. A Cogeneration System that operates simultaneously to the rice mill. Process steam is utilized in parboiling and S-X-M. A non condensing (backpressure) T-G shall supply electrical power to the mill. The flue gases shall be used for drying paddy in a continuous dryer. The combustion equipment is a fluidized bed combustor. The steam generator is a water tube boiler.

The utility will not buy-back electrical power in a partial basis during certain lapse of time. The flow chart of this alternative is shown in Figure 7.

Throughout this proposal, all energy requirements of the mill, paraboiling plant, and S-X-M plant could be generated by a highly efficient combustion device and turbine. This implies the need to salvage the actual diesel generator. It could be traded at favorable conditions.

In this proposal, the flue gases will be required for drying paddy . The drying analysis in Alternative 3, showed that there would exist more than enough flue gas heat for drying, as this alternative involves a firing rate as much as 3 times the firing rate of Alternative 3. [Section 5.2]. This assumption will be confirmed by an additional energy balance.

The S-X-M equipment would be located within the actual milling plant. The purpose of this facility is the extraction of bran and oil from the rice. The recovery of deffated rice bran and crude dewaxed rice-oil are the following subprocesses. A S-X-M facility has many similarities to a petrochemical plant from the viewpoint of processes and unit operations. The information about operations and energy demand of a S-X-M process has been obtained mainly from [10] and [15].

7.4.1 Electrical Power demand.-

The demand of electrical power of every process proposed in this alternative is listed as follows:

Improved Rice Mill including S-X-M equipment:	330 Kw
Steam generation auxiliaries (pumps and fans):	30 Kw
Drying Facilities (Paddy):	25 KW
Paraboiling Plant	20 Kw
Additional ash handling	10 Kw
Accesories and instruments	5 Kw
TOTAL ELECTRICAL DEMAND:	420 Kw

The available electrical power (Section 5.3.3) is: 627 Kw

Hence, there is a balance of 207 Kw available.

7.4.2 Process Steam Requirements.-

The requirements of process steam are the following:

3.5 M.T. Paraboiling Plant	(25 psig sat):	1,995 Kg/hr
6.0 M.T. S-X-M plant	(85 psig sat):	3,600 Kg/hr
Washing and pumping systems :		350 Kg/hr
Oil refining:		440 Kg/hr
	TOTAL REQUIRED STEAM:	6,385 Kg/hr

The available process steam (Section 5.3.1) is: 8,300 Kg/hr

Hence the balance of process steam is 1915 Kg/hr.

7.4.3 Energy Balance for drying.-

By using data from Section 7.3.2 we can calculate the overall drying requirements of heat flow for 4,100 Kg/hr of paddy for a dryer with 60% efficiency:

(4,100 Kg/hr) (61.1 Kcal/ Kg) /(0.60)

= 417,500 Kcal/hr for paddy.

a) If steam is utilized for drying:

Enthalpy of dry steam, hs (85 psig sat): 1187 BTU/lb
Enthalpy of wet steam, hw (15 psig sat): 180 BTU/lb

Available heat : 1007 BTU/lb

or 1800 Kcal/kg.

Steam required for drying paddy : 417,500/ 1800 = 232 Kg/hr. Assuming that 208 Kg/hr of steam are needed for bran drying, the total steam requirement is:

232 + 208 = 440 Kg/hr or 970/lb hr.

b) If flue gases are utilized for drying, and a combustion air preheater is included, we can use as much as 15% of NHV,

(.15) (6,225 BTU/lb) (4,250 lb/hr) = 4.4 KBTU/hr

or 1,133,385 Kcal/hr

Hence, the heat in the flue gases is twice as much the projeted requirements of heat for drying paddy. Also, there is heat available in the steam for either paddy or bran drying. This confirms the asumption made in the introduction of Section 7.4. Finally, the electricity, process steam and flue gases demanded in Alternative 4 can be satisfied by the cogeneration system.

7.5. SUMMARY OF RESULTS.- A summary of results of the analysis of every alternative is shown in Table 6.

Table 6

SUMMARY OF RESULTS OF ANALYSIS OF ALTERNATIVES

ENERGY SYSTEMS	ALTERNATIVES 1	2	3		4	
Electric Kw						
D-G (a)	200	200	200		---	
T-G (a)	---	---	160		627	
Total (a)	200	200	360		627	
Required	180	200	200		420	
To sell	---	---	160		---	
Balance	20	---	---		207	
T-G Steam :			MBTU/hr	lb/hr	MBTU/hr	lb/hr
Available			1.22	5,317	3.56	18,280
Required	---	---	0.55	5,317	2.38	12,247
Balance	---	---	0.67	5,317	1.18	18,280
Process Steam:			MBTU/hr	lb/hr	MBTU/hr	lb/hr
Available	---	---	5.3	5,317	18	18,280
Required	---	---	4.4	4,396	14	14,064
Balance	---	---	0.9	921	4	4,216
Flue Gases:			Mcal/hr			
Available	182.	182.	512		1,133	
Required	---	160.6	417		417	
Balance	182.	21.4	95		716	

Alternative	2	3	4
Total input Steam : MBTU/hr (lb/hr)	---	17.7 (5,317)	26.47 (18,280)
Total Energy Required : KBTU/hr	89.232	5,800	16,610

(a) denotes available electrical power.

Table 6 shows that for every alternative, all the proposed energy systems fulfill the requirements of electrical power demand, turbo-generator steam, process steam and flue gases. Therefore, we can say that each of the four proposed alternatives in Chapter 6 is technically viable.

CHAPTER 8

SELECTION OF THE ENERGY SYSTEMS

In order to select the most economical alternative it is necessary to determine the costs and savings involved and to evaluate the cash flow of each of the four alternatives.

The investment cost for each project is the installed cost of the equipment specified for an alternative. The operation and maintenance costs per year (O&M) are estimated as a percentage of the installed cost. It is assumed that the escalation of the O&M costs is negligible.

The challenger fuel is Oil # 2 at a price of $0.85/gal. This price is considered constant throughout the planning horizon of each alternative project.

The cash inflows of an alternative are all income to the project, which includes selling electricity to a utility at $0.025 per Kwh, and income from equipment salvaged as a result of the implementation of an alternative. This cash inflow is assumed to happen at the beginning of the project. All savings in each alternative (avoided costs in substitu-tution of Fuel Oil #2) are included as income received at the end of every year after the installation of the project.

In general, it is assumed that all cash flows for each alternative are pure or conventional, i.e., with negative flow at the beginning of the project (cost of implementation) and positive cash flows (avoided costs) thereafter.

Since the rice milling industry in Peru is exempted from corporate taxes, depreciation schedules will not be included as an analysis element. First, the savings and expenditures of each proposal should be determined. Second, a before tax cash flow analysis is performed for each alternative. Then, a comparison study is made of the alternatives.

For a preliminary analysis, the planning horizon is assumed to be infinity. This planning horizon is used to determine the profitability of the project in the long run. This assumption is made on the basis that the mill will keep the equipment as long as possible and there will be an effective preventive maintenance program. Some other planning horizons are considered later on the basis of the estimated economic life of each alternative.

As mentioned, no inflation is included in the preliminary analysis of each cash flow. Hence, only the time value of the money is utilized as the unique component of the minimum attractive rate of return (MARR) of the project. This rate of return should be equal or higher than the average cost of capital of Ingenio Guadalupe Rice Mill, considered to be 12%.

Two additional assumptions are included. These are:

FIRST.- The cost to be avoided -savings- because of the implementation of a specific subsystem within any proposed alternative is determined by:

$$\text{Energy savings} = Np\ (Ei - Eo)\ /\ Na \qquad [7.1]$$

Where:

Ei is the energy input to the subsystem.

Eo is the energy output from the subsytem and available for other processes.

Np is the efficiency of a proposed subsytem.

Na is the efficiency of the actual or would be subsystem but fired with a traditional fuel as Oil # 2.

If $Np = Na$ for an alternative:

Then:

$$\text{Energy saved} = Ei - Eo \qquad [7.2]$$

If the output energy has a low quality with respect to the proposed process -energy not readily available-, or if there is not a process proposal, we should assume $Eo = 0$.

SECOND.- All costs associated with rice drying, except an intermediate blower , are to be asigned to an external drying proposal investment. Also, all the cash flow, composed of incomes and outcomes to/from a specific production process (drying, paraboiling or solvent extraction milling S-X-M) should be assumed to be break even. Thus, no other costs nor savings, except those indicated in the assumption above and in the introduction of this chapter must be included in the cash flow of any energy conservation alternative.

8.1. CALCULATIONS TO DETERMINE SAVINGS OF EACH ALTERNATIVE.-

The energy data for the calculations are from Table 6.

8.1.1. Savings of Alternative 1.-

Since Alternative 1 is to do nothing, there are no savings in this alternative.

8.1.2. Savings of Alternative 2.-

a) Savings due to fuel oil saved in drying paddy:

Total Energy required for drying, (Table 6):

160.6 Mcal/hr = 89,232 BTU/hr

b) Total energy saved per year:

(89,232 BTU/hr) (2,520 hrs/yr) = 225 MBTU/yr

c) Total dollar savings:

(1lb/19,750 BTU) (7 gl/lb) (225 MBTU/yr) ($.85/gl)

= $9,683 / year

8.1.3. Savings of Alternative 3.-

a) Energy sold to utility:

(160 Kw) (360 days/year) (24 hr/day)

= 1,382,400 Kwh/year

b) Revenues from electricity sold to utility:

(1,380,400 Kwh/year) ($0.025 / Kwh)

= $34,560.

c) Energy saved from process steam:

(4.4 MBTU/hr) (2100 hr) = 9,240 MBTU/year

d) Energy saved from drying paddy:

(0.23 MBTU/hr) (2520 hr) = 584 MBTU/year

e) Process energy saved (BTUs) = (c) + (d)

= 9,824 MBTU/year

f) Total dollar savings from processes:

(9,284 MBTU/year) (1 lb/19750 BTU) (1gl/7lb) ($0.85/gl)

= $60,400 / year

g) Total cash inflow [(b) + (f)]:

$60,400 + $34.560 = $94,960 / year

8.1.4. Savings from alternative 4.-

a) Salvage value of Diesel Generator (year-one-time):

$ 13,000

b) Savings from change of prime mover fuel:

(2.38 MBTU/yr) (2,520 hr/yr) = 5,997 MBTU/year

c) Savings from process steam:

(14. MBTU/yr) (2,520 hr/yr) = 35,280 MBTU/year

d) Savings from drying paddy:

(0.23 MBTU/year) (2520 hr/yr) = 584 MBTU/year

e) Total energy saved in Alternative 4:

(b) + (c) + (d) = 41,861 MBTU/yr

f) Total dollar savings of Alternative 4:

(41,861 MBTU/yr) (1gl/7lb) (1lb/19750 BTU) ($.85/gl)

= $257,373 / year

8.2. CALCULATIONS TO DETERMINE COSTS OF THE ALTERNATIVES.*

8.2.1. Costs of Alternative 1.- No expenses.

8.2.2. Costs of Alternative 2.-

a) Installed cost:

- Piping and ductwork for exhaust gases	$ 75
- Damper to regulate flow rate of gases	15
- Blower (12 kw) with 16 HP motor	520
Total installed cost :	$ 610

b) Operation and Maintenance cost per year:

Estimated to be 12% of installed cost	$ 85

8.2.3. Costs of Alternative 3.-

a) A water tube boiler of 6,000 lb/hr (including accesories and economiser)	$ 46,500
b) A Stoker furnace of 1,500 lb/hr (including ash collection devices)	12,700

c) Husk storage building;

Steel structure, 12 ksq ft, @ $0.35/sq ft,
Concrete floor, 2.5 ksq ft, @ $0.40/sq ft,
Asbestos roof, 1 ksg ft, @ $0.28/sq ft.

Total construction cost:	5,480

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*US.vendors quoted US.-made equipment. The rest of the costs were estimated by Peruvian contractors and the author.

d) Pneumatic system to transport ash to silo;	
($1.52/ lb-hr) (1,236 lb/hr) (0.2 ash/husk) =	$375
e) Ductwork for exhaust gases to dryer :	$180
f) Blower of 15 Kw (including 20 HP motor) :	$620
g) Turbo-generator package by Carling (200 Kw);	
FOB price at Worcester, Mass:	$34,500
Freight and insurance to Peru:	1,200
Installation:	700
Total installed cost of Alternative 3:	$102,305

h) Operation and Maintenance cost per year;

Estimated at 13% of the installed cost: $13,300.=

8.2.4. Costs of Alternative 4.-

Installed Cost.-

a) Fluidized Bed combustor and boiler turn-key package by Keeler / Dorr-Oliver, (6,000 lb husk/hr, 25,000 lb steam/hr)	$270,000
b) Turbo-generator by Coppus (650 Kw)	
FOB Worcester, Mass	$88,000
Freigth and insurance to Peru	3,500
Installation	3,400
c) Transformer (1000 KW)	3,500
d) Ash handling and storage equipment;	
($3.82/lh-hr) (4,250 lb/hr) (0.2 ash/husk):	$3,247
f) 20 Kw Blower (includes 30 HP. motor)	800
g) Switchgear for electrical conection, (already existing control panel, wiring only)	250
Total installed cost:	$372,697
h) Operation and maintenance Cost is 10% of total installed cost:	$37,270

8.3 SUMMARY OF RESULTS OF CALCULATIONS OF SAVINGS AND COSTS.-

Table 7 shows the installed cost, the operation and maintenance cost, the energy saved, and the dollar savings of each alternative.

TABLE 7

COSTS AND SAVINGS OF PROPOSED ALTERNATIVES

PROPOSED ALTERNATIVE	INSTALLED COST	O & M COST	ENERGY SAVINGS	DOLLAR SAVINGS
#	$	$/yr	MBTU/yr	$/yr
1	----	----	----	----
2	610	85	225	9,683
3	102,305	13,300	9,842*	94,960**
4	372,697	37,270	41,861	257,373

* This figure does not include the electricity sold to the utility (1,382 Mwhr/year).

** This figure includes the revenues from electricity sold to the utility ($34,560/yr).

8.4. CASH FLOW ANALYSIS.-

The following before tax cash flow analysis considers all cash inflows and outflows listed in Table 7. As mentioned, the planning horizon is infinity.

The MARR is assumed to be equal to the average cost of capital of the project, i.e., 12% compounded yearly.

The measure of economical merit is the Equivalent Anual Cost (EAC). The EAC method converts all cash flows to an equivalent uniform annual series of cash flows at the end of every year of the planning horizon. This measure of merit is well understood by the management of the enterprise.

The annual worth or EAC of Alternative j is:

$$EACj = (IC - VS)\ (A/Pi,t) + (O\&M - S) \qquad 8.1$$

for j=1, 2, 3, and 4.

Where:

IC is the installed cost,
VS is the value of salvage of an equipment (if any),
O&M is the operation and maintenance cost,
S is the combined savings and revenues,

(A/Pi,t) is the factor to convert a present value cash flow into a uniform amount series, and

$$(A/Pi,t) = [i\ (1+i)^{n}\ ]\ /\ [(1+i)^{n} - 1] \qquad 8.2$$

Where:

i is the interest rate or MARR and,
n is the planning horizon of the project.

For our project we have i = 12% and n = infinity (if),

Thus, the Equivalent Annual Cost of alternative j is:

$$EACj = (ICj - VSj)\ (A/P\ 12,if) + (O\&M - S) \qquad 8.3$$

Equations 8.1 and 8.3 are valid only when (O&M - S) is constant throughout the planning horizon.

Thus, we can define a constant value Aj,

$$Aj = O\&Mj - Sj \tag{8.4}$$

and

$$(A/P,i,inf) = i\ ^{*} \tag{8.5}$$

By substituting values of 8.4 and 8.5 in equation 8.3,

$$EACj = i(ICj - VSj) + Aj \tag{8.6a}$$

or,

$$EACj = 0.12(ICj - VSj) + Aj \tag{8.6b}$$

Equation 8.6 is to be used as a general formula to determine the EAC of each alternative. An alternative is said to be profitable if its EAC is equal or less than zero. A profile of the generalized cash flow is depicted in Figure 8.

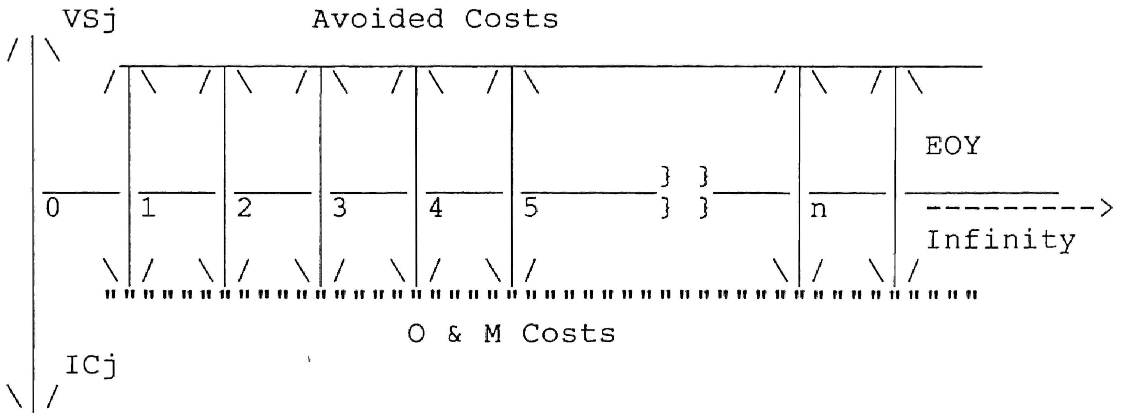

Fig. 8. General profile of an alternative cash flow with infinite horizon and constant O&M costs and savings.

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*See Appendix C for determination of equation 8.5.

Applying equation equation 8.6b to the values listed in Table 7 gives the EAC of each alternative. These values and and Net Present Values (NPVj = -EACj/i) of alternatives 2, 3, and 4 are shown in Table 8.

TABLE 8

CASH FLOW ELEMENTS AND EQUIVALENT ANNUAL COST OF EACH ALTERNATIVE (Infinite Planning Horizon)

Cash Flow elements	Alternative		
j =	2	3	4
Total Installed Cost (IC - VS)j	610	102,305	359,697
Cost/year (O&Mj)	85	13,300	37,270
Savings (Sj)	9,683	94,960	257,373
EACj	-9,524	-69,383	-176,939
NPVj	74,373	578,191	1,474,494

By using either method, NPV or EAC, we conclude that the alternatives must be ranked in the following order: 4, 3, 2. Evidently, we should select Alternative 4 as the most profitable of all four alternatives evaluated. However, if finacial restrictions arise any of the subsequent alternatives can be selected, since all alternatives have an EAC smaller than zero.

We next determine the simple payback period SP, and the discounted payback DP, of the projects. The discounted payback is the time required to convert the EAC to zero by using a compounded interest rate (12 %). The discounted payback N is determined by linear interpolation in equation [8.7b]. In addition, we consider the economic life of alternatives 2, 3, and 4 to be 5, 10 and 15 years respectively. Using equation 8.8 we can calculate a new set of EACs for these specific planning horizons. Since the projects have different time spans, it is assumed that any selected project is to be repeated after the end of its economic life. The values of simple and discounted paybacks, and the EACs for each project are listed in Table 9.

Reordering terms in equation 8.3 and making $X = IC - VS$ and $Y = O\&M - S$ we have:

$$X\ (A/P\ 12,N) + Y = 0 \qquad 8.7a$$

or

$$(A/P\ 12,N) = -Y/X \qquad 8.7b$$

For the set $(j,t) = (2,5), (3,10)$, and $(4,15)$ we have

$$EACj = X\ (A/P\ 12,t) + Y \qquad 8.8$$

Where:
X is the installed cost minus salvage value,
Y is the net uniform amount at the end of a year,
N is the discounted payback of a project,
j is the alternative number,
t is the economic life of alternative j.

TABLE 9

PAYBACK PERIODS AND EQUIVALENT ANNUAL COSTS FOR THE PROJECTS

(Finite Planning Horizon)

PAYBACKS AND EACS	PROJECTS			
j =	1	2	3	4
X	0	610	102,305	359,697
Y	0	-9,598	-81,060	-220,103
S. Payback	0	.0635	1.262	1.634
(A/P 12,N)	---	15.134	.7924	.6120
D. Payback	---	.073	1.616	1.916
Eco. Life (t)	---	5	10	15
(A/P 12, t)	---	.2774	.1770	.1468
EACj(12, t)	--	-9,428	-62,950	-167,300

By using either payback method we find all projects to have respectable paybacks. If we use the EAC(t) method the ranking is: 4, 3, 2. Again, it is the current financial situation of the mill that ultimately determines the selection of a project. Note that the differences between the EACj with infinite planning horizon (Table 8) and the EACj (12,t) are quite small; the percent differences are -1, - -8.7 and -5.6% for projects 2, 3 and 4 respectively.

CHAPTER 9

SENSITIVITY ANALYSIS

> "If a man will begin with certainties, he shall end in doubts; but if he will be content to begin with doubts he shall end in certainties."
>
> - Francis Bacon -

9.1 INTRODUCTION.-

The quotation above reflects the problem that analysts face dealing with the real world. So far, our economic analyses have been built from data considered completely certain.

Since uncertainty is almost universally present in the economic decision-making of our projects, some sensitivity analysis will be considered in our study. [18]

Our sensitivity analysis centers on the effect of inflation and on the increase of the installed cost due to delay in the approval, funding and implementation of the project. As a consequence to inflation and some other factors, such as risk and floating lending and borrowing interest rates, the cost of capital to the company may fluctuate in the future.

9.2. FORMULATION OF A GENERAL EQUATION FOR SENSITIVITY ANALYSIS.-

This sensitivity analysis requires a generalized expression to be used in a iterative way. It will include all the cash flows. Several assumptions drawn and used in Chapter 8 have to be droped in order to determine the required equation. For this reason we shall relax the condition of a cash flow without any inflation. Two inflation indexes are inserted in the generalized equation. One for the costs and one for the savings. In addition, a factor (f) shall be used to modify the installed cost, by certain percentages, within a range.

Most of the O&M cost accounts for maintenance service by another company, and for spare parts that need to be imported in advance, to perform an effective preventive maintenance program. Since these cost elements depend mainly on interna-tional rates, we must assign them an independent index of of escalation (p), which is estimated to vary from 4% to 6% per year. The currency involved in this cash-flow element is U.S. dollars.

The cash-flow savings are due to avoided costs in fuel oil, because of replacement of the diesel generator by a turbo-generator. The prices of petroleum destilates in Peru are given by the Ministry of Energy and Mining through the state monopoly Petroperu. These prices have escalated about 4% per per year (in the average) during the last five years (1980 - 1985). Assuming that this policy will be continued during the time span of the proposals, we will assign this rate to the savings escalation index (q). The currency for the savings is Soles (Peruvian currency). However, this cash flow is expressed in U.S. dollars for consistency and simplicity.

The MARR is the result of compounding the cost of capital (i), and the inflation index for costs (p), i. e.:

$$\text{MARR} = [(1+i)\ (1+p)] - 1 = p+pi+i \qquad [9.1]$$

The general equation to perform the sensitivity analysis is:

$$\text{EAC}(j,i,N,p,q,f) =$$

$$= (A/P\ I,N)\ \{K(f) + \quad [O(1+p)^{n} - S(1+q)^{n})\ (1+I)^{n}\ ]\}$$

Where: [9.2]

EAC(j,i,n,p,q) is the Equivalent Annual Cost for:
alternative j,
I = MARR = $(p+pi+i)$,
i = cost of capital,
N = planning horizon,
p = cost escalation index,
q = savings escalation index q.
K is the net investment at the beginning of year one.
n is the year number = 1, 2, 3... N.
f is the factor to alter the installed cost.

This general equation has been used to generate tables and graphs with diverse input parameters (j,i,n,p,q,f). The computer program was written using the Statistical Analysis System (SAS). The code and output are listed in Appendix D.

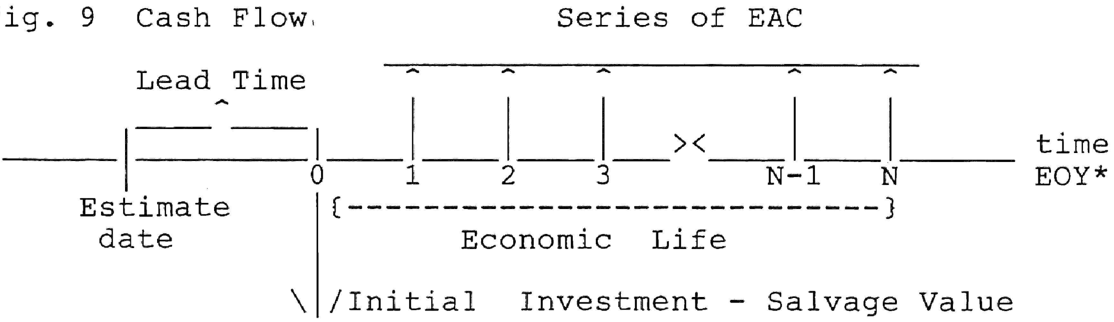
9.3. THE PERIOD BETWEEN THE ESTIMATE DATE AND THE ANALYSIS ZERO POINT.-

A <u>preliminary period</u> (near term) means the period from the estimate date to the analysis base year (zero point) inclusive. It is during this period that the project or program is studied, evaluated, authorized and funded. Also, It includes the <u>lead time of project implementation</u>, e.i., for a facility , the time to install the equipment and any additional time until the project begins to generate profits or to avoid costs. During this period there are several changes likely to occur in the cash flow of the alternatives.

The important cash flow elements that can escalate during the preliminary period, are the initial investment (K) and the MARR (I) as a function of p and i. Therefore, in order to evaluate the effects of a change in the installed cost, the value of K has been increased or decreased certain percentage by using the factor (f). Varying i we can explore diverse EAC values for different MARRs.

The management of Ingenio Guadalupe S. A. is interested in knowing the profitability of the proposed alternatives in adverse conditions, which are much likely to occur due to a continuous increase of the inflation rate in Peru and the devaluation of the Sol (Peruvian currency). Thus, we have estimated some increases in the installed costs of alternatives 3 and 4 which have a significant share of imported equipment. Because of the recent increases in the international interest rates, there have been important changes in the borrowing and lending interest rates in Peru. It is estimated that by the end of the year 1985 the average commercial interest rate of the Industrial Bank of Peru will be as high as 15% compounded yearly. [4] Hence, increases in the cost of capital and MARR of the company should be considered. The range for f, 80% to 140%, is selected considering that some increase in the equipment cost can occur, and the possibility that the rice mill can obtain a tax credit. Figure 9 shows a diagram of a typical cash flow that includes the preliminary period or lead time.

Fig. 9 Cash Flow



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*(EOY) End of the year.

9.4. ANALYSIS OF EAC VERSUS COST OF CAPITAL.-

A computer program to evaluate the sensitivity of the EAC of the projects, using the cost of capital (i) as an independent variable, was written. The computer code written in SAS, and selected output plots are listed in Appendix D-1.

In this run,the values of the escalation factors for the O&M cost and avoided costs were fixed to 4% per year. Since the company is interested in knowing the profitability of the projects in the short to medium term, the planning horizons were set to 1, 3, and 5 years. The values of F (the K modifier) were varied from 0.8 to 1.4 in increments of 0.2. The cost of capital was given a range from 10 to 20% in order to explore a broad range of interest rates. Equation 9.2 was sligthly modified to provide for an iterative summation of cash flow elements to be carried to the present by using a P given A factor (P/A i,N). Then, the Net Present Value (NPV) and Equivalent Annual Cost (EAC) were computed.

Figure 10 shows the graphs for 1 year time-life and a 20% discount on the installed cost. Figure 11 depicts the same data but under rather different conditions; the economic life is 3 years and there is a 20% increase in the initial cost. Projects 3 and 4 do not pay back in 1 year , but they do in 3 years or more. Project 4 is breakeven (EAC =0) with a MARR about 20% and F=1.2, for an economic life of 3 years.

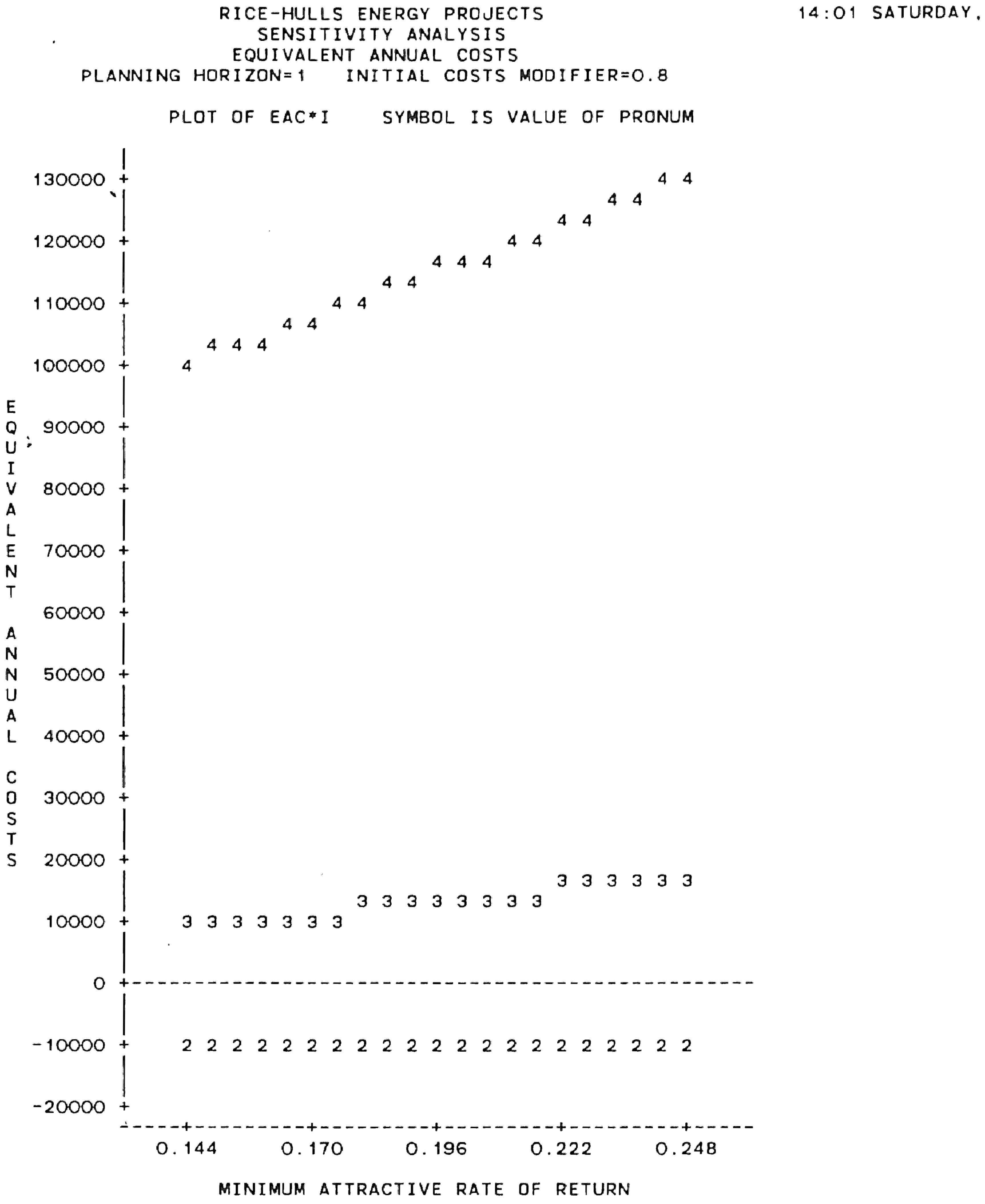
RICE-HULLS ENERGY PROJECTS
SENSITIVITY ANALYSIS
EQUIVALENT ANNUAL COSTS
PLANNING HORIZON=1 INITIAL COSTS MODIFIER=0.8
14:01 SATURDAY,
PLOT OF EAC*I SYMBOL IS VALUE OF PRONUM
EQUIVALENT ANNUAL COSTS
130000
120000
110000
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
-10000
-20000
0.144
0.170
0.196
0.222
0.248
MINIMUM ATTRACTIVE RATE OF RETURN
4
3
2

Figure 10.

```
            RICE-HULLS ENERGY PROJECTS                    14:01 SATURDAY,
               SENSITIVITY ANALYSIS
              EQUIVALENT ANNUAL COSTS
   PLANNING HORIZON=3   INITIAL COSTS MODIFIER=1.2

          PLOT OF EAC*I    SYMBOL IS VALUE OF PRONUM
```

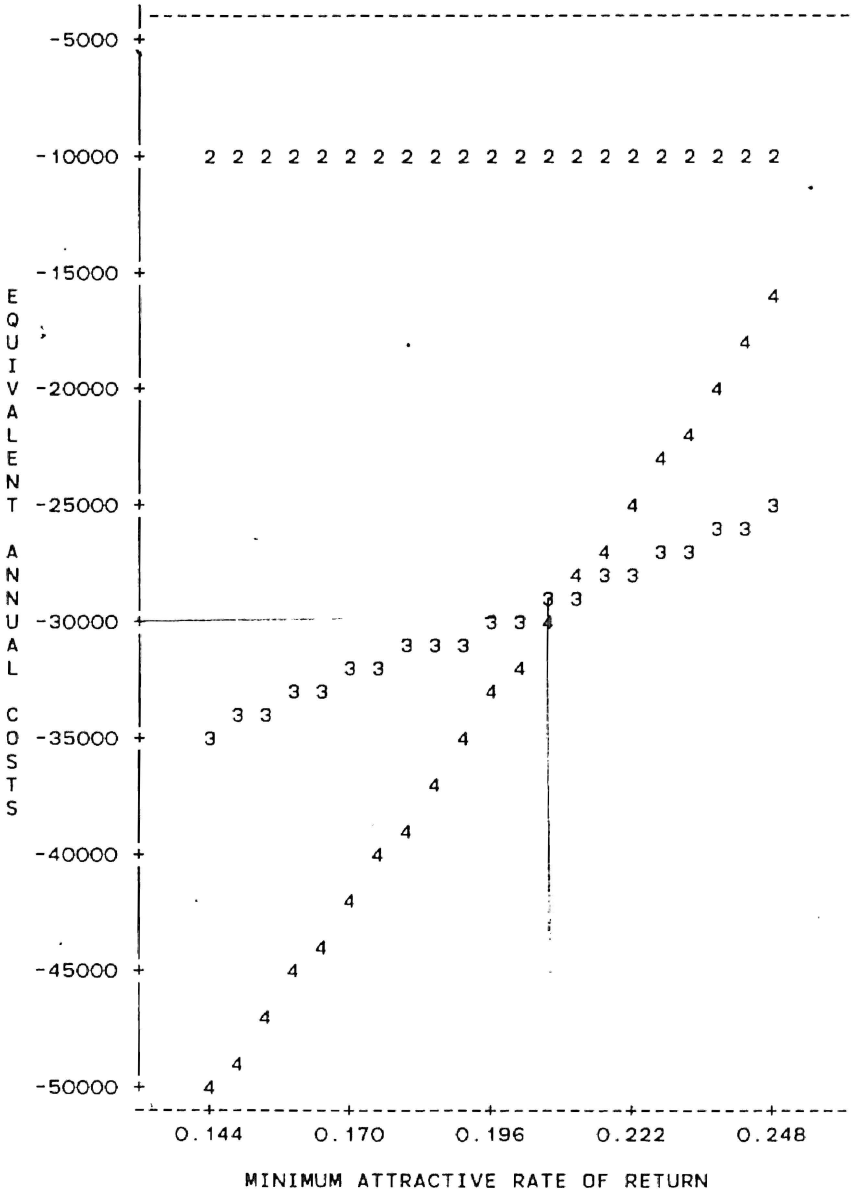

Figure 11.

9.5. ANALYSIS OF EAC BY INSTALLED COST MODIFIER (F).-

An additional program was ran to perform this analysis. The computer code and the output listing are in Appendix D-2.

Figure 12 and 13 show plots of EAC by F (the initial cost modifier) for projects 3 and 4. These graphs show marked lines for economic lifes of 2, 3 and 4 years.

Figure 12 depicts the EAC vs F lines for Alternative 3, when a combined interest rate of 22% is used (MARR). This project shows respectable savings, even for an initial cost increased by 60%, for economic lifes of 3 and 4 years. For a 2 years time, this project can payoff only if its initial cost is not increased over 25% the estimated cost. But, in general this project will pay off for economic lifes higher than 3 years, in spite of of increases in installed cost of 60% and more.

Figure 13 depicts the EAC vs F lines for Alternative 4, when a combined interest rate of 25% is used (MARR). This diagram shows intersections with the zero-EAC line for time lifes 2, 3 and 4 at initial cost that are 90, 130 and 156% of the estimated value. Since the extreme conditions of the studied range are very remote, it can be implied that this alternative will remain profitable even under very high interest rates and significant increases in the installed cost.

```
                 RICE-HULLS ENERGY PROJECTS                    14:44 SATURDAY, J
                    SENSITIVITY ANALYSIS
                   EQUIVALENT ANNUAL COSTS
                  FOR 2, 3, AND 4 YEARS  (N)
ALTERNATIVE=3   MINIMUM ATTRACTIVE RATE OF RETURN=0.219

            PLOT OF EAC*F    SYMBOL IS VALUE OF N
```

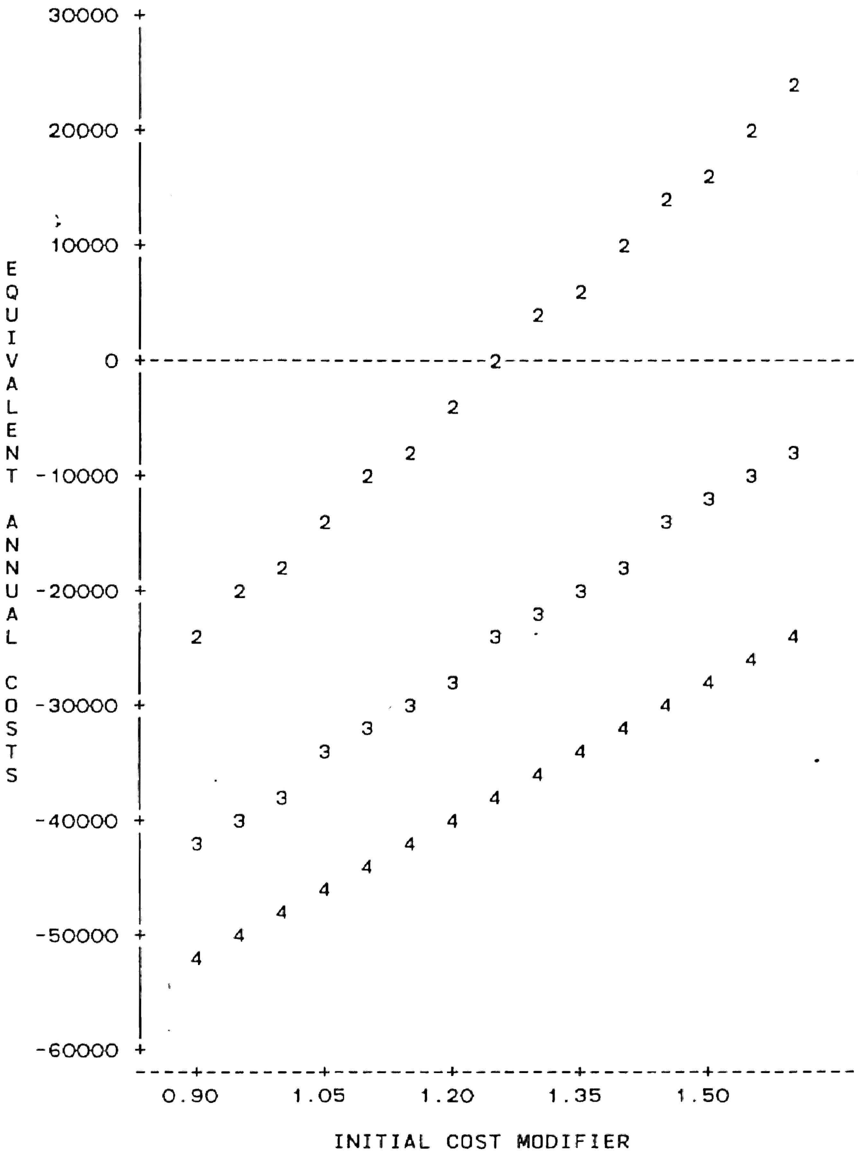

Figure 12.

```
                 RICE-HULLS ENERGY PROJECTS                    14:44 SATURDAY, JU
                    SENSITIVITY ANALYSIS
                   EQUIVALENT ANNUAL COSTS
                  FOR 2, 3, AND 4 YEARS  (N)
      ALTERNATIVE=4   MINIMUM ATTRACTIVE RATE OF RETURN=0.2508
```

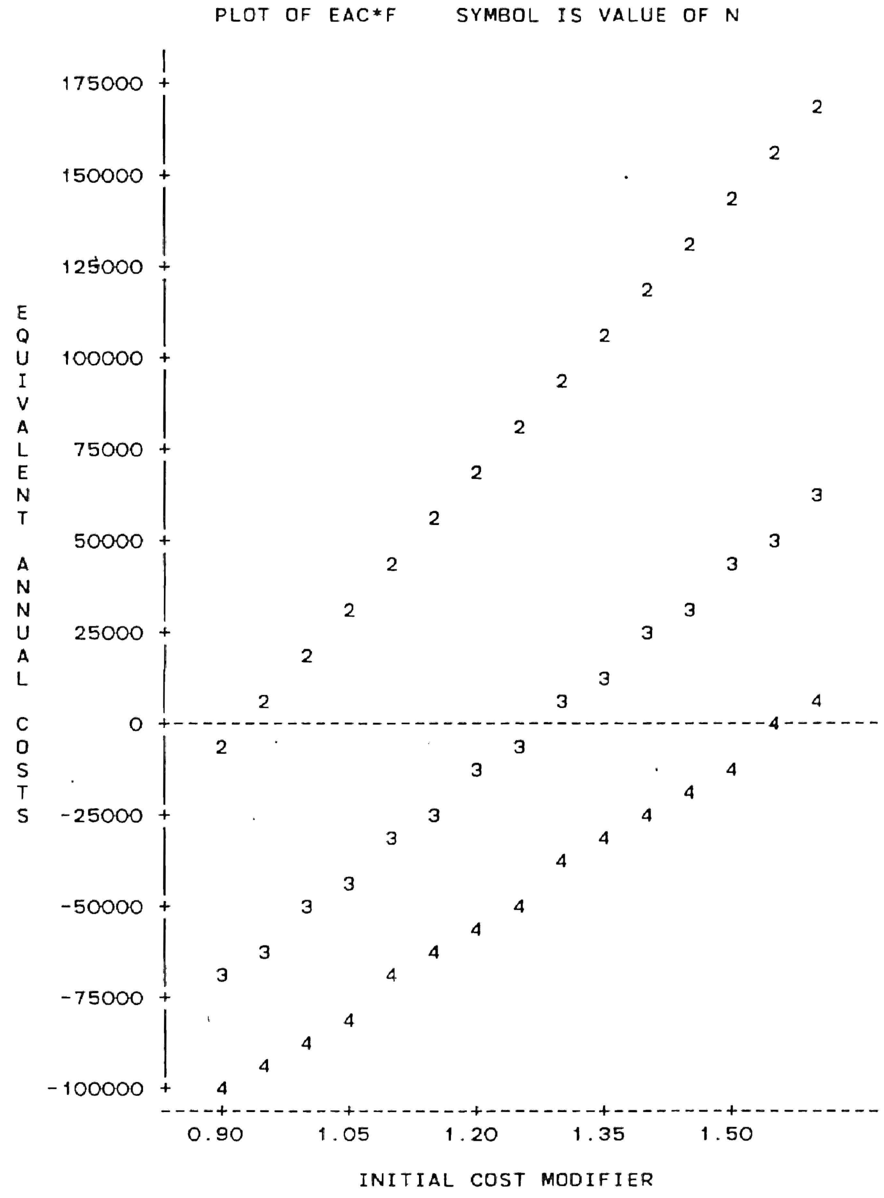

Figure 13.

9.6. ANALYSIS OF EAC BY DIFFERENT PLANNING HORIZONS.-

A third computer program have been ran to evaluate the profitability of the three proposals throughout the time. The planning horizon (N) has been varied from 1 to 10 years in order to explore a broad time span. The escalation rates have been fixed to 6% for costs and 4% for savings. The computer code and the output are listed in Appendix D-3.

Several plots have been obtained with the cost of capital set to 12, 15 and 20% and the installed cost ranging from 80% to 140% of the estimate. Figure 14 shows a graph for a 22% interest (MARR) and a cost of installment increased by 20%. As expected, project 2 is completely flat and it is not sensible to any change of time. Alternative 3 pays off in 2 years but its savings become quite flat after an eigth year economic life (about $60,000 per year). Alternative 4 begins to produce savings after 2.7 years and it would be break-even with Alternative 3 if a planning horizon of 3 years is selected.

It can be concluded, that in most of the cases, Alternatives 3 and 4 are quite responsive to the time specified as the planning horizon, under the evaluated interest rates.

RICE-HULLS ENERGY PROJECTS 13:56 SATURDAY, J
SENSITIVITY ANALYSIS
EQUIVALENT ANNUAL COSTS
MINIMUM ATTRACTIVE RATE OF RETURN=0.219 INITIAL COST MODIFIER=1.2

PLOT OF EAC*N SYMBOL IS VALUE OF PRONUM

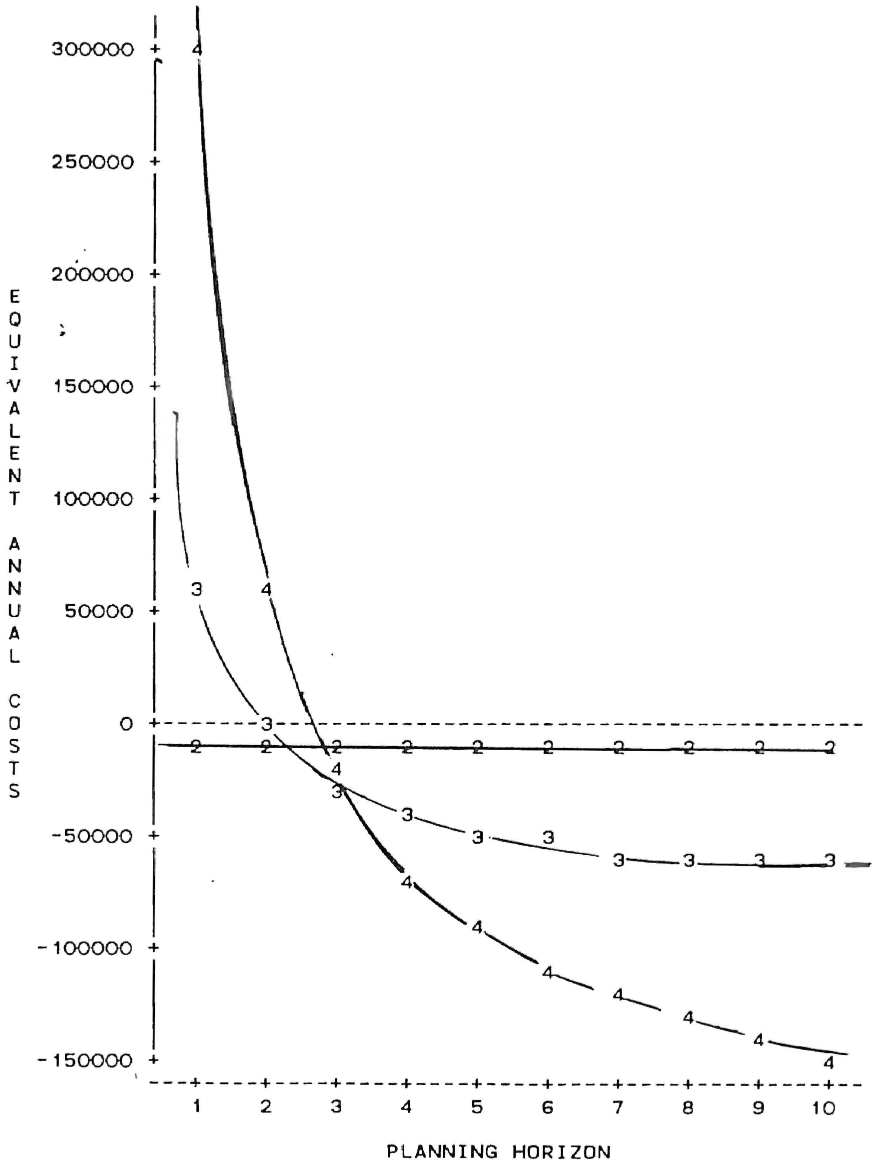

Figure 14.

CHAPTER 10

CONCLUSIONS AND RECOMMENDATIONS

In this case study we have found appropriate alternatives to fulfill the energy requirements of the Ingenio Guadalupe Rice Mill. The Analysis of Alternative Solutions in Chapter 7 has proven that the waste heat recovered from diesel engines (a common prime mover in Peru) can be effectively use for drying paddy. Also, this analysis has proven that flue gases from rice husk combustion can be used for drying purposes. In addition, cogeneration of electrical power and steam for process such as paraboiling or oil extraction by solvent is a feasible alternative for a rice mill with a production capacity of 18,000 M.T. per year or more.

Four alternatives have been evaluated:

Alternative 1: Do nothing.

Alternative 2: Utilize diesel-generator exhaust gas to dry paddy. Figures 15 and 16 depict the recommended dryer.

Alternative 3: Cogenerate electricity (160 Kw) to be sold to a utility and utilize backpressure (exhaust from turbine) steam for paraboiling process. Dry paddy with a mixture of dry air and flue gases. Figures 17 and 18 show the diagram of a stoker-spreader-boiler system and the flow chart of a paraboiling process.

Alternative 4: Cogenerate electricity (650 Kw) and backpressure steam to supply power and heat for the milling, paraboiling and S-X-M processes, flue gas for drying.In Figure 19 is shown a circulating bed steam boiler system and Figure 20 show a flow chart of the S-X-M process.

Each of the four alternatives proposed in Chapter 6 is technically viable as demonstrated in Chapter 7.

The economic analysis of Chapter 8 was directed toward finding the economical feasibility of the four proposed alternatives. The measure of merit was the Equivalent Cost of Capital (EAC) which allows consistent comparison among projects with unequal economic lives. For a preliminary infinite planning horizon, the alternatives were ranked in the order 4, 3, 2. All alternatives evaluated had an EAC smaller than zero, therefore all are profitable for a MARR of 12% or below. The assumption of an infinite economic life was made on the basis that the mill will keep the equipment as long as possible and there will be an effective maintenace schedule. The diferences between the EACs with an infinite planning horizon and the EACs with limited but reasonable planning horizons were insignificant. If an alternative is selected on the basis of pay back methods, both simple and discounted payback methods indicated that the projects are all cost effective.

The sensitivity analysis, in Chapter 9, was oriented toward the exploration of changes in the profitability of the projects due to delay in their implementation and/or to the inflation consequences. Recognizing these uncertainties we can explore the profitability of the projects under conditions different than the estimated values in Chapter 8.

Projects 2, 3, and 4 have a fast pay off even under high escalation rates (8%) and higher initial costs (150%). Project 2 has an extremely fast pay back of less than one month under diverse conditions. If the escalation indexes remain at 4 and 6% per year for savings and costs respectively, and the cost of capital is 15%; Alternatives 3 and 4 will pay back in 2 and 3 years, even with a 20% increase in the cost of installment, which is very likely to occur.

If financial restrictions arise, it is recommended to implement projects 2, 3, and 4 in an incremental basis. Thus, Project 2 should be implemented as soon as possible. Then Project 3, and when the funding for Project 4 is approved and it is installed, the optimal operation of the proposed Cogeneration and Waste Heat Recovery System will be realized.

The food and energy supply are two of the biggest challenges for the near future. These problems constitute the strategic factors for the economic development of Peru and other Third World countries. Rational energy policies should encourage Industrial Energy Conservation and Management projects and the development of appropriate technologies.

Ingenio Guadalupe Rice Mill is a Peruvian company concerned with improving its productivity and upgrading the quality of its produces. We can conclude that one of the most effective ways to improve the productivity of a rice mill and to upgrade the product quality through new processes is by reducing its energy costs. This does not imply, necessarily, a reduction in its energy consumption, but, the effective utilization of a renewable and economical energy source as a fuel: the rice husk. The cogeneration potential in a rice mill is not new, but the new waste-to-energy technologies and the skyrocketing escalation of prices of fossil fuels make it possible where before it was considered a remote idea. Flue gases are actually a stream of money flowing through the chimney; it is an almost free heat flow for drying agriculture produces.

Every effort to improve the energy usage in the rice milling industry in Peru will lead both the goverment enterprises and the milling industry to significant savings in dollars and BTUs. The utilization of refuse derived fuels is an effective energy alternative for Peru. This is a basic idea of a relatively new concept, e.g. <u>Energy Management</u> which is a more thourough and deeper concept than simply conserving energy. Our concern has been the evaluation of the judicious energy utilization in a food production system by recovering waste heat and/or by energy cogeneration.

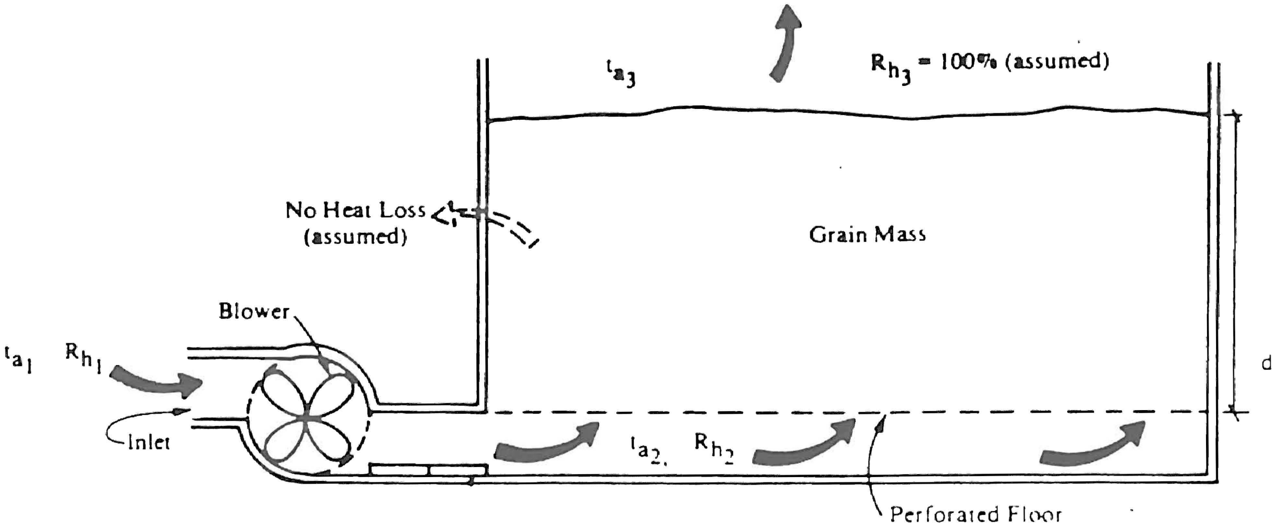

FIGURE 15 A fixed-bed drying method.

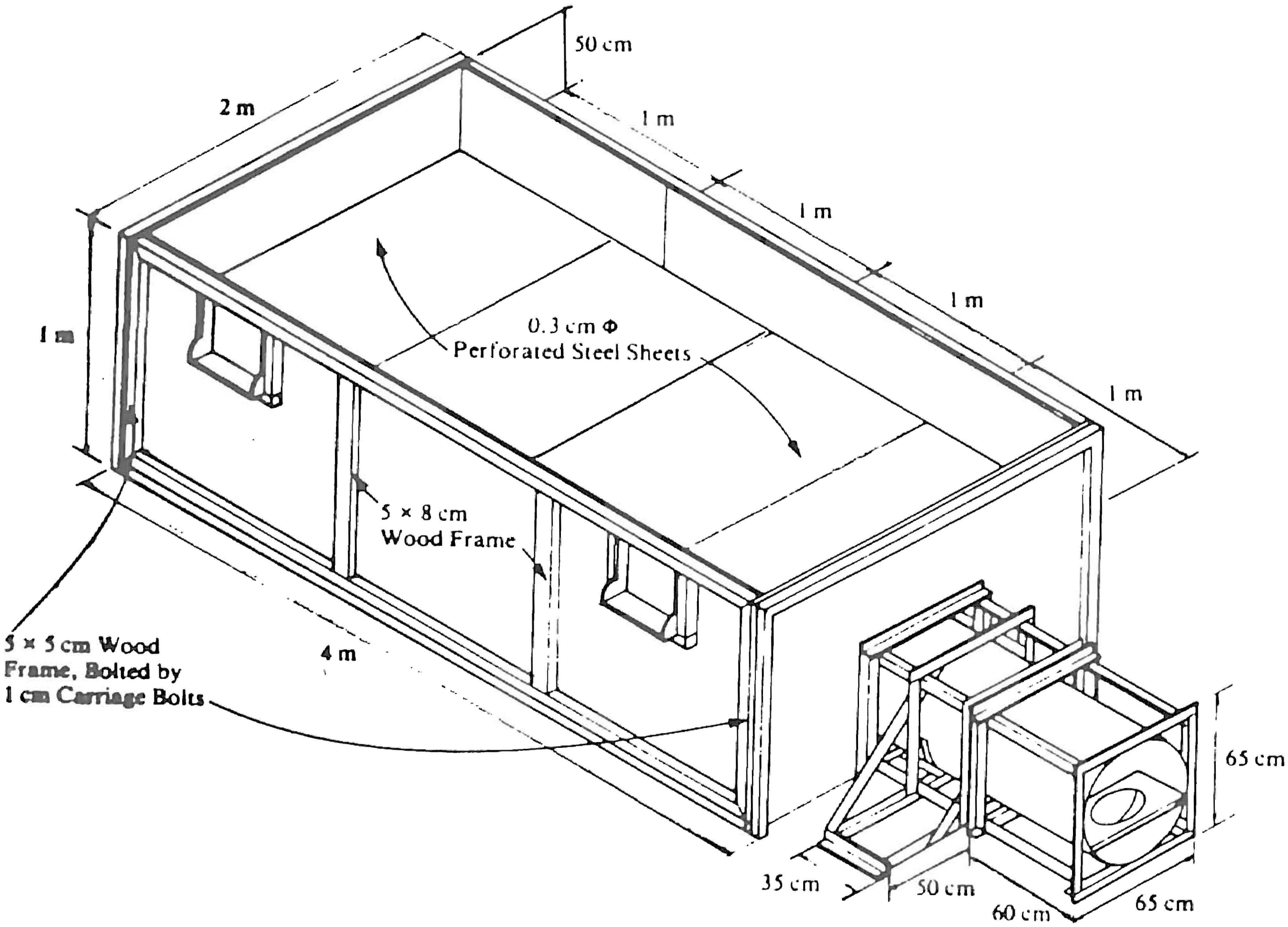

FIGURE 16 Isometric view of a flat-bed grain dryer developed by the University of the Philippines at Los Baños.

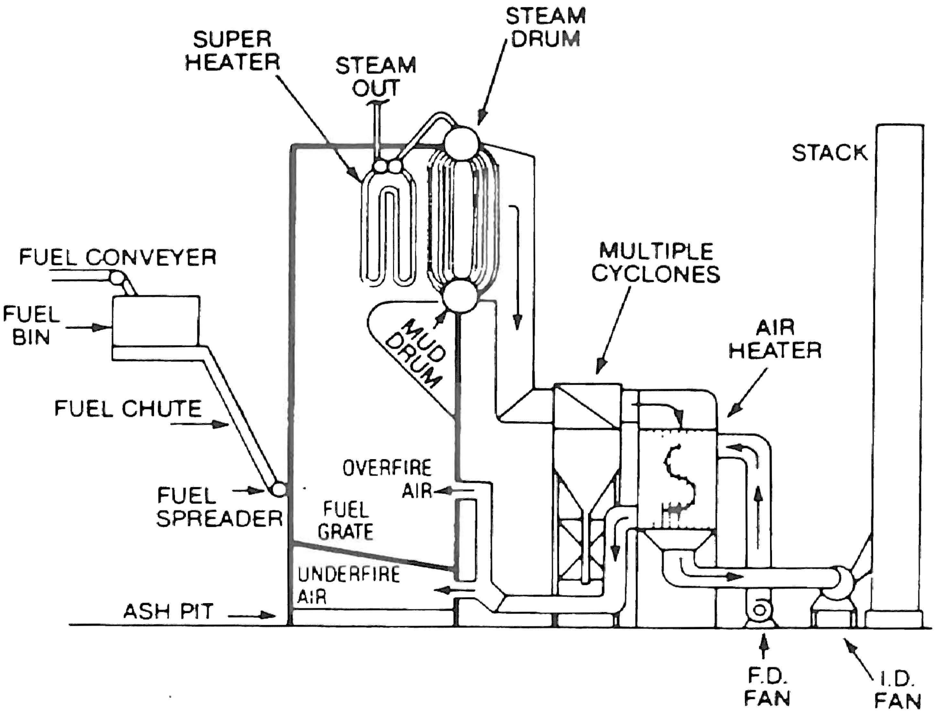

FIG. 17 The spreader-stoker system including steam drum, superheater, air pollution control equipment, and air heater. Note, with respect to the spreader-stoker, the partial pyrolysis and combustion of fuel above the grate, with final solid-fuel reactions occurring on the grate. Note also the ability to separate gas phase reactions from gas-solid reactions by placement of the overfire air port, and by distrubution of the air (from Junge, 1975).

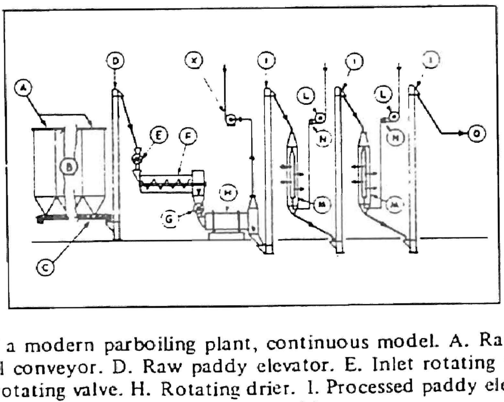

Figure 18 Layout of a modern parboiling plant, continuous model. A. Raw paddy. B. Soaking tanks. C. Horizontal conveyor. D. Raw paddy elevator. E. Inlet rotating valve. F. Continuous steamer. G. Outlet rotating valve. H. Rotating drier. I. Processed paddy elevators. K. Aspirator. L. Blower. M. Dryers. N. Air heater. O. Processed paddy.

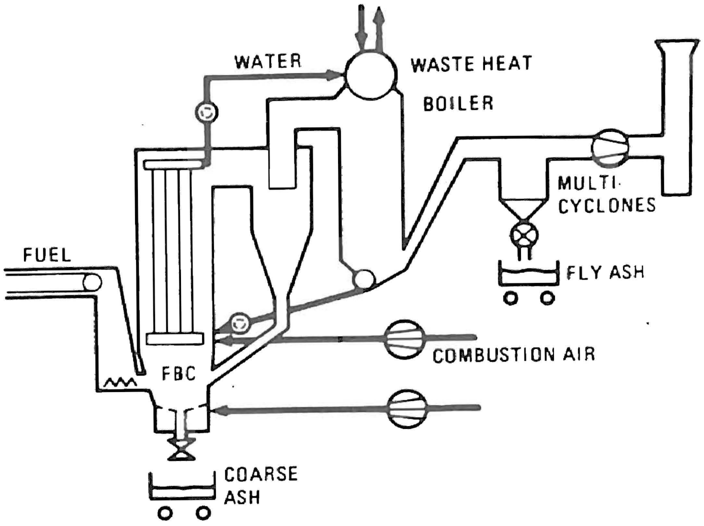

Fig 19 Circulating bed boiler system

[*Energy World*]

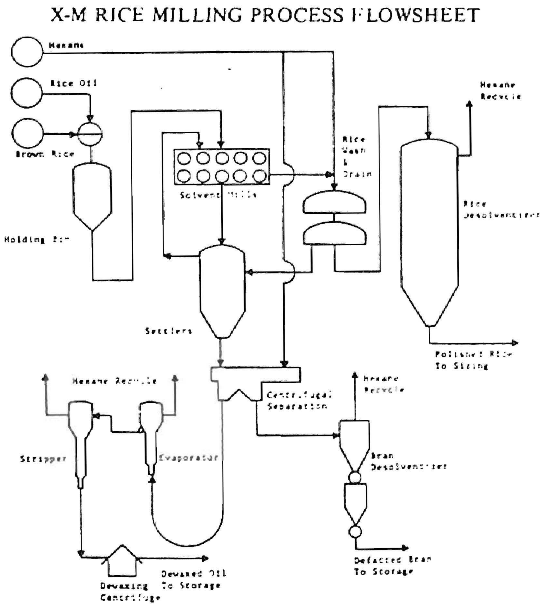

Fig 20 Simplified flow-sheet of X-M process.

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APPENDICES

APPENDIX A

APPENDIX A-1. ULTIMATE ANALYSIS OF SELECTED FUELS

Fuel material	Ultimate Analysis (dry wt basis)						
	C	H	O	N	S	Ash	Btu/ lb
Utah coal	77.9	6.0	9.9	1.5	0.6	4.1	14,170
Pittsburgh coal #1	75.5	5.0	4.9	1.2	3.1	10.3	13,650
Pittsburgh coal #2	73.3	5.3	10.2	0.7	2.8	7.6	13,097
Wyoming coal	70.0	4.3	20.2	0.7	1.0	13.8	14,410
Douglas fir bark	56.2	5.9	36.7	0.0	0.0	1.2	9,500
Wood	52.0	6.3	40.5	0.1	0.0	1.0	9,000
Pine bark	52.3	5.8	38.8	0.2	0.0	2.9	8,780
Bagasse	47.3	6.1	35.3	0.0	0.0	11.3	9,140
Raw sewage	45.5	6.8	25.8	2.4	0.5	19.0	7,080
Bovine waste	42.7	5.5	31.3	2.4	0.3	17.8	7,380
Rice hulls	38.5	5.7	39.8	0.5	0.0	15.5	6,610
Rice straw	39.2	5.1	35.8	0.6	0.1	19.2	6,540
MSW	33.9	4.6	22.4	0.7	0.4	38.0	5,645
Paper mill sludge	30.9	7.2	51.2	0.5	0.2	10.2	5,350
Sewage sludge	14.2	2.1	10.5	1.1	0.7	71.4	2,040

APPENDIX A-2. CONDUCTIVITY OF SELECTED MATERIALS

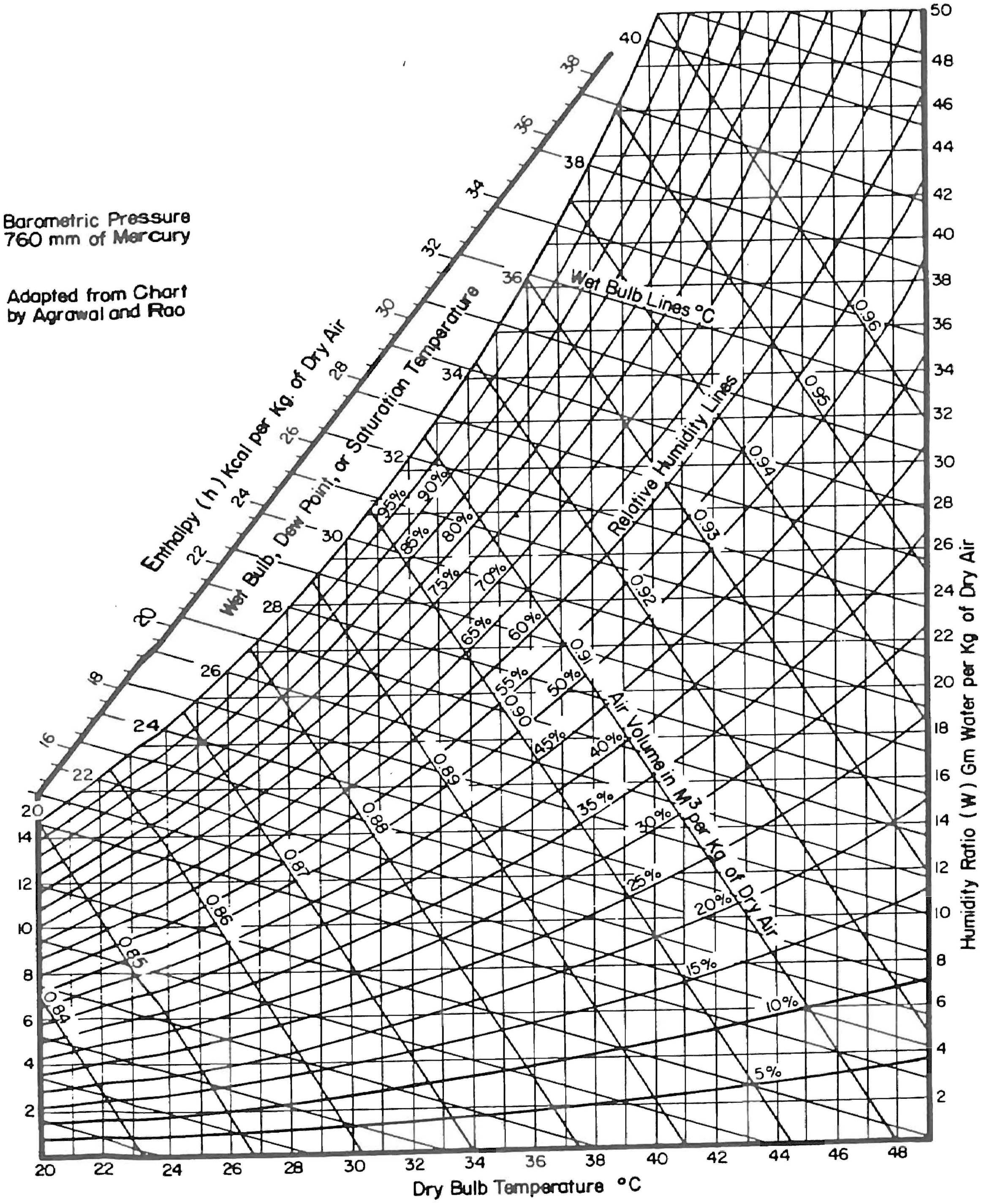
Thermal conductivities[a]

Thickness in.	k	Material	Treatment or Condition	k
Unground Hulls		Asbestos	Shredded	0.2844
1	0.2486	Rice hulls	Ground	.2517
2	.3288	Rice hulls	Whole	.2486
3	.4184	Mineral wool		.2116
4	.5308	Cork	Granulated	.2000
5	.5993	Rice hulls	20% H_3PO_4	.2391
Ground Hulls		Rice hulls	20% $(NH_4)H_2PO_4$	.2377
1	.2517	Rice hulls	20% of 60:40 solution of boric acid:borax	0.2271
2	0.3590			

[a] From Fieger et al. (59).

APPENDIX B

PSYCHROMETRIC CHART



APPENDIX C

DETERMINATION OF FORMULA FOR CAPITALIZATION

Prove that (A/P i, infinity) = i.

By definition;

$$(A/P\ i,\ N) = \{\ i\ (1+i)^{n}\ /\ [(1+i)^{n}\ -1]\}\qquad [1]$$

and,

$$(P/A\ i,\ N) = 1/\ (A/P\ i, N)\qquad [2]$$

If N is very large we can use limit conditions in equation 2:

$$(P/A\ i,\ inf) = \lim_{N\text{--->}infinity} \{[1+i]^{n}\ -1]\ /\ [\ i\ (1+i)PTnPT]\}\qquad [3]$$

or

$$= \lim_{N\text{--->}inf.} \{(1+i)^{n}/[i(1+i)^{n}\ ]\} - \lim_{N\text{--->}inf.} \{1/[i(1+i)^{n}\ ]\}$$

Thus, $(P/A\ i,\ inf) = 1/i.$ [4]

from equations 2 and 4 we have:

$$(A/P\ i,\ inf) = i\qquad [5]$$

Equation 5 is to be used to capitalize cash flows of an infinite planning horizon.

APPENDIX D

SAS PROGRAMS AND OUTPUT LISTING

APPENDIX D-1

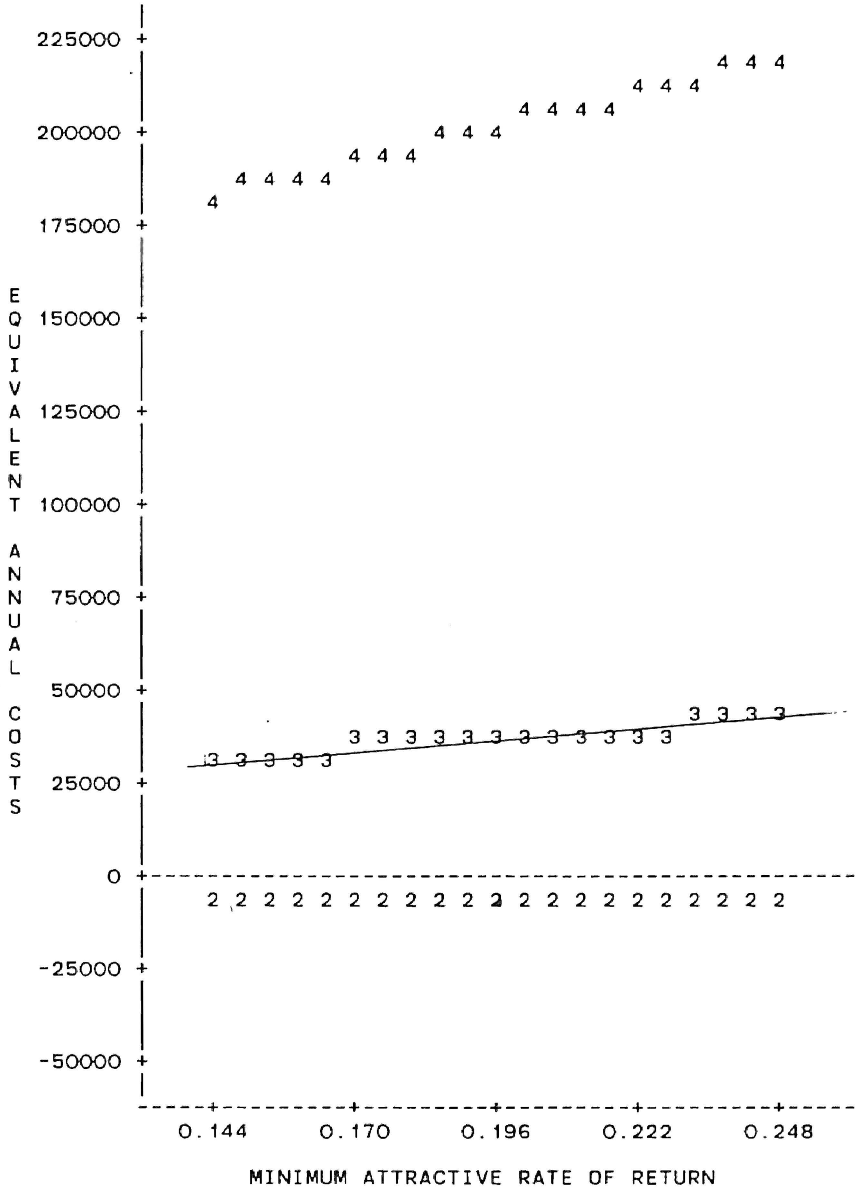
SAS PROGRAM AND OUTPUT FOR EQUIVALENT ANNUAL COSTS VERSUS INTEREST RATE (MARR)

```
1        S A S   L O G    OS SAS 82.4         VS2/MVS JOB U12099BB STEP SAS       PROC

NOTE: THE JOB U12099BB HAS BEEN RUN UNDER RELEASE 82.4 OF SAS AT OKLAHOMA STATE UNIVERSIT

NOTE: SAS OPTIONS SPECIFIED ARE:
       SORT=4

1           *                                                                         00000
2           *                                                                         00000
3           EQUIVALENT ANNUAL COSTS                                                   00000
4           *                                                                         000001
5           *;                                                                        000001
6           TITLE1 RICE-HULLS ENERGY PROJECTS;                                        000001
7           TITLE2 SENSITIVITY ANALYSIS;                                              000001
8           TITLE3 EQUIVALENT ANNUAL COSTS;                                           000001
9           DATA RICE1;                                                               000001
10          DROP I1-I9  NN  T;                                                        000001
11          ARRAY K(J) I1-I3;                                                         000001
12          ARRAY O(J) I4-I6;                                                         000001
13          ARRAY S(J) I7-I9;                                                         000001
14               INPUT  I1-I9;                                                        00000
15            P=.04;  Q=.04;                                                          00000
16          DO N =   1, 3, 5;                                                         00000
17          DO F = .8 TO 1.4 BY 0.2; *INITIAL COSTS (K) MULT FACTOR;                  00000
18          DO J = 1 TO 3 BY 1;                                                       00000
19          DO COC = .10 TO .20 BY .005;                                              00000
20            I=COC + (P*COC) + P;  *MARR = F(INFLATION, COST OF CAPITAL);            00000
21             T=0.0;                                                                 00000
22             DO NN=1 TO N BY 1;                                                     00000
23                T=T+ ( -O*((1+P)**NN) + S*((1+Q)**NN)) * ((1+I)**-NN);              00000
24             END;                                                                   00000
25             NPV = T - K*F; *NET PRESENT VALUE;                                     00000
26             EAC=(-NPV)*(  I*((1+I)**N) / (((1+I)**N)-1)  );                        00000
27             PRONUM=J+1; *LABELING VARIABLE;                                        00000
28           OUTPUT;                                                                  00000
29            END; END;  END; END;                                                    00000
30          LABEL  J=ALTERNATIVE                                                      00000
31                 N=PLANNING HORIZON                                                 00000
32                 I=MINIMUM ATTRACTIVE RATE OF RETURN                                00000
33                 P=ESCALATION INDEX-COSTS                                           00000
34                 Q=ESCALATION INDEX-SAVINGS                                         00000
35                 EAC=EQUIVALENT ANNUAL COSTS                                        00000
36                 F=INITIAL COSTS MODIFIER;                                          00000
37          CARDS;                                                                    00000

NOTE: DATA SET WORK.RICE1 HAS 756 OBSERVATIONS AND 10 VARIABLES. 226 OBS/TRK.
NOTE: THE DATA STATEMENT USED 0.27 SECONDS AND 76K.

39          ;                                                                         00000
40          *END OF CREATION OF VALUES OF EAC;                                        00000
41          PROC PLOT  DATA=RICE1; BY N F;                                            00000
42               PLOT EAC*I=PRONUM / HPOS=50  VREF=0.0;                               00000

NOTE: THE PROCEDURE PLOT USED 0.48 SECONDS AND 122K AND PRINTED PAGES 1 TO 12.
NOTE: SAS USED 122K MEMORY.

NOTE: SAS INSTITUTE INC.
      SAS CIRCLE
      PO BOX 8000
      CARY, N.C.  27511-8000
```

```
                 RICE-HULLS ENERGY PROJECTS                    14:01 SATURDAY, JUNE
                    SENSITIVITY ANALYSIS
                  EQUIVALENT ANNUAL COSTS
      PLANNING HORIZON=1   INITIAL COSTS MODIFIER=0.8

             PLOT OF EAC*I    SYMBOL IS VALUE OF PRONUM

         |
  130000 +                                          4 4
         |                                      4 4
         |                                  4 4
  120000 +                              4 4
         |                        4 4 4
         |                    4 4
  110000 +                4 4
         |            4 4
         |      4 4 4
  100000 +    4
         |
E        |
Q  90000 +
U        |
I        |
V  80000 +
A        |
L        |
E  70000 +
N        |
T        |
   60000 +
A        |
N        |
N  50000 +
U        |
A        |
L  40000 +
         |
C        |
O  30000 +
S        |
T        |
S  20000 +
         |                                  3 3 3 3 3 3
         |                  3 3 3 3 3 3 3 3
   10000 +    3 3 3 3 3 3 3
         |
         |
       0 +--------------------------------------------------
         |
         |
  -10000 +    2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
         |
         |
  -20000 +
         -----+---------+---------+---------+---------+-----
            0.144     0.170     0.196     0.222     0.248

                 MINIMUM ATTRACTIVE RATE OF RETURN
```

RICE-HULLS ENERGY PROJECTS 14:01 SATURDAY, JUNE
SENSITIVITY ANALYSIS
EQUIVALENT ANNUAL COSTS
PLANNING HORIZON=1 INITIAL COSTS MODIFIER=1

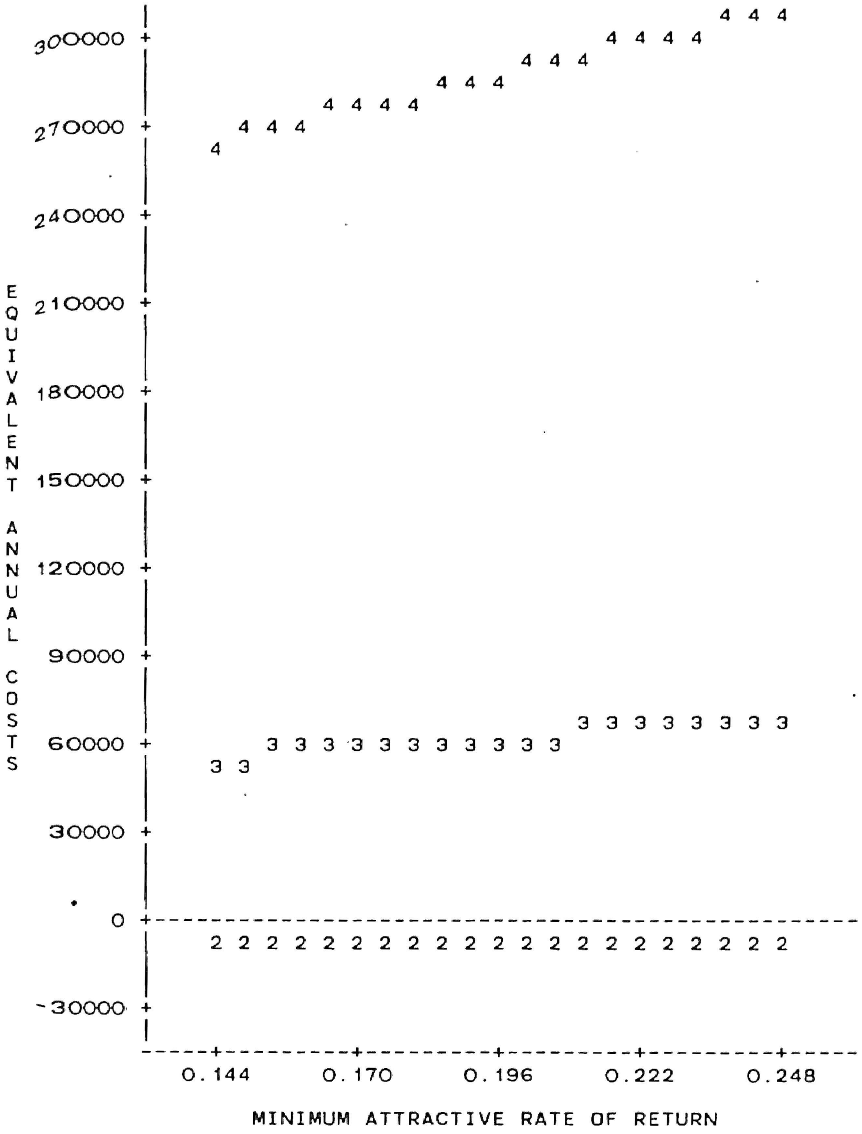
PLOT OF EAC*I SYMBOL IS VALUE OF PRONUM



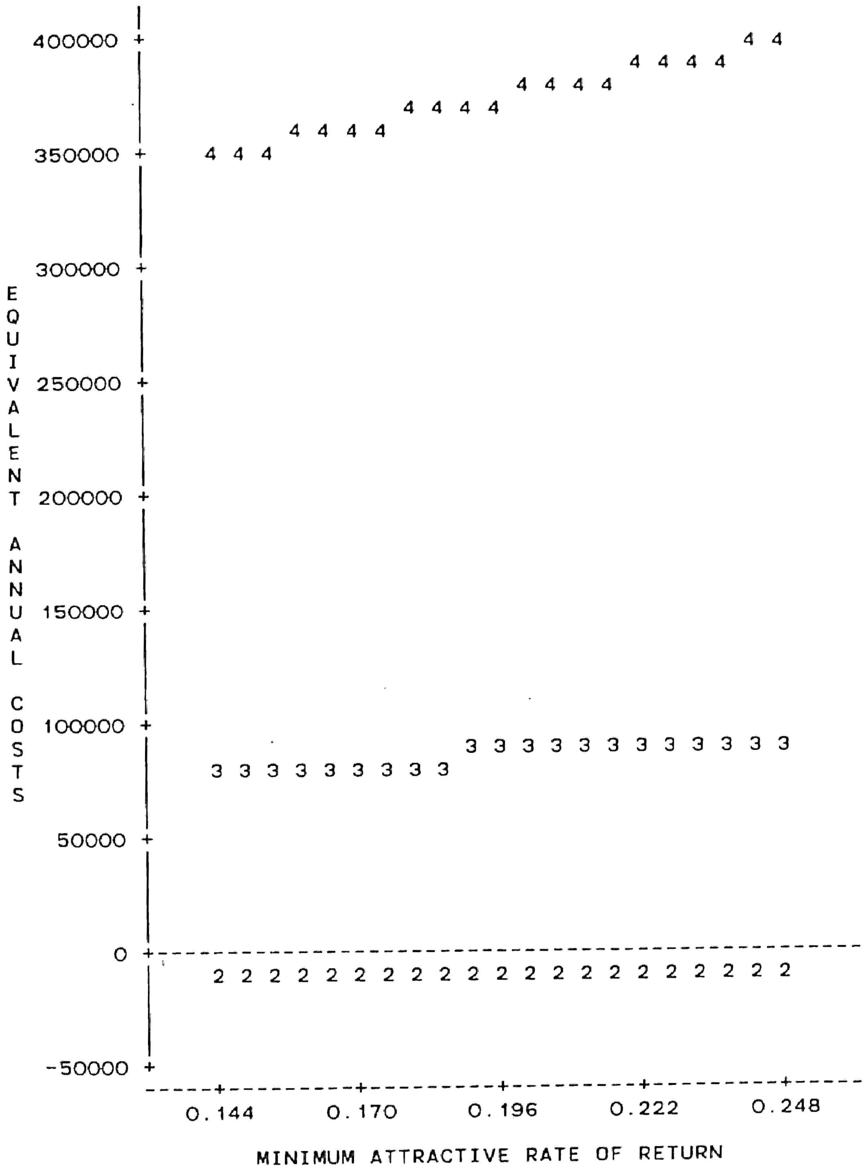
RICE-HULLS ENERGY PROJECTS
SENSITIVITY ANALYSIS
EQUIVALENT ANNUAL COSTS
PLANNING HORIZON=1   INITIAL COSTS MODIFIER=1.2

14:01 SATURDAY, JUN

PLOT OF EAC*I   SYMBOL IS VALUE OF PRONUM



```
                RICE-HULLS ENERGY PROJECTS                    14:01 SATURDAY, JUNE
                   SENSITIVITY ANALYSIS
                 EQUIVALENT ANNUAL COSTS
     PLANNING HORIZON=1    INITIAL COSTS MODIFIER=1.4

            PLOT OF EAC*I    SYMBOL IS VALUE OF PRONUM
```

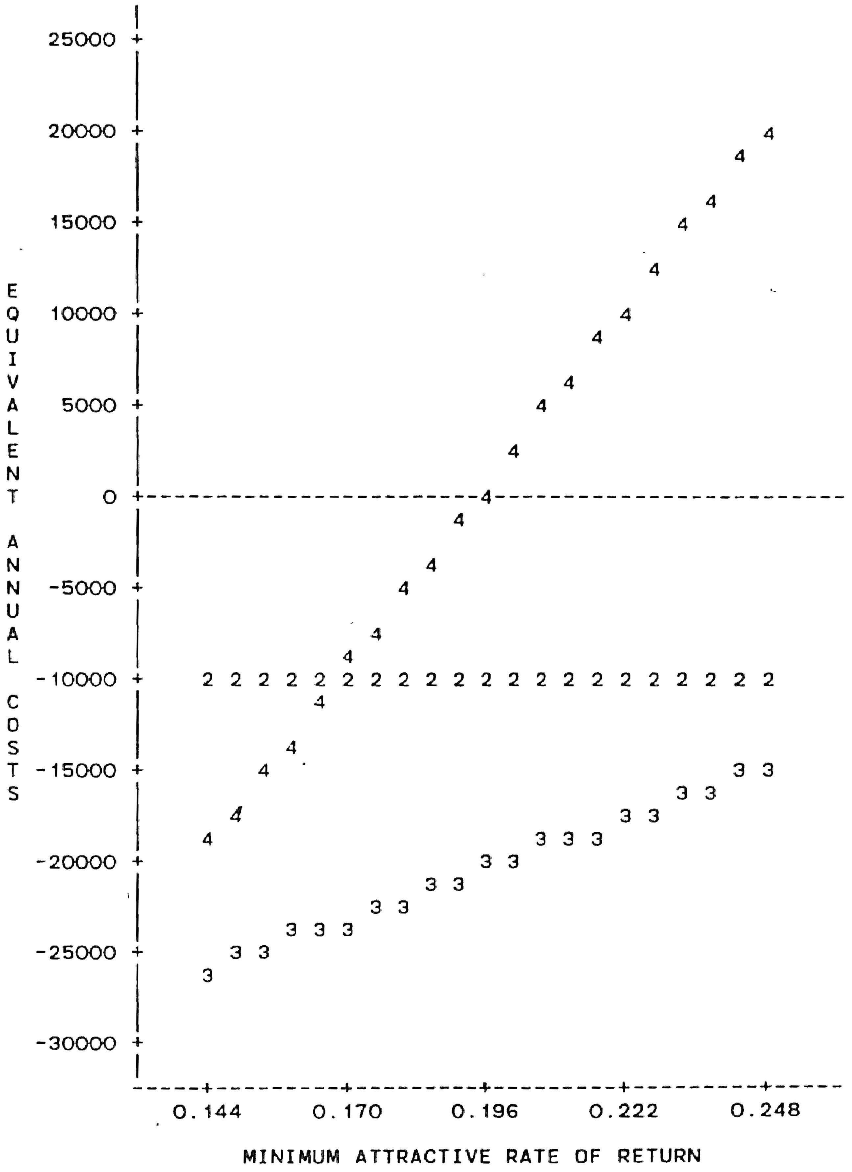


```
                          RICE-HULLS ENERGY PROJECTS                      14:01 SATURDAY, JUNE
                             SENSITIVITY ANALYSIS
                           EQUIVALENT ANNUAL COSTS
                 PLANNING HORIZON=3   INITIAL COSTS MODIFIER=0.8

                        PLOT OF EAC*I    SYMBOL IS VALUE OF PRONUM

            |--------------------------------------------------
     -10000 +    2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
            |
            |
            |
     -20000 +
            |
            |
            |
     -30000 +
            |
            |
E           |
Q    -40000 +
U           |
I           |                                            3
V           |                            3 3 3 3 3 3 3 3
A    -50000 +              3 3 3 3 3 3 3
L           |    3 3 3 3 3
E           |
N           |
T    -60000 +
            |
A           |
N           |
N    -70000 +
U           |
A           |
L           |
     -80000 +
C           |
O           |
S           |
T    -90000 +                                          4 4
S           |                                      4 4
            |                                  4 4
            |                              4 4
    -100000 +                          4 4
            |                    4 4 4
            |                4 4
            |            4 4
    -110000 +        4 4
            |    4 4
            |
            |
    -120000 +
            |
            -----+---------+---------+---------+---------+-----
               0.144     0.170     0.196     0.222     0.248

                      MINIMUM ATTRACTIVE RATE OF RETURN
```

```
                   RICE-HULLS ENERGY PROJECTS                    14:01 SATURDAY, JUNE
                      SENSITIVITY ANALYSIS
                    EQUIVALENT ANNUAL COSTS
         PLANNING HORIZON=3   INITIAL COSTS MODIFIER=1

               PLOT OF EAC*I    SYMBOL IS VALUE OF PRONUM

           |--------------------------------------------------
    -10000 +    2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
           |
           |
           |
           |
    -20000 +
           |
           |
           |
           |
    -30000 +
E          |
Q          |
U          |                                      3 3 3 3
I          |                            3 3 3 3 3
V   -40000 +                  3 3 3 3 3
A          |        3 3 3 3 3
L          |    3 3
E          |
N          |
T   -50000 +
           |
A          |                                          4 4
N          |                                        4
N          |                                    4 4
U   -60000 +                                  4
A          |                                4
L          |                            4 4
           |                          4
C          |                      4 4
O   -70000 +                    4
S          |                  4
T          |              4 4
S          |            4
           |        4 4
    -80000 +      4
           |    4
           |
           |
           |
    -90000 +
           |
           |
           |
           |
   -100000 +
           -----+---------+---------+---------+---------+-----
              0.144     0.170     0.196     0.222     0.248

                   MINIMUM ATTRACTIVE RATE OF RETURN
```

```
                         RICE-HULLS ENERGY PROJECTS                        14:01 SATURDAY, JUNI
                            SENSITIVITY ANALYSIS
                          EQUIVALENT ANNUAL COSTS
                 PLANNING HORIZON=3   INITIAL COSTS MODIFIER=1.2

                      PLOT OF EAC*I    SYMBOL IS VALUE OF PRONUM

         |---------------------------------------------------
   -5000 +
         |
         |
         |
         |
  -10000 +    2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
         |
         |
         |
         |
  -15000 +
E        |                                            4
Q        |
U        |                                          4
I        |
V -20000 +                                        4
A        |
L        |                                      4
E        |                                    4
N        |
T -25000 +                                  4         3
         |                                        3 3
A        |                                4   3 3
N        |                              4 3 3
N        |                            3 3
U -30000 +                        3 3 4
A        |                  3 3 3
L        |              3 3         4
         |          3 3           4
C        |      3 3
O -35000 +    3                 4
S        |
T        |                    4
S        |
         |                  4
  -40000 +                4
         |
         |              4
         |
         |            4
  -45000 +          4
         |
         |        4
         |
         |      4
  -50000 +    4
         -----+---------+---------+---------+---------+-----
            0.144     0.170     0.196     0.222     0.248

                      MINIMUM ATTRACTIVE RATE OF RETURN
```

```
                    RICE-HULLS ENERGY PROJECTS                    14:01 SATURDAY, JUN
                       SENSITIVITY ANALYSIS
                     EQUIVALENT ANNUAL COSTS
          PLANNING HORIZON=3    INITIAL COSTS MODIFIER=1.4

              PLOT OF EAC*I    SYMBOL IS VALUE OF PRONUM
```



```
                 RICE-HULLS ENERGY PROJECTS                     14:01 SATURDAY, JUN
                    SENSITIVITY ANALYSIS
                  EQUIVALENT ANNUAL COSTS
      PLANNING HORIZON=5   INITIAL COSTS MODIFIER=0.8

             PLOT OF EAC*I    SYMBOL IS VALUE OF PRONUM

          |--------------------------------------------------
   -10000 +    2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
          |
          |
   -20000 +
          |
          |
   -30000 +
          |
          |
   -40000 +
          |
E         |
Q  -50000 +
U         |
I         |
V  -60000 +                                    3 3 3 3 3
A         |                3 3 3 3 3 3 3 3 3 3
L         |    3 3 3 3 3 3
E  -70000 +
N         |
T         |
   -80000 +
A         |
N         |
N  -90000 +
U         |
A         |
L -100000 +
          |
C         |
O -110000 +
S         |
T         |
S -120000 +
          |
          |
  -130000 +
          |
          |                                            4
  -140000 +                                      4 4 4
          |                                4 4 4
          |                          4 4 4
  -150000 +                    4 4 4
          |                4 4
          |          4 4 4
  -160000 +    4 4 4
          -----+---------+---------+---------+---------+-----
             0.144     0.170     0.196     0.222     0.248

                  MINIMUM ATTRACTIVE RATE OF RETURN
```

```
                 RICE-HULLS ENERGY PROJECTS                     14:01 SATURDAY, JUN
                    SENSITIVITY ANALYSIS
                  EQUIVALENT ANNUAL COSTS
       PLANNING HORIZON=5   INITIAL COSTS MODIFIER=1

             PLOT OF EAC*I    SYMBOL IS VALUE OF PRONUM

          |
        0 +--------------------------------------------------
          |
          |
   -10000 +    2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
          |
          |
   -20000 +
          |
          |
   -30000 +
          |
E         |
Q  -40000 +
U         |
I         |
V  -50000 +
A         |                                  3 3 3 3 3 3
L         |                  3 3 3 3 3 3 3 3
E  -60000 +    3 3 3 3 3 3 3
N         |
T         |
   -70000 +
A         |
N         |
N  -80000 +
U         |
A         |
L  -90000 +
          |
C         |
O -100000 +
S         |
T         |
S -110000 +                                            4
          |                                        4 4
          |                                  4 4 4
  -120000 +                              4 4
          |                          4 4
          |                    4 4 4
  -130000 +                4 4
          |            4 4
          |      4 4 4
  -140000 +    4
          |
          |
  -150000 +
          -----+---------+---------+---------+---------+-----
             0.144     0.170     0.196     0.222     0.248

                 MINIMUM ATTRACTIVE RATE OF RETURN
```

```
                    RICE-HULLS ENERGY PROJECTS                    14:01 SATURDAY, JU
                       SENSITIVITY ANALYSIS
                     EQUIVALENT ANNUAL COSTS
           PLANNING HORIZON=5   INITIAL COSTS MODIFIER=1.2

               PLOT OF EAC*I    SYMBOL IS VALUE OF PRONUM

            |-----------------------------------------------------
     -10000 +    2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
            |
            |
            |
     -20000 +
            |
            |
            |
     -30000 +
            |
            |
E           |
Q    -40000 +
U           |
I           |                                        3 3 3
V           |                              3 3 3 3 3
A    -50000 +                    3 3 3 3 3
L           |          3 3 3 3 3
E           |    3 3 3
N           |
T    -60000 +
            |
A           |
N           |
N    -70000 +
U           |
A           |
L           |
     -80000 +
C           |
O           |                                          4 4
S           |                                        4
T    -90000 +                                    4 4
S           |                                  4
            |                                4
            |                            4 4
    -100000 +                          4
            |                      4 4
            |                    4
            |                4 4
    -110000 +              4
            |          4 4
            |        4
            |    4 4
    -120000 +
            |
            -----+---------+---------+---------+---------+-----
               0.144     0.170     0.196     0.222     0.248

                    MINIMUM ATTRACTIVE RATE OF RETURN
```

```
                   RICE-HULLS ENERGY PROJECTS                    14:01 SATURDAY, JUNE
                      SENSITIVITY ANALYSIS
                    EQUIVALENT ANNUAL COSTS
        PLANNING HORIZON=5   INITIAL COSTS MODIFIER=1.4

               PLOT OF EAC*I    SYMBOL IS VALUE OF PRONUM

           |--------------------------------------------------
    -10000 +    2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
           |
           |
           |
           |
    -20000 +
           |
           |
           |
           |
    -30000 +
E          |
Q          |
U          |
I          |                                        3 3 3
V   -40000 +                                3 3 3 3
A          |                          3 3 3
L          |                  3 3 3 3
E          |            3 3 3
N          |    3 3 3 3
T   -50000 +
           |
A          |
N          |
N          |                                            4
U   -60000 +                                          4
A          |                                        4
L          |                                      4
           |                                    4
C          |                                  4
O   -70000 +                                4
S          |                              4
T          |                            4
S          |                          4
           |                        4
    -80000 +                      4
           |                    4
           |                  4
           |                4
           |              4
    -90000 +            4
           |          4
           |        4
           |      4
           |    4
   -100000 +
           -----+---------+---------+---------+---------+-----
              0.144     0.170     0.196     0.222     0.248

                   MINIMUM ATTRACTIVE RATE OF RETURN
```

APPENDIX D-2

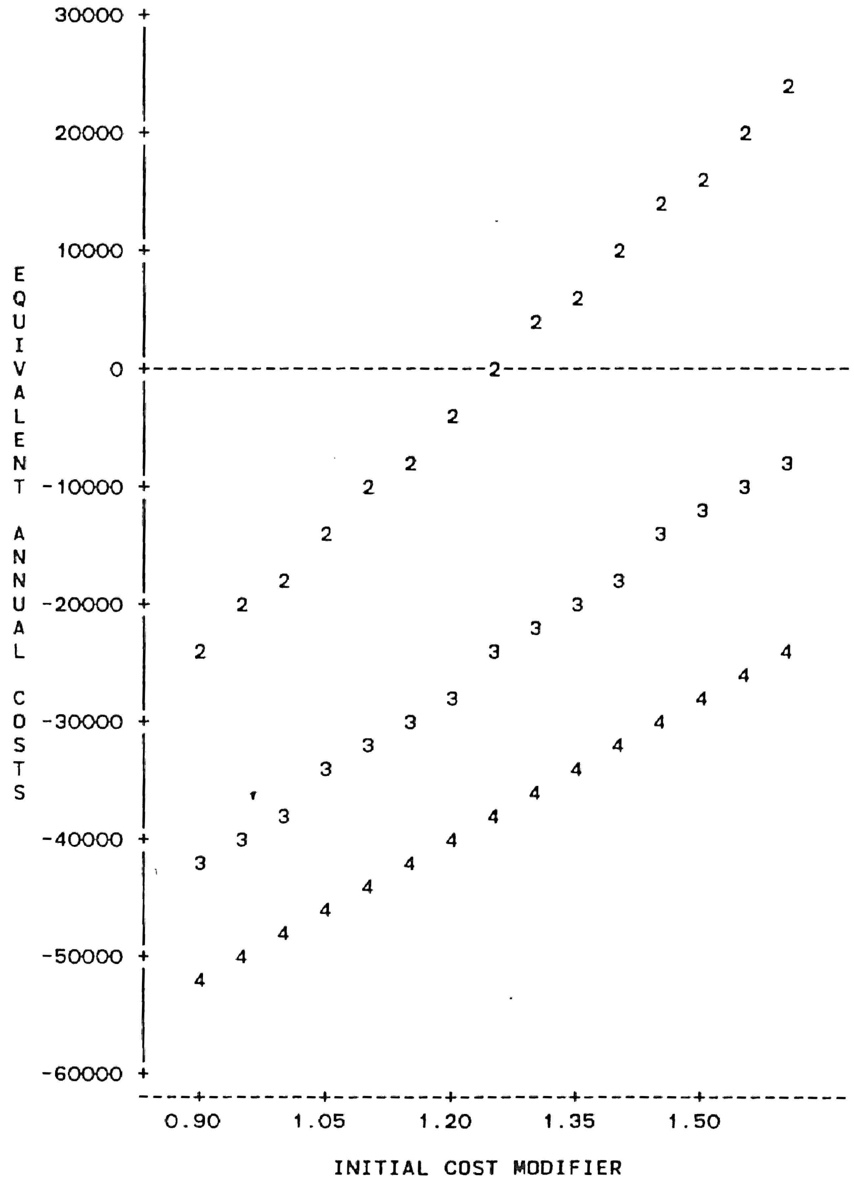
SAS PROGRAM AND OUTPUT LISTING OF EAC BY INSTALLED COST MODIFIER (F)

```
1        S A S    L O G     OS SAS 82.4          VS2/MVS JOB U12099BB STEP SAS       PROC

NOTE: THE JOB U12099BB HAS BEEN RUN UNDER RELEASE 82.4 OF SAS AT OKLAHOMA STATE UNIVERSI

NOTE: SAS OPTIONS SPECIFIED ARE:
       SORT=4

1           *                                                                     0000C
2           *                                                                     0000C
3           EQUIVALENT ANNUAL COSTS                                               0000C
4           *                                                                     0000C
5           *;                                                                    0000C
6           TITLE1 RICE-HULLS ENERGY PROJECTS;                                    0000C
7           TITLE2 SENSITIVITY ANALYSIS;                                          0000C
8           TITLE3 EQUIVALENT ANNUAL COSTS;                                       0000C
9           TITLE4 FOR 2, 3, AND 4 YEARS  (N) ;                                   0000C
10          DATA RICE1;                                                           0000C
11          DROP I1-I9  NN  T;                                                    0000C
12          ARRAY K(J) I1-I3;                                                     0000C
13          ARRAY O(J) I4-I6;                                                     0000C
14          ARRAY S(J) I7-I9;                                                     0000C
15               INPUT  I1-I9;                                                    0000C
16            P=.06;  Q=.04;                                                      0000C
17          DO J = 2 TO 3 BY 1;                                                   0000C
18          DO COC = .15, .18, .20 ; *COC=COST OF CAPITAL;                        0000C
19            I=COC + (P*COC) + P;  *MARR = F(INFLATION, COST OF CAPITAL);        0000C
20          DO F = .90 TO 1.6 BY .05;                                             0000C
21          DO N =  2, 3, 4;                                                      0000C
22             T=0.0;                                                             0000C
23             DO NN=1 TO N BY 1;                                                 0000C
24                T=T+ ( -O*((1+P)**NN) + S*((1+Q)**NN)) * ((1+I)**-NN);          0000C
25             END;                                                               0000C
26             NPV = T - K*F; *NET PRESENT VALUE;                                 0000C
27             EAC=(-NPV)*(  I*((1+I)**N) / (((1+I)**N)-1)  );                    0000C
28             PRONUM=J+1; *LABELING VARIABLE;                                    0000C
29           OUTPUT;                                                              0000C
30               END; END; END; END;                                              0000C
31          LABEL                                                                 0000C
32                N=PLANNING HORIZON                                              0000C
33                I=MINIMUM ATTRACTIVE RATE OF RETURN                             0000C
34                PRONUM=ALTERNATIVE                                              0000C
35                P=ESCALATION INDEX-COSTS                                        0000C
36                Q=ESCALATION INDEX-SAVINGS                                      0000C
37                F=INITIAL COST MODIFIER                                         0000C
38                EAC=EQUIVALENT ANNUAL COSTS;                                    0000C
39          CARDS;                                                                0000C

NOTE: DATA SET WORK.RICE1 HAS 270 OBSERVATIONS AND 10 VARIABLES. 226 OBS/TRK.
NOTE: THE DATA STATEMENT USED 0.17 SECONDS AND 76K.

41          ;                                                                     0000C
42          *END OF CREATION OF VALUES OF EAC;                                    0000C
43          PROC PLOT  DATA=RICE1; BY PRONUM I;                                   0000C
44            PLOT EAC*F=N /HPOS=50 VREF=0.0;                                     0000C

NOTE: THE PROCEDURE PLOT USED 0.25 SECONDS AND 122K AND PRINTED PAGES 1 TO 6.
NOTE: SAS USED 122K MEMORY.
```

```
2        S A S   L O G    OS SAS 82.4          VS2/MVS JOB U12099BB STEP SAS        PROC

NOTE: SAS INSTITUTE INC.
      SAS CIRCLE
      PO BOX 8000
      CARY, N.C.  27511-8000
```

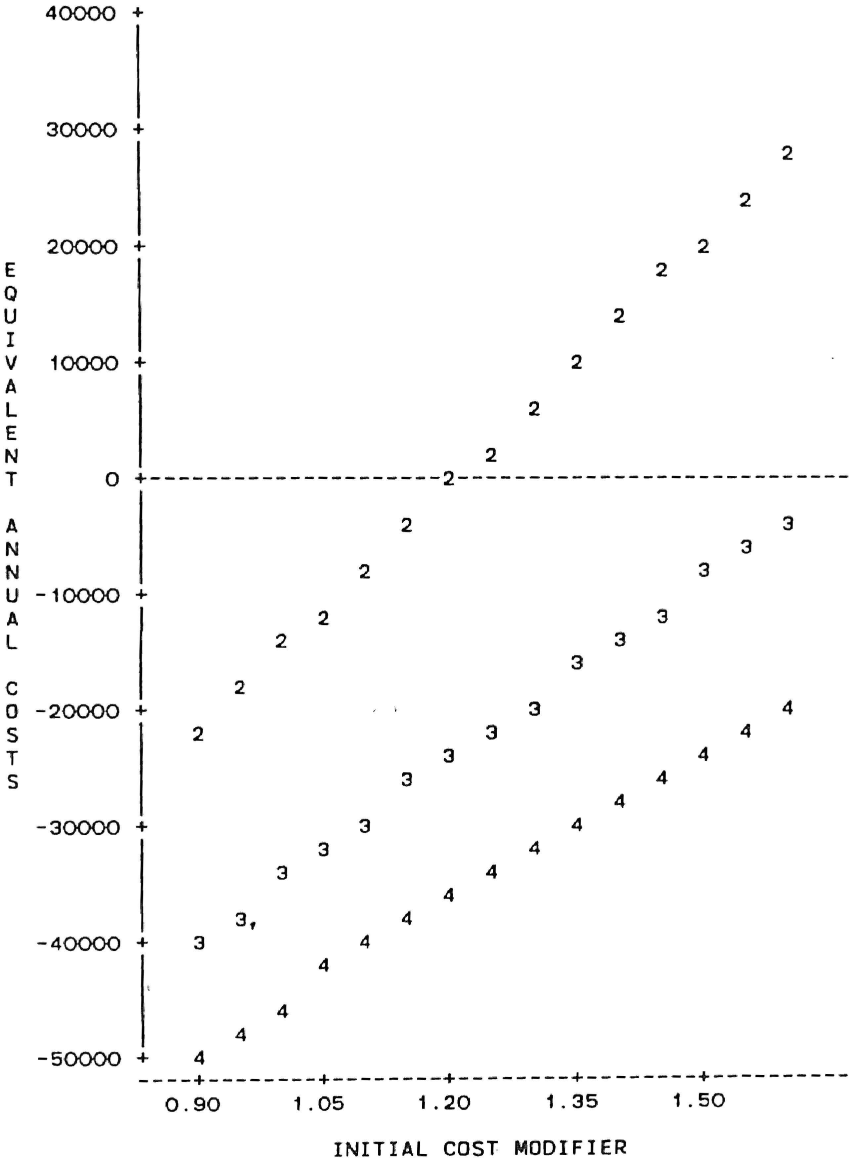
RICE-HULLS ENERGY PROJECTS 14:44 SATURDAY, JUNE
SENSITIVITY ANALYSIS
EQUIVALENT ANNUAL COSTS
FOR 2, 3, AND 4 YEARS (N)
ALTERNATIVE=3 MINIMUM ATTRACTIVE RATE OF RETURN=0.219

PLOT OF EAC*F SYMBOL IS VALUE OF N

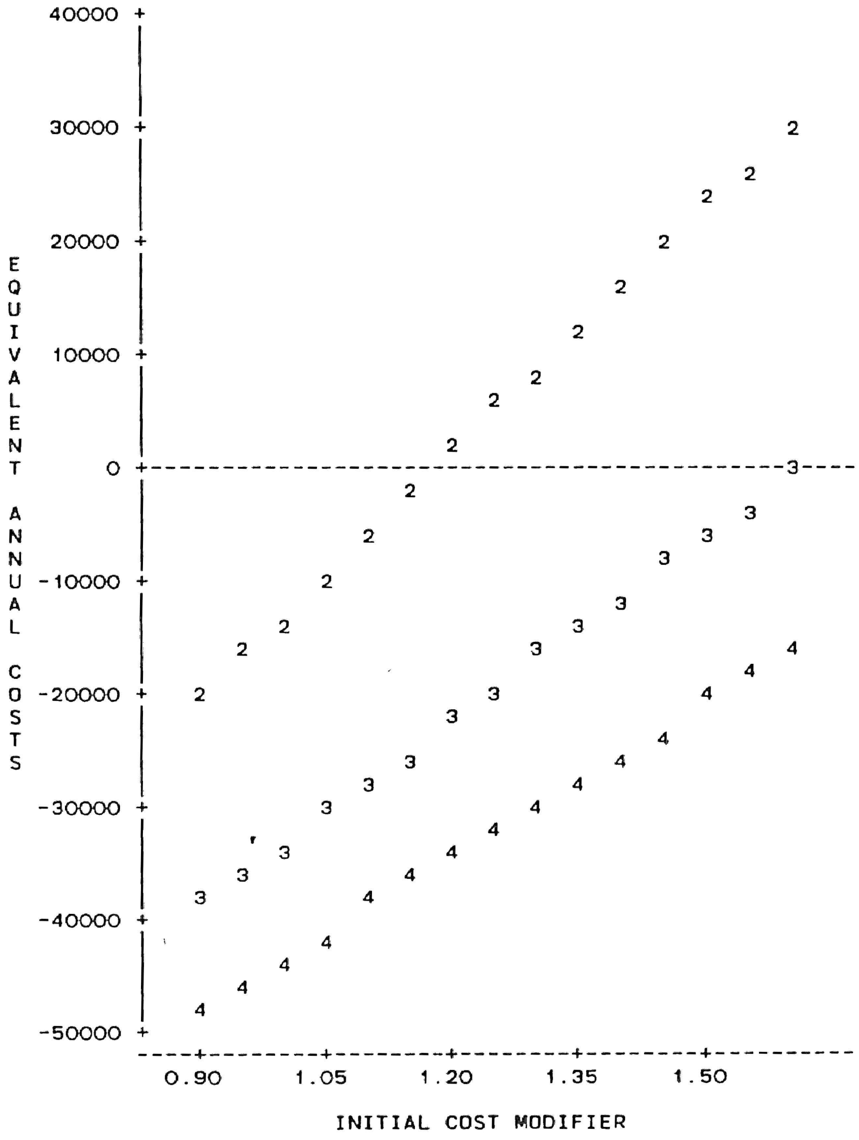


RICE-HULLS ENERGY PROJECTS
SENSITIVITY ANALYSIS
EQUIVALENT ANNUAL COSTS
FOR 2, 3, AND 4 YEARS (N)
ALTERNATIVE=3 MINIMUM ATTRACTIVE RATE OF RETURN=0.2508

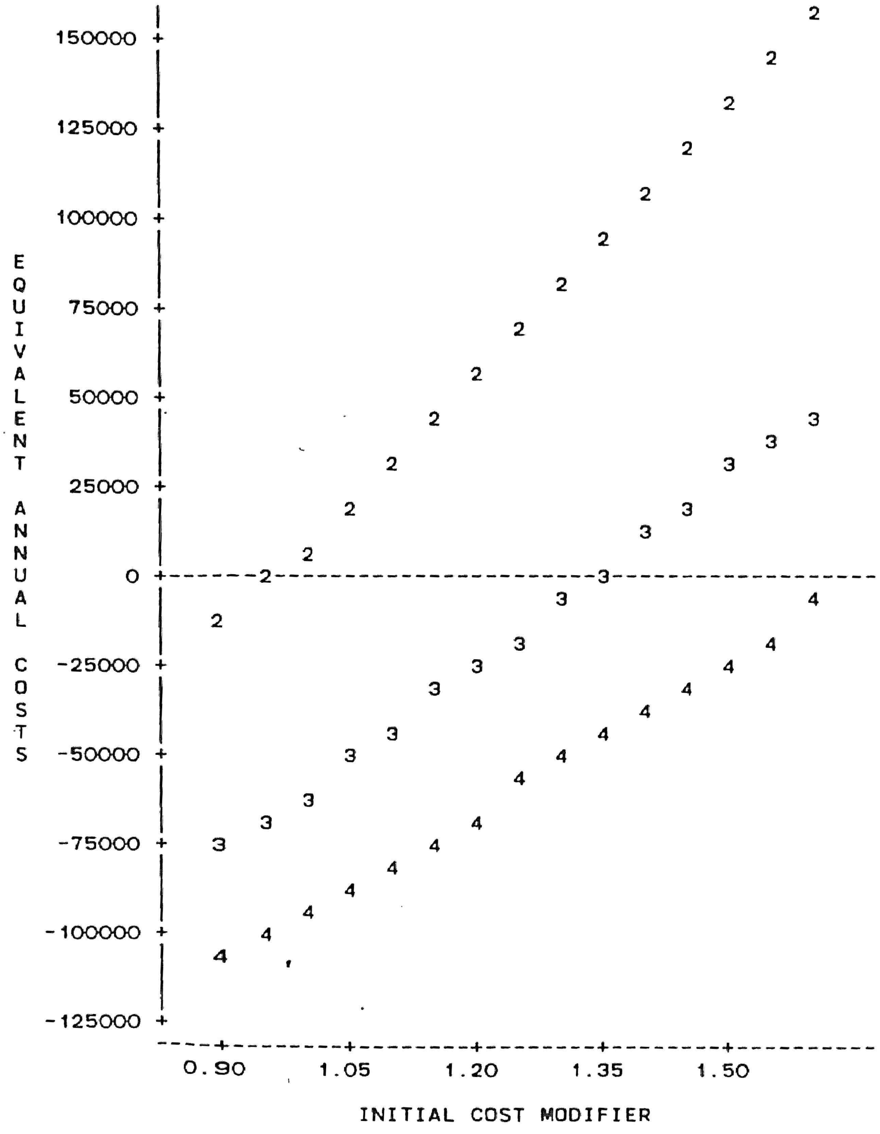
PLOT OF EAC*F SYMBOL IS VALUE OF N



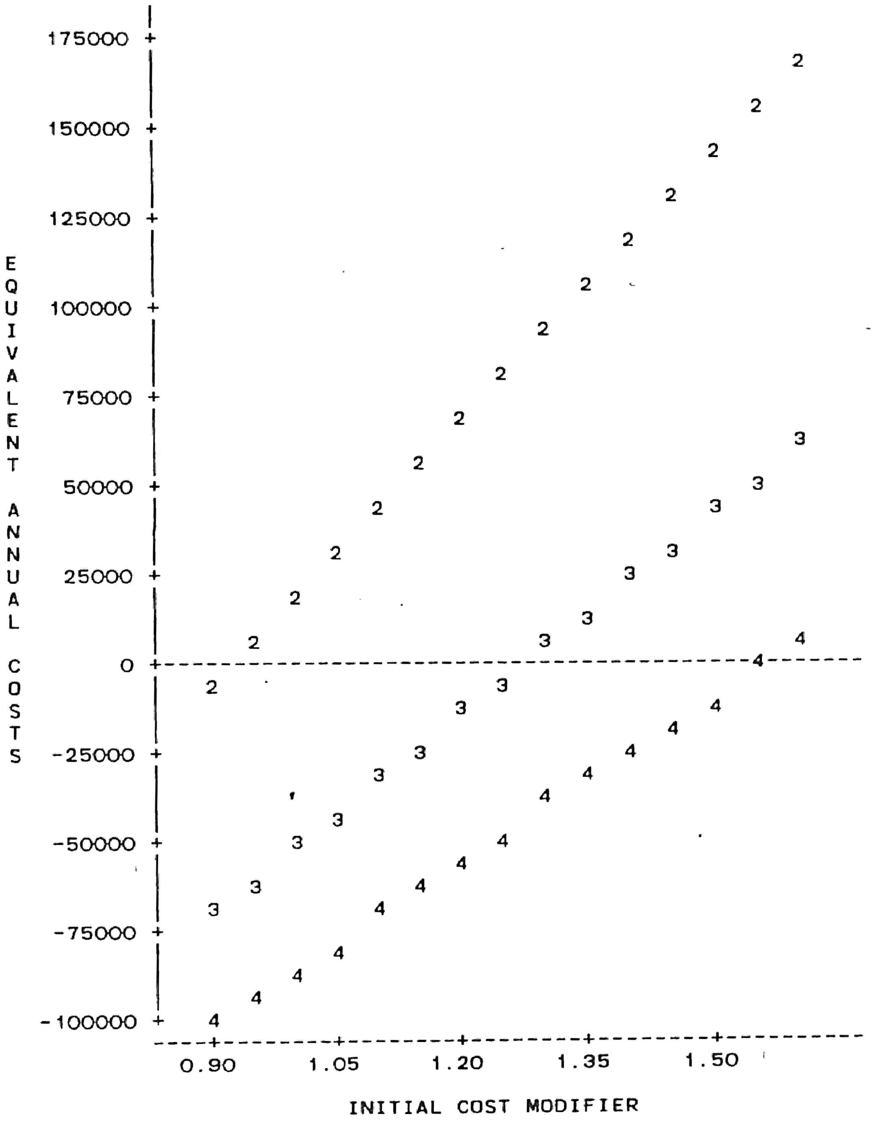
```
                    RICE-HULLS ENERGY PROJECTS                    14:44 SATURDAY, JUN
                       SENSITIVITY ANALYSIS
                     EQUIVALENT ANNUAL COSTS
                    FOR 2, 3, AND 4 YEARS  (N)
  ALTERNATIVE=3   MINIMUM ATTRACTIVE RATE OF RETURN=0.272

                PLOT OF EAC*F    SYMBOL IS VALUE OF N
```



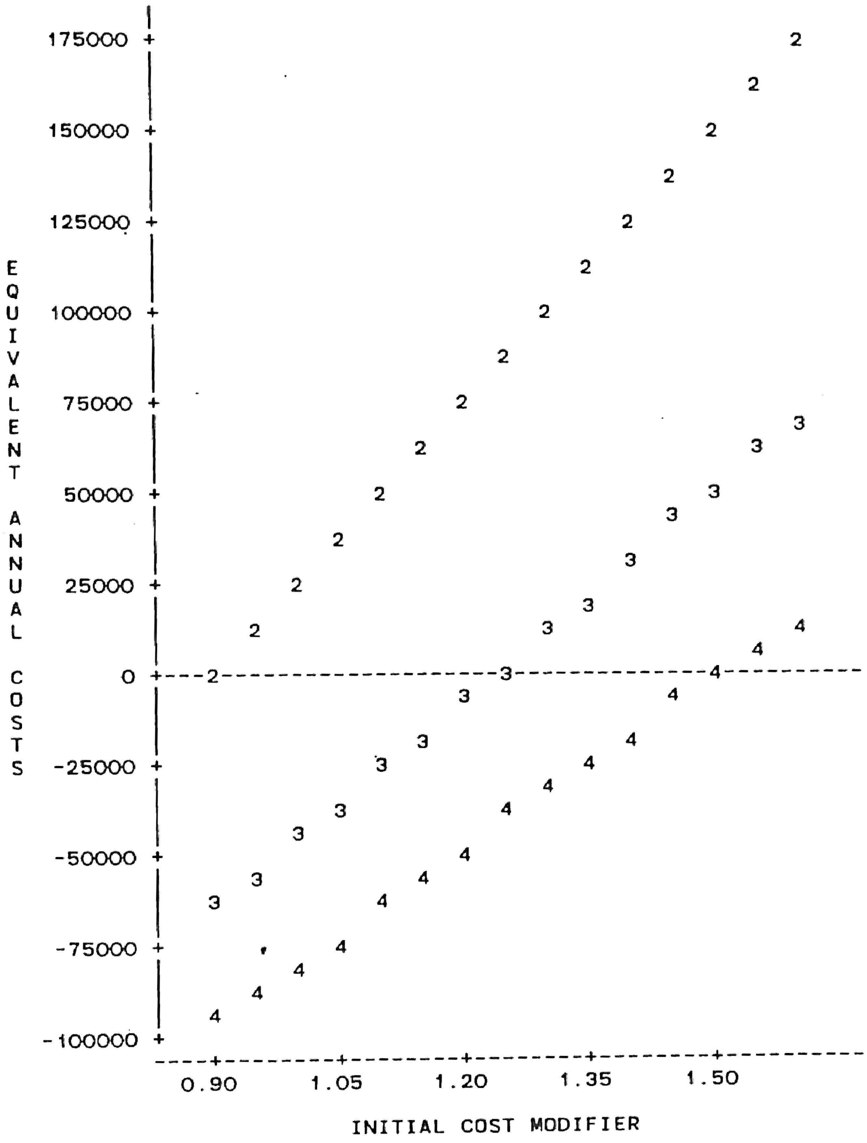
```
                 RICE-HULLS ENERGY PROJECTS                    14:44 SATURDAY, JUNE
                    SENSITIVITY ANALYSIS
                  EQUIVALENT ANNUAL COSTS
                 FOR 2, 3, AND 4 YEARS  (N)
ALTERNATIVE=4    MINIMUM ATTRACTIVE RATE OF RETURN=0.219

          PLOT OF EAC*F    SYMBOL IS VALUE OF N
```



```
                    RICE-HULLS ENERGY PROJECTS                          14:44 SATURDAY, JUNE
                       SENSITIVITY ANALYSIS
                     EQUIVALENT ANNUAL COSTS
                    FOR 2, 3, AND 4 YEARS   (N)
     ALTERNATIVE=4    MINIMUM ATTRACTIVE RATE OF RETURN=0.2508

               PLOT OF EAC*F    SYMBOL IS VALUE OF N
```



```
                    RICE-HULLS ENERGY PROJECTS                    14:44 SATURDAY, JUNE
                       SENSITIVITY ANALYSIS
                     EQUIVALENT ANNUAL COSTS
                    FOR 2, 3, AND 4 YEARS  (N)
      ALTERNATIVE=4   MINIMUM ATTRACTIVE RATE OF RETURN=0.272

                 PLOT OF EAC*F    SYMBOL IS VALUE OF N
```



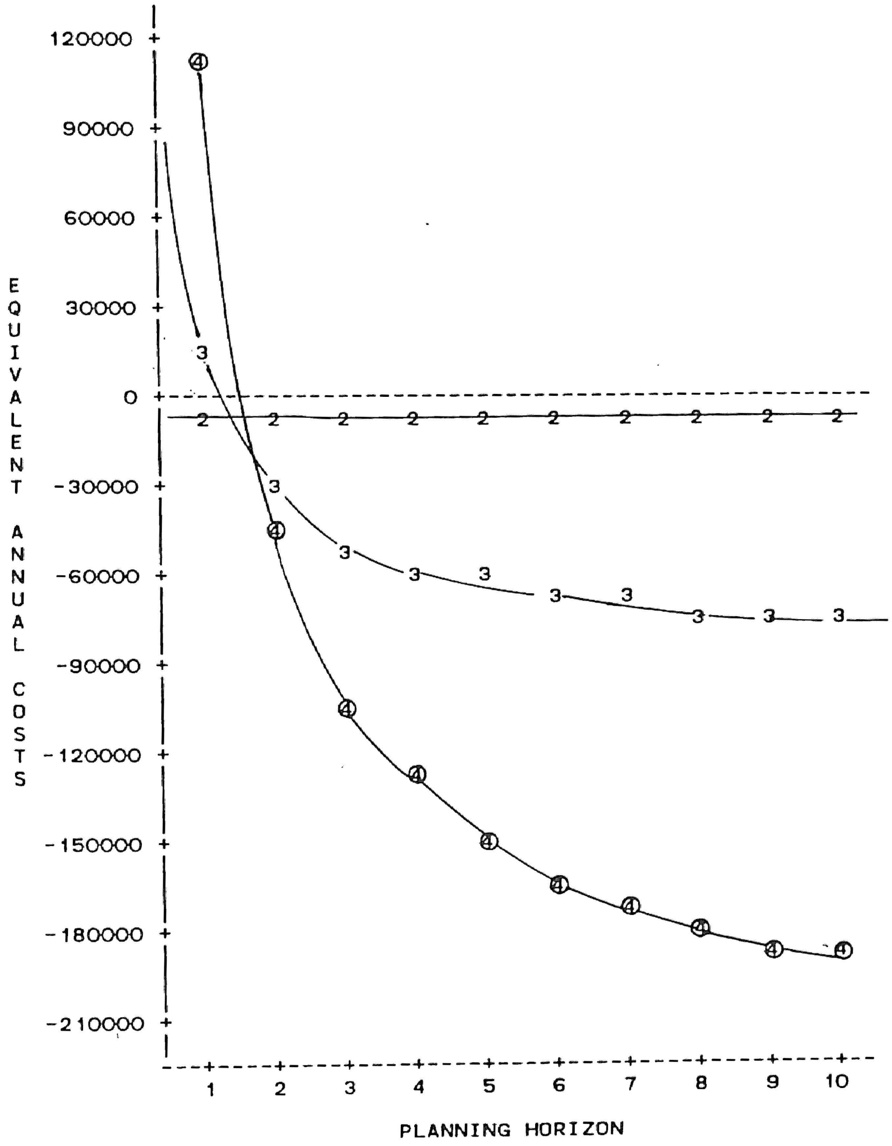
APPENDIX D-3

SAS PROGRAM AND OUTPUT LISTING OF EAC BY DIFFERENT PLANNING HORIZONS

```
1        S A S   L O G    OS SAS 82.4          VS2/MVS JOB U12099BB STEP SAS       PROC

NOTE: THE JOB U12099BB HAS BEEN RUN UNDER RELEASE 82.4 OF SAS AT OKLAHOMA STATE UNIVERSITY (

NOTE: SAS OPTIONS SPECIFIED ARE:
       SORT=4

1           *                                                                              00000070
2           *                                                                              00000080
3           EQUIVALENT ANNUAL COSTS                                                        00000090
4           *                                                                              00000100
5           *;                                                                             00000110
6           TITLE1 RICE-HULLS ENERGY PROJECTS;                                             00000120
7           TITLE2 SENSITIVITY ANALYSIS;                                                   00000130
8           TITLE3 EQUIVALENT ANNUAL COSTS;                                                00000140
9           DATA RICE1;                                                                    00000150
10          DROP I1-I9  NN  T;                                                             00000160
11          ARRAY K(J) I1-I3;                                                              00000170
12          ARRAY O(J) I4-I6;                                                              00000180
13          ARRAY S(J) I7-I9;                                                              00000190
14                INPUT  I1-I9;                                                            00000200
15            P=.06;  Q=.04;                                                               00000210
16          DO COC = .12, .15, .20; *COC=COST OF CAPITAL;                                  00000220
17            I=COC + (P*COC) + P;  *MARR = F(INFLATION, COST OF CAPITAL);                 00000230
18          DO F = .8 TO 1.4 BY 0.2; *INITIAL COSTS (K) MULT FACTOR;                       00000240
19          DO N =   1 TO 10 BY 1;                                                         00000250
20          DO J = 1 TO 3 BY 1;                                                            00000260
21             T=0.0;                                                                      00000270
22             DO NN=1 TO N BY 1;                                                          00000280
23                T=T+ ( -O*((1+P)**NN) + S*((1+Q)**NN)) * ((1+I)**-NN);                   00000290
24             END;                                                                        00000300
25             NPV = T - K*F; *NET PRESENT VALUE;                                          00000310
26             EAC=(-NPV)*(  I*((1+I)**N) / (((1+I)**N)-1)  );                             00000320
27             PRONUM=J+1; *LABELING VARIABLE;                                             00000330
28           OUTPUT;                                                                       00000340
29            END; END;  END; END;                                                         00000350
30          LABEL  J=ALTERNATIVE                                                           00000360
31                 N=PLANNING HORIZON                                                      00000370
32                 I=MINIMUM ATTRACTIVE RATE OF RETURN                                     00000380
33                 P=ESCALATION INDEX-COSTS                                                00000390
34                 Q=ESCALATION INDEX-SAVINGS                                              00000400
35                 F=INITIAL COST MODIFIER                                                 00000410
36                 EAC=EQUIVALENT ANNUAL COSTS;                                            00000420
37          CARDS;                                                                         00000430

NOTE: DATA SET WORK.RICE1 HAS 360 OBSERVATIONS AND 10 VARIABLES. 226 OBS/TRK.
NOTE: THE DATA STATEMENT USED 0.23 SECONDS AND 76K.

39          ;                                                                              00000450
40          *END OF CREATION OF VALUES OF EAC;                                             00000460
41          PROC PLOT  DATA=RICE1; BY I F;                                                 00000470
42                PLOT EAC*N=PRONUM / HPOS=50  VREF=0.0;                                   00000480

NOTE: THE PROCEDURE PLOT USED 0.40 SECONDS AND 122K AND PRINTED PAGES 1 TO 12.
NOTE: SAS USED 122K MEMORY.

NOTE: SAS INSTITUTE INC.
      SAS CIRCLE
      PO BOX 8000
      CARY, N.C.  27511-8000
```

RICE-HULLS ENERGY PROJECTS 13:56 SATURDAY, JU
SENSITIVITY ANALYSIS
EQUIVALENT ANNUAL COSTS
MINIMUM ATTRACTIVE RATE OF RETURN=0.1872 INITIAL COST MODIFIER=0.8

PLOT OF EAC*N SYMBOL IS VALUE OF PRONUM



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                        RICE-HULLS ENERGY PROJECTS                         13:56 SATURDAY, JUNE
                           SENSITIVITY ANALYSIS
                         EQUIVALENT ANNUAL COSTS
   MINIMUM ATTRACTIVE RATE OF RETURN=0.1872   INITIAL COST MODIFIER=1

                 PLOT OF EAC*N    SYMBOL IS VALUE OF PRONUM
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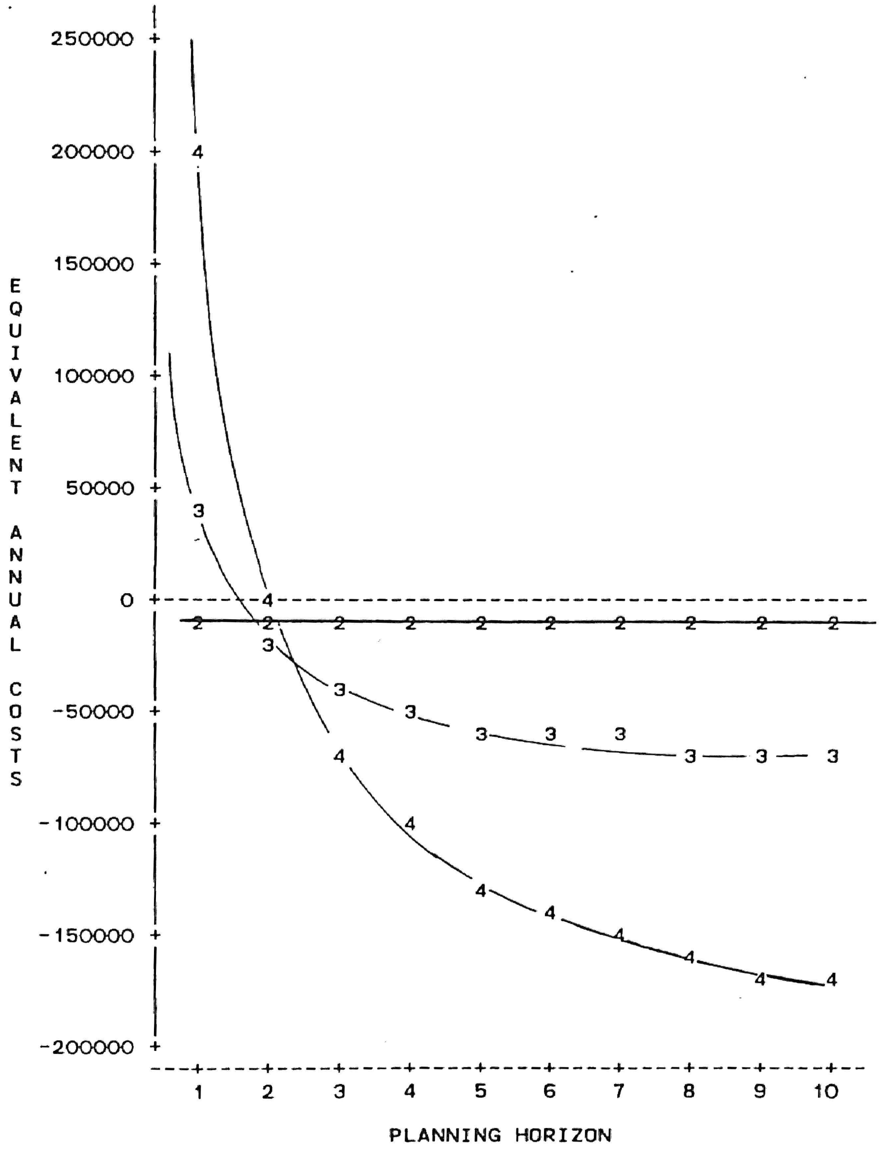
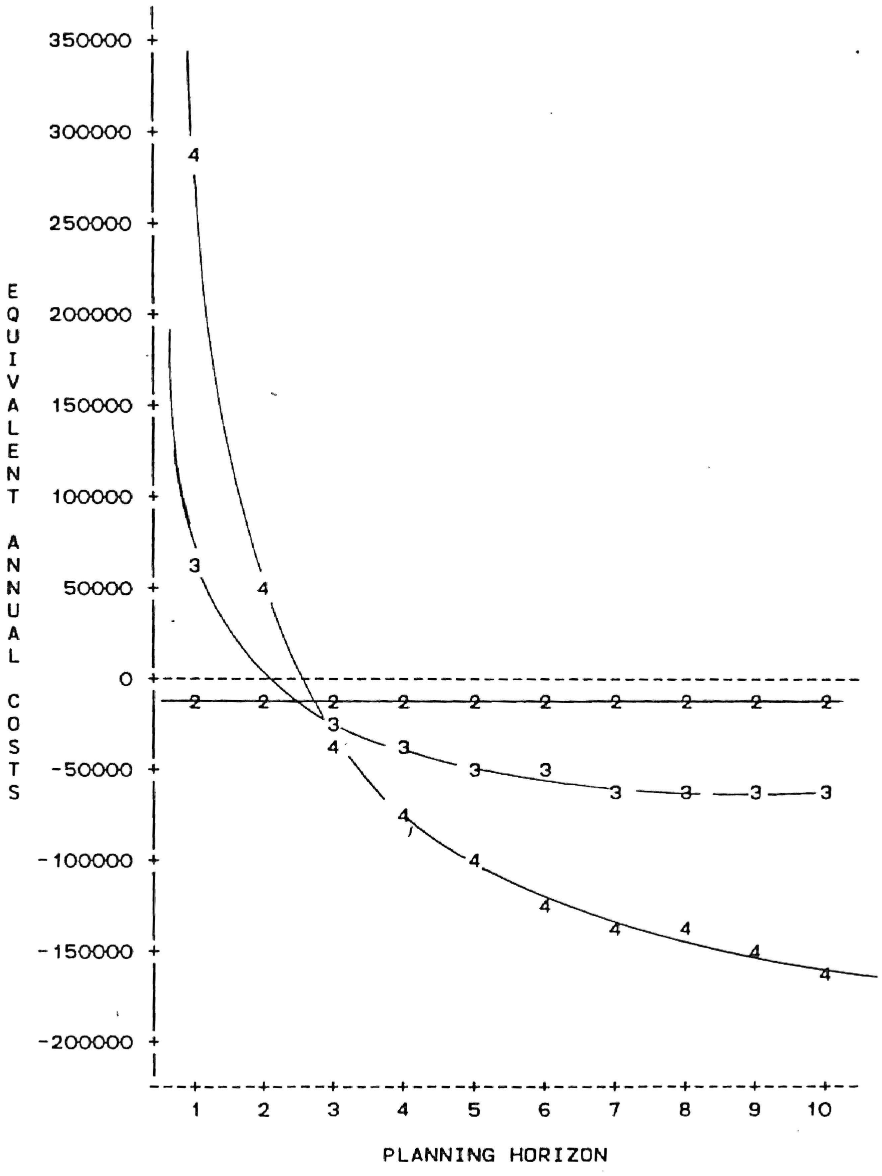


RICE-HULLS ENERGY PROJECTS
SENSITIVITY ANALYSIS
EQUIVALENT ANNUAL COSTS
MINIMUM ATTRACTIVE RATE OF RETURN=0.1872   INITIAL COST MODIFIER=1.2

13:56 SATURDAY, JUN

PLOT OF EAC*N   SYMBOL IS VALUE OF PRONUM



1 OBS HIDDEN

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                    RICE-HULLS ENERGY PROJECTS                    13:56 SATURDAY, JUNE
                       SENSITIVITY ANALYSIS
                     EQUIVALENT ANNUAL COSTS
MINIMUM ATTRACTIVE RATE OF RETURN=0.1872    INITIAL COST MODIFIER=1.4

              PLOT OF EAC*N    SYMBOL IS VALUE OF PRONUM
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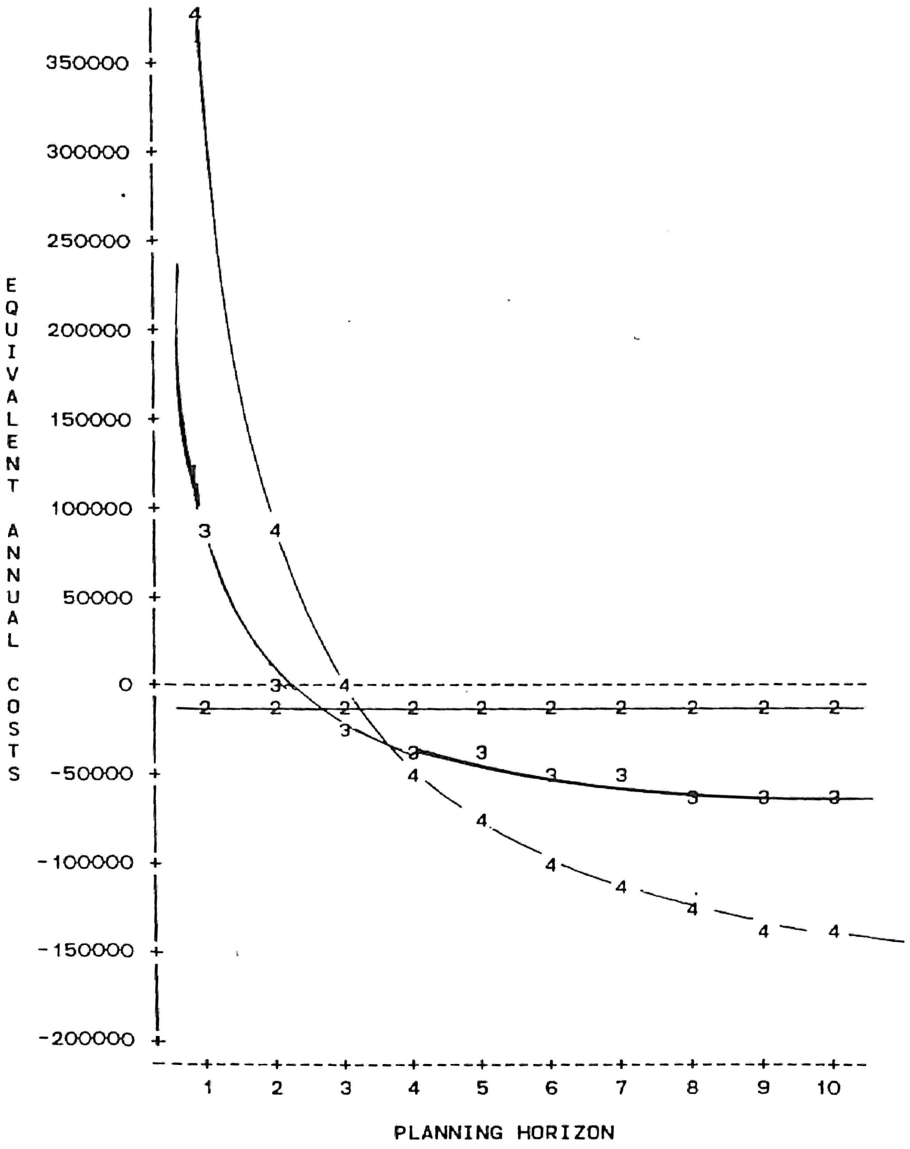
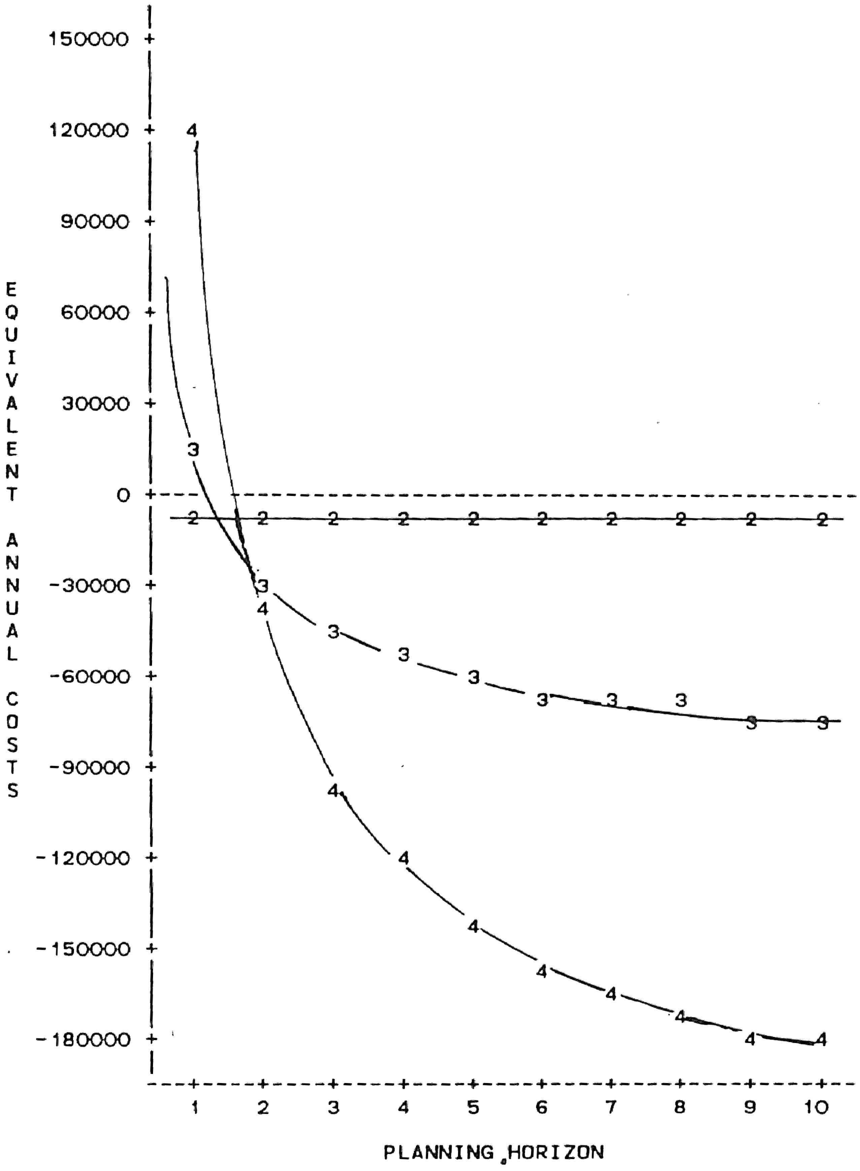


RICE-HULLS ENERGY PROJECTS
SENSITIVITY ANALYSIS
EQUIVALENT ANNUAL COSTS
MINIMUM ATTRACTIVE RATE OF RETURN=0.219   INITIAL COST MODIFIER=0.8

13:56 SATURDAY, JUNE

PLOT OF EAC*N   SYMBOL IS VALUE OF PRONUM



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               RICE-HULLS ENERGY PROJECTS                        13:56 SATURDAY, JUNE
                  SENSITIVITY ANALYSIS
                EQUIVALENT ANNUAL COSTS
MINIMUM ATTRACTIVE RATE OF RETURN=0.219    INITIAL COST MODIFIER=1

          PLOT OF EAC*N     SYMBOL IS VALUE OF PRONUM
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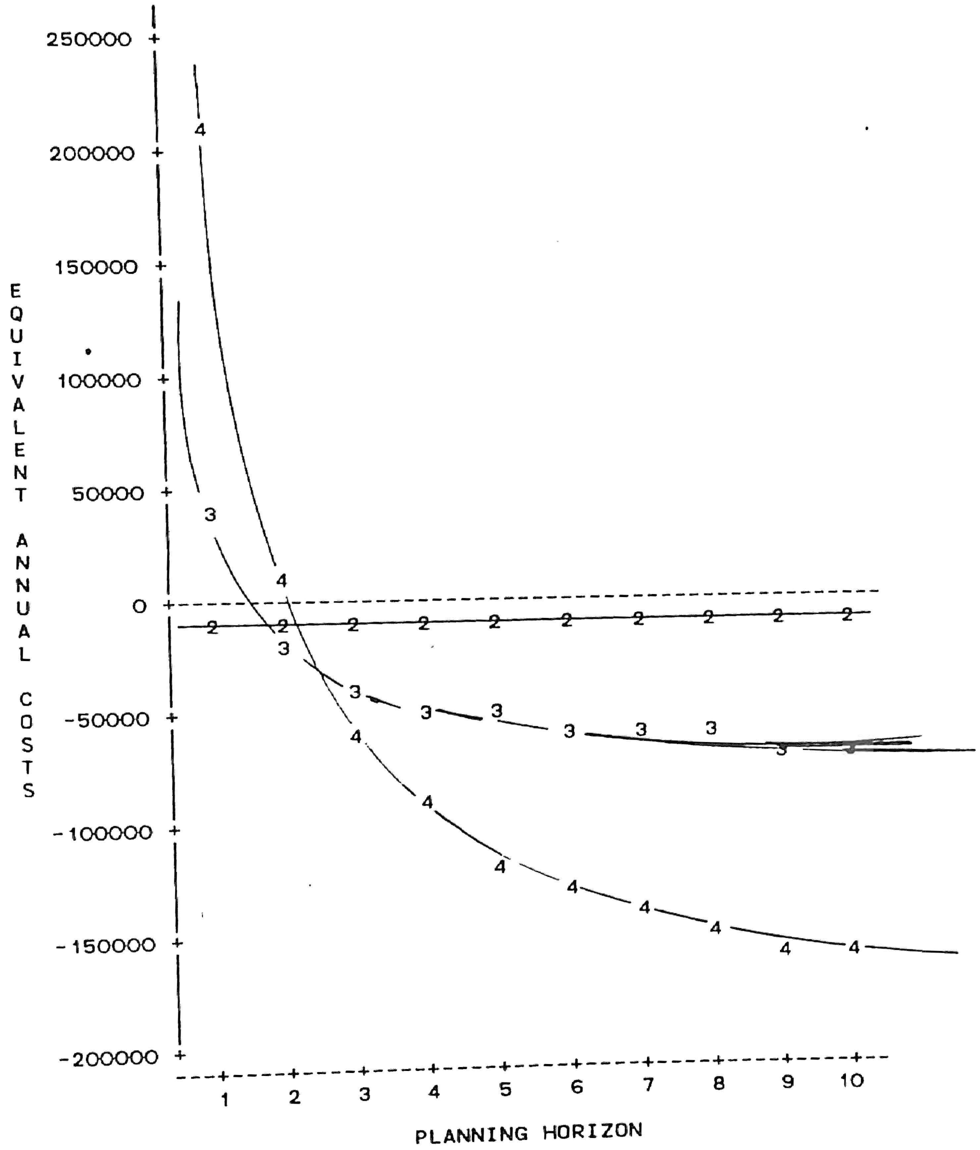
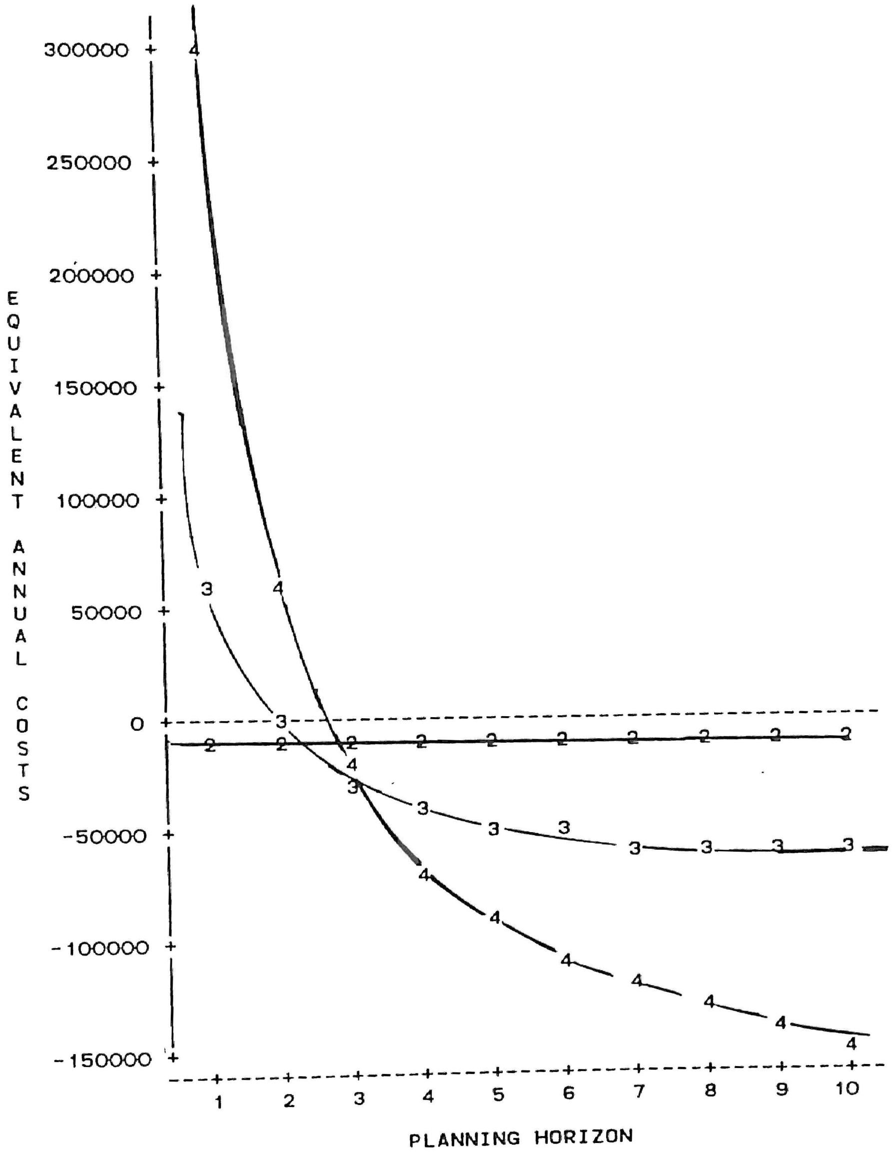


RICE-HULLS ENERGY PROJECTS 13:56 SATURDAY, JU
SENSITIVITY ANALYSIS
EQUIVALENT ANNUAL COSTS
MINIMUM ATTRACTIVE RATE OF RETURN=0.219 INITIAL COST MODIFIER=1.2

PLOT OF EAC*N SYMBOL IS VALUE OF PRONUM



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                    RICE-HULLS ENERGY PROJECTS                    13:56 SATURDAY, JU
                       SENSITIVITY ANALYSIS
                     EQUIVALENT ANNUAL COSTS
MINIMUM ATTRACTIVE RATE OF RETURN=0.219   INITIAL COST MODIFIER=1.4

             PLOT OF EAC*N    SYMBOL IS VALUE OF PRONUM
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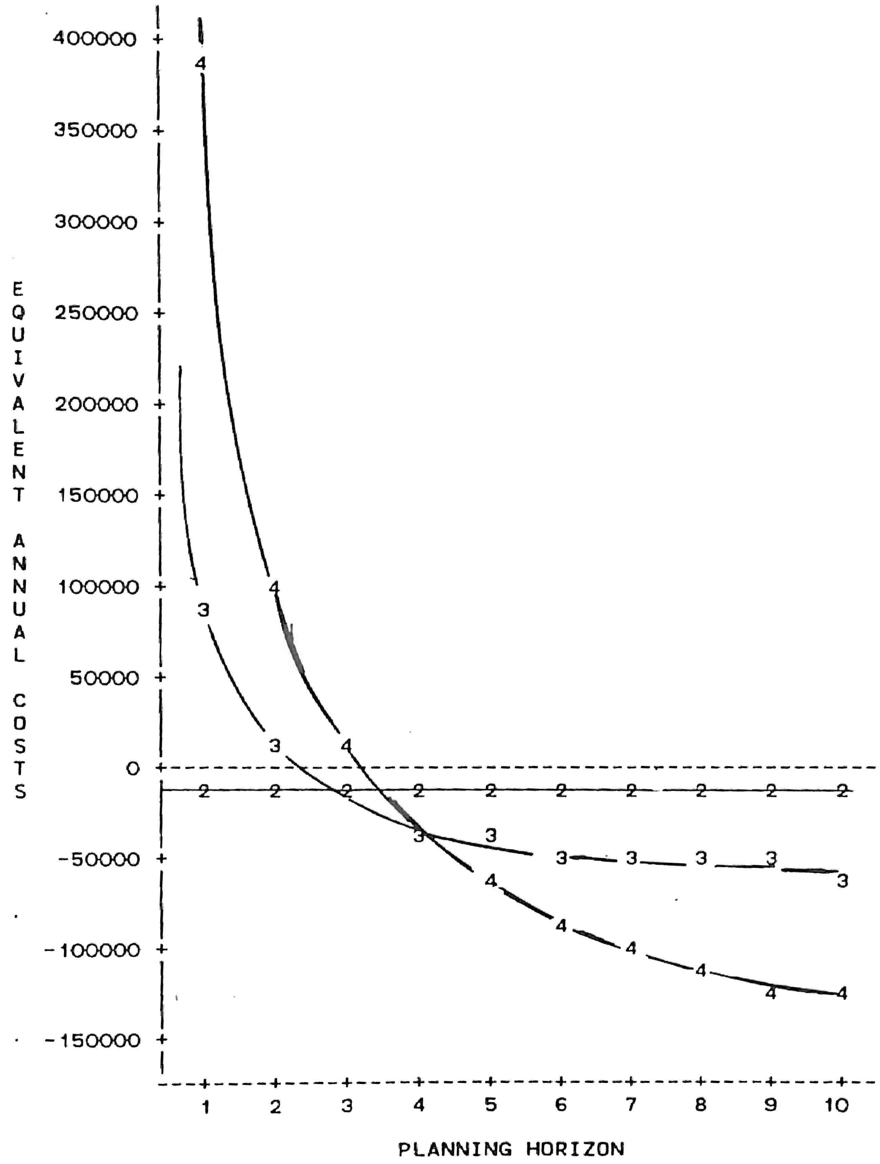

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2 OBS HIDDEN
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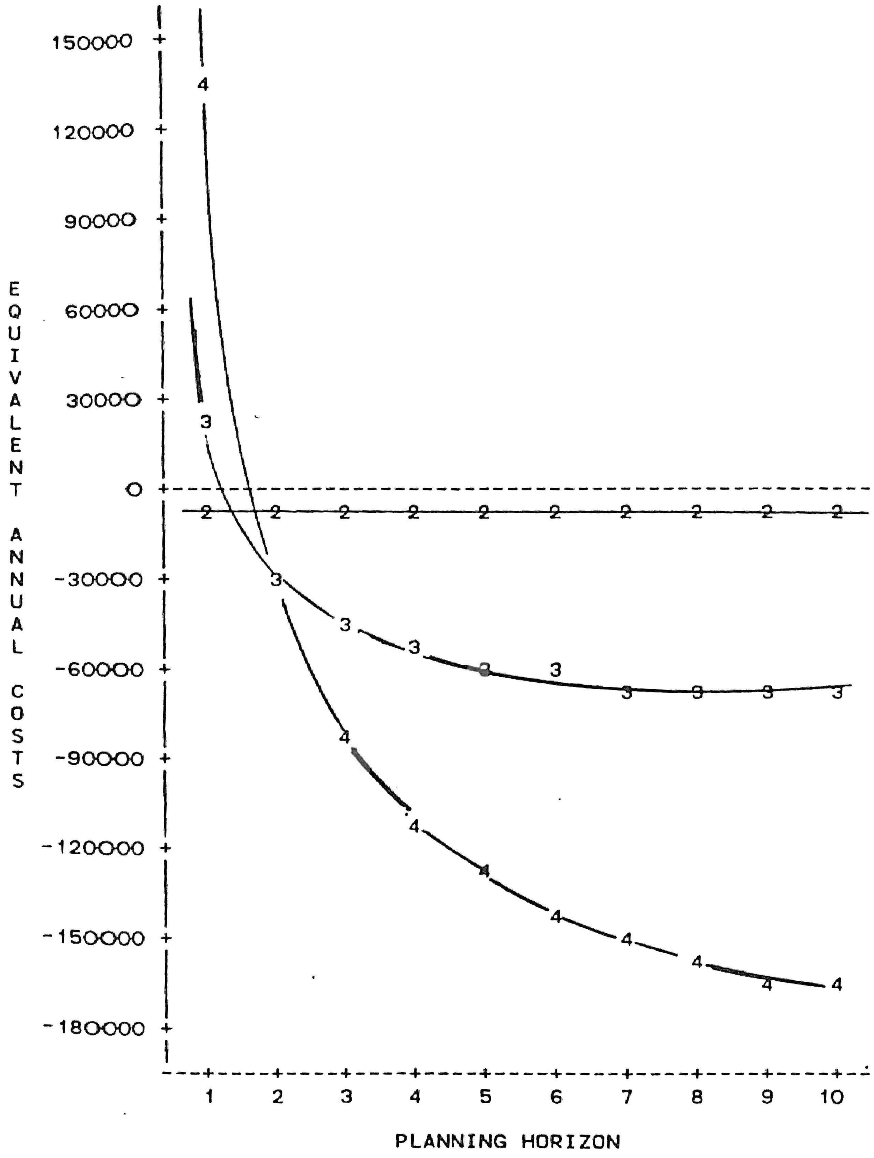
RICE-HULLS ENERGY PROJECTS 13:56 SATURDAY, JU
SENSITIVITY ANALYSIS
EQUIVALENT ANNUAL COSTS
MINIMUM ATTRACTIVE RATE OF RETURN=0.272 INITIAL COST MODIFIER=0.8

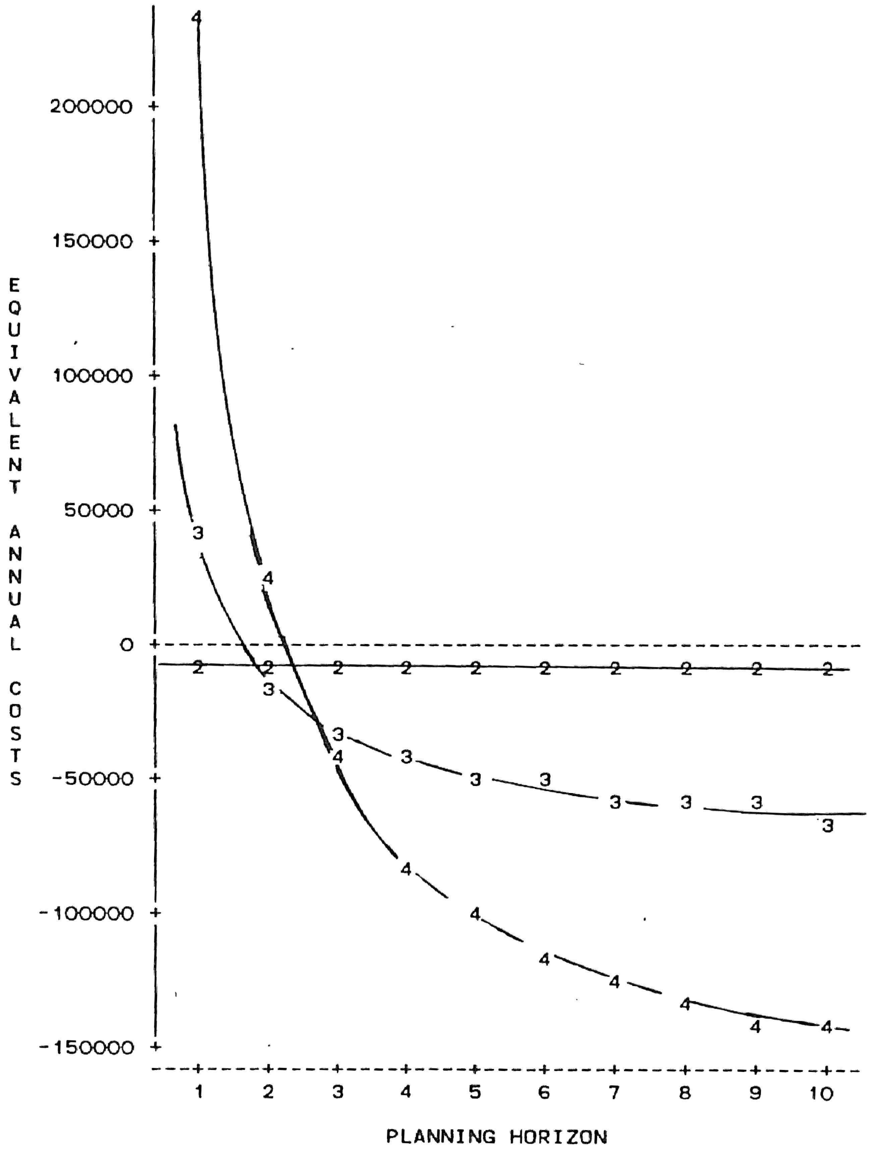
PLOT OF EAC*N SYMBOL IS VALUE OF PRONUM



1 OBS HIDDEN

RICE-HULLS ENERGY PROJECTS
SENSITIVITY ANALYSIS
EQUIVALENT ANNUAL COSTS
MINIMUM ATTRACTIVE RATE OF RETURN=0.272 INITIAL COST MODIFIER=1

PLOT OF EAC*N SYMBOL IS VALUE OF PRONUM



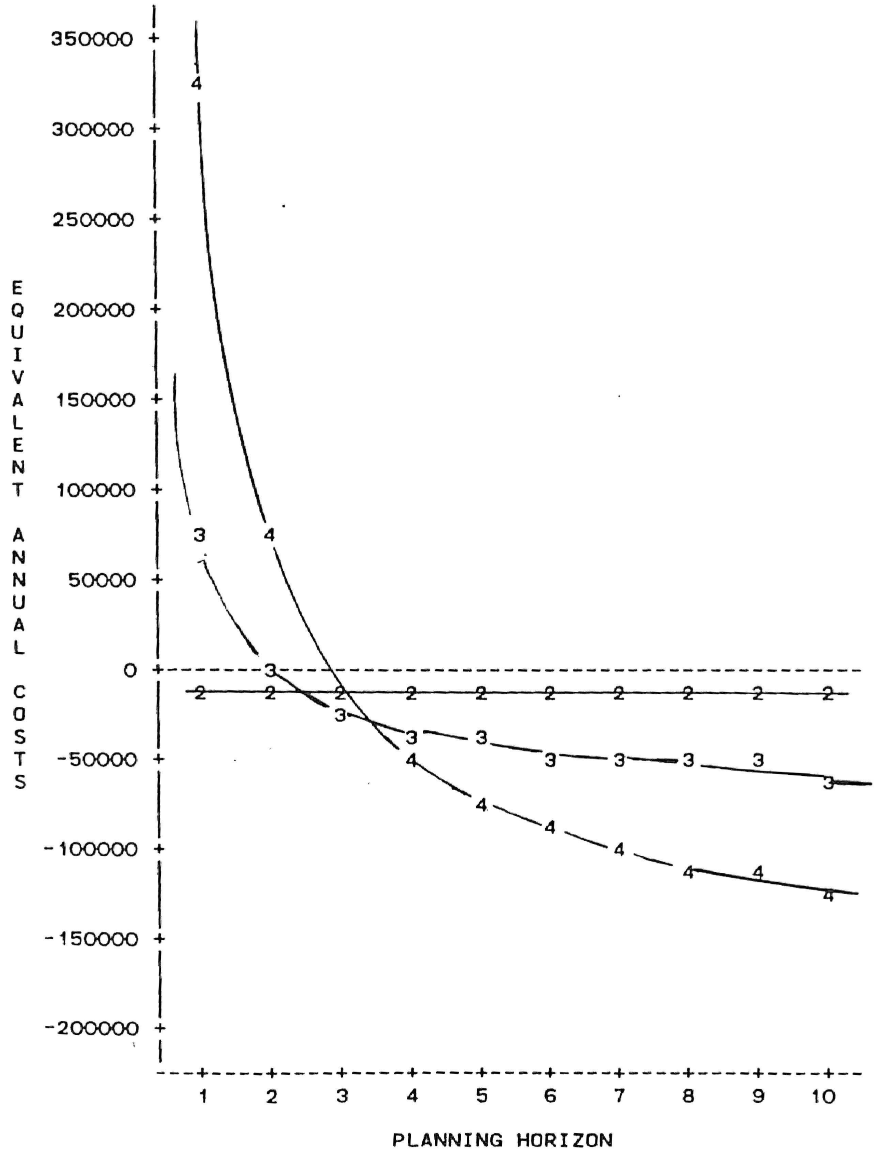
RICE-HULLS ENERGY PROJECTS 13:56 SATURDAY, JU

SENSITIVITY ANALYSIS

EQUIVALENT ANNUAL COSTS

MINIMUM ATTRACTIVE RATE OF RETURN=0.272 INITIAL COST MODIFIER=1.2

PLOT OF EAC*N SYMBOL IS VALUE OF PRONUM



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                    RICE-HULLS ENERGY PROJECTS                    13:56 SATURDAY, JUNI
                       SENSITIVITY ANALYSIS
                     EQUIVALENT ANNUAL COSTS
MINIMUM ATTRACTIVE RATE OF RETURN=0.272    INITIAL COST MODIFIER=1.4

                 PLOT OF EAC*N    SYMBOL IS VALUE OF PRONUM
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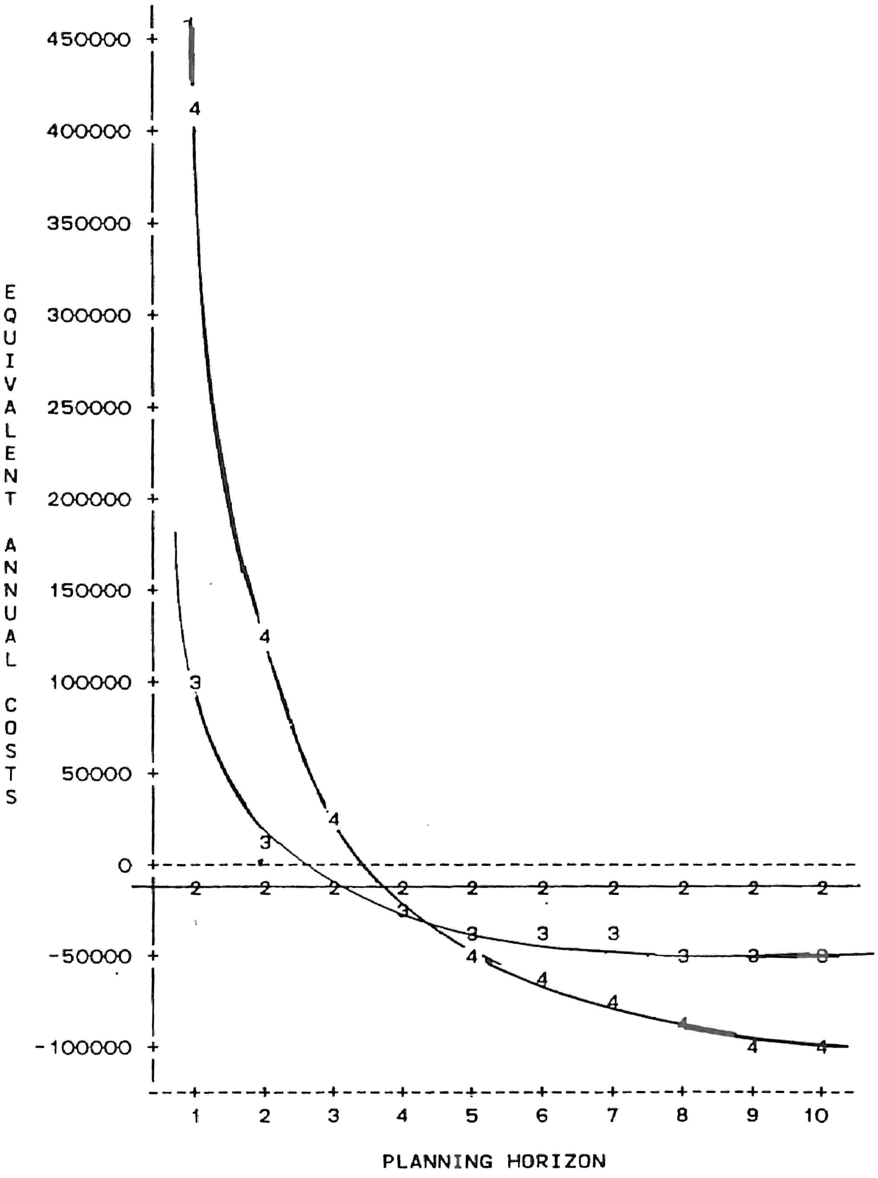

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1 OBS HIDDEN
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