Hydro and Geothermal Electricity As An Alternative for Industrial Petroleum Consumption in Costa Rica

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April 1982

MTR-81W239

SPONSOR:
Inter-American Development Bank

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ABSTRACT

This report assesses the potential for substitution of electricity for petroleum in the industrial/agro-industrial sector of Costa Rica. The study includes a preliminary estimate of the process energy needs in this sector, a survey of the principal petroleum consuming industries in Costa Rica, an assessment of the electrical technologies appropriate for substitution, and an analysis of the cost trade offs of alternative fuels and technologies. The report summarizes the total substitution potential both by technical feasibility and by cost effectiveness under varying fuel price scenarios and identifies major institutional constraints to the introduction of electric based technologies. Recommendations to the Government of Costa Rica are presented.

The key to the success of a Costa Rican program for substitution of electricity for petroleum in industry rests in energy pricing policy. The report shows that if Costa Rica Bunker C prices are increased to compare equitably with Caribbean Bunker C prices, and increase at 3 percent per annum relative to a special industrial electricity rate structure, the entire substitution program, including both industrial and national electric investment, would be cost effective. The definition of these pricing structures and their potential impacts need to be assessed in depth.

ACKNOWLEDGMENT

This report was prepared for the Inter-American Development Bank to assist that institution, the government of Costa Rica, as well as other countries of Latin America in defining renewable energy investment opportunities which will lead to improved energy utilization and national development.

The authors wish to express their appreciation for the support, insight, and encouragement provided by Leonardo da Silva and the staff of the Inter-American Development Bank, both in Washington, D.C. and in San Jose, in the planning and review of this report.

This effort would not have been possible without the willing support of many officials from government and industry in Costa Rica. In particular, we wish to acknowledge the assistance of Rogelio Sotela Muñoz, Director of the Secretary of Energy, who provided the MITRE team office space, access to Costa Rican national energy data, and the introductions and scheduling of the many contacts the team had in Costa Rica. A listing of the Costa Rican officials and organizations providing support and input to this study is located in Appendix A of this study.

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GLOSSARY

Abbreviations

BBL	barrel
BHP	boiler horse power
Btu	British thermal unit
cm	centimeter
¢	cents U.S.
CIIU	Clasificacion Industrial International Uniforme
C	Costa Rican Colones
d	day
^{o}C	degree centigrade
^{o}F	degree Fahrenheit
$	dollars U.S.
GDP	gross domestic product
GHZ	Giga Hertz
GJ	gigajoules (10^9J)
GW	gigawatt (10^9W)
hr	hour
ICE	Instituto Costarricense de Electricidad
IDB	Inter-American Development Bank
J	Joule
kgS	kilogram steam
kPa	kilo Pascal
kV	kilovolt
kWh	kilowatt-hour
l	liter
lbs	pounds
LCC	life cycle cost
LPG	liquefied petroleum gas
MMBtu	million British thermal unit
MJ	megajoules (10^6J)
mo	month
MW	megawatt (10^6W)
PW	present worth
RECOPE	Refinadora Costarricense de Petroleo, S.A.
SNE	Servicio Nacional de Electricidad
TJ	terajoule (10^{12}J)
V	volt
yr	year

Conversions

Currency:

U.S. $1.00 = C18.9

Units:

1 Btu = 1,055 Joules
1 BBL = 42 U.S. gallons = 35 Imperial Gallons
1 U.S. gallons = 3.785 liters
1 kg = 2.205 lbs
1 kWh = 3.6 MJ
1 calorie = 4.186 Joules
1 Joule = 0.239 calories

Energy:

1 BBL Gasoline	= 5.19 GJ
1 BBL Diesel	= 5.78 GJ
1 BBL Bunker C	= 6.20 GJ
1 BBL Kerosene-Jet Fuel	= 5.48 GJ
1 BBL Crude Oil	= 5.78 GJ

Multiples:

kilo = 10^3
mega = 10^6
giga = 10^9
tera = 10^{12}

SUMMARY

Costa Rica, as other countries of Central America, has suffered serious economic penalties from dependence on imported petroleum. In order to reduce this dependence and maintain its economic growth, Costa Rica must look to its indigenous energy resources for substitution for this petroleum.

Fortunately, Costa Rica is endowed with numerous energy resources. Hydro and geothermal potential stands foremost on this list. The question arises as to how these resources might be best applied to substitute for current petroleum needs.

Although the transportation sector is the largest consumer of petroleum in Costa Rica, technological development of electric powered vehicles has not yet attained adequate success to offer significant potential for substitution at this time. However, in the industrial sector, the second largest consumer of petroleum, there are significant technological opportunities for substitution of petroleum fired systems with alternative electric powered technologies.

It is the objective of this study to investigate both the technical and economic potentials for this substitution of electricity for petroleum in the industrial sector of Costa Rica.

Energy Supply and Demand in Costa Rica

Commercial energy consumption in Costa Rica has grown by over 85 percent in the last decade. In 1979, commercial energy consumption amounted to 41.69×10^{15} Joules (J) or 7.21×10^{6} barrels of oil equivalent (BOE). Petroleum products accounted for 70.1 percent or 5.06×10^{6} barrels (BBL) of the total commercial energy consumed. Hydro and geothermal electricity accounted for 15.5 percent and commercial biomass resources accounted for 14.4 percent.

Costa Rica imports all of its petroleum needs. The cost of petroleum imports in 1979 exceeded 200 million dollars. At present, no commercial petroleum resources have been identified in Costa Rica. In contrast, the hydro and geothermal electric potential in Costa Rica is estimated at 8500 MW and 720 MW respectively (Republica de Costa Rica, 1981 and Obiols, 1979). Only 445 MW of the hydro potential is presently developed.

Both the industrial and agro-industrial sectors are major energy consumers in Costa Rica accounting for 27 percent of the total energy consumed in 1979. Imported petroleum is the key fuel for these sectors amounting to 1.34×10^6 BBL or 26 percent of total petroleum imports. The petroleum products consumed are almost entirely Bunker C and diesel. At present, petroleum accounts for 44 percent of the industrial and agro-industrial sector energy consumption while electricity accounts for 16 percent and biomass fuels account for 40 percent.

Industrial Petroleum Consumption Data

A significant contribution of this study is the detailed characterization of industrial petroleum consumption by industrial sub-sector and process energy needs (i.e., for steam and hot water generation, low or high temperature process heat, and mechanical energy). This represents the first time data of this level of detail have been estimated for Costa Rica. In 1980, approximately 42 percent of the petroleum consumed by Costa Rican industry was for the production of high temperature process heat.* About 25 percent was for generation of steam and hot water, while about 9 percent was for electricity generation. Detailed industrial petroleum consumption data are found in the industrial energy matrices presented in Section 2.0.

Technical Potential for Electric Substitution

A survey of industries in Costa Rica was conducted to initiate this study. The survey indicated that petroleum fuels are used most commonly to provide:

- Steam
- Hot water
- Low temperature (less than 100°C) process heat
- High temperature (greater than 100°C) process heat
- Mechanical power (Motors)
- Electricity
- Transportation

*Process heat greater than 100°C.

A summary of the 1980 industrial and agro-industrial petroleum consumption and resulting energy products is presented in Table S-I.

The industrial petroleum based technologies most commonly observed in Costa Rica, can be grouped as follows:

- Bunker C and diesel oil-fired boilers for steam and hot water

- Bunker C, diesel and kerosene oil-fired combustors for low and high temperature process heat

- Diesel oil-fired internal combustion engines for on-site mechanical power and/or electricity

The petroleum-based industrial energy technologies may be substituted by several different electric technologies. The electric technologies may be classified as direct substitutes (i.e., providing the same energy product and requiring no change to the existing industrial process) or indirect substitutes (i.e., replacing both the energy production system and the existing industrial process).

The direct electric substitutes applicable to industry in Costa Rica are:

- Electric boilers

- Electric heaters

- Heat pumps

- Electricity grid expansion (as a substitute for on-site diesel generated electricity)

The indirect substitutes most applicable to industry in Costa Rica are:

- Microwave systems

- Electric membrane separators

In addition to the potential electric substitutes, a newly available retrofit biomass gasification technology for small (less than 10 GJ/hr) industrial boilers and combustors was evaluated against existing petroleum-based systems.

TABLE S-I

1980 ENERGY PRODUCT MATRIX FOR THE INDUSTRIAL AND AGRO-INDUSTRIAL SECTOR
(IN 10^3 BBL)

Petroleum Consumption in 10^3 BBL/yr	Gasoline	Diesel	Bunker C	Kerosene	Av. Gas	Asphalts	Total
Steam	—	63.4	237.5	—	—	—	300.9
Hot Water	—	3.3	20.9	—	—	—	24.2
Low Temperature Process Heat	—	33.8	22.5	15.5	—	—	71.8
High Temperature Process Heat	—	44.8	484.1	16.6	—	—	545.5
Motors	—	70.4	—	—	—	—	70.4
Transport	27.6	118.8	—	—	4.5	—	150.9
Electricity	—	130.0	—	NEG	NEG	—	32.2
Other	—	—	—	—	—	49.6	49.6
Total	27.6	464.5	765.0	32.1	4.5	49.6	1,343.3

A conversion matrix relating the potential technical substitution of the existing petroleum-based technologies with appropriate substitute electric and biomass technologies is shown in Table S-II. A matrix relating the existing petroleum-based and potential electric substitute technologies to the various industrial and agro-industrial sub-sectors in Costa Rica is presented in Table S-III. This matrix identifies the spectrum of technically feasible electric alternatives.

The industrial sub-sectors with the highest petroleum consumption and also with potentially convertible petroleum based technologies are:

- Food products
- Beverages
- Paper Products
- Textiles
- Rubber products
- Coffee beneficiators
- Fresh fruit producers

Economic Potential for Electric Substitution

The main conclusion of the study is that substitution of about 52 percent of current industrial and agro-industrial petroleum consumption is technically feasible. The extent to which this substitution is economically feasible is heavily dependent on the relative pricing structure of petroleum and electricity.

Table S-IV summarizes the analysis of the economic potential for substitution of electricity for petroleum in the industrial sector. For each of five combinations of petroleum and electricity prices and price growth rates, the table presents the industrial/agro-industrial petroleum energy consumption that could be converted to electricity on a cost effective basis. Two substitution options are considered. In the first, only conversions from petroleum to electricity are compared. The second option permits, in addition, conversion of diesel and kerosene systems to Bunker C if Bunker C is more economical than electricity.

TABLE S-II

TECHNOLOGY CONVERSION MATRIX

Existing Petroleum-based Technologies	Direct Electric Substitutes: Electric Boilers/ Hot Water Generator	Direct Electric Substitutes: Electric Heaters	Direct Electric Substitutes: Heat Pumps	Direct Electric Substitutes: Grid Expansion	Indirect Electric Substitutes: Microwave System	Indirect Electric Substitutes: Electric Membrane Separators	Indirect Electric Substitutes: Electrolysis-based Ammonia	Biomass Substitutes: Gasifier/Burners	Biomass Substitutes: Producer Gas	Biomass Substitutes: Methane Generators
Steam/hot water Boilers	◉	◉	◉		●	●		◉		
Combustors (>100°C)		◉	●		●			●		●
Combustors (<100°C)		●			◉			●		●
Internal Combustion Engines				◉					●	
Conventional Ammonia Synthesis							●			

● Potential conversion

◉ Conversion selected for detailed analysis.

TABLE S-III

EXISTING AND POTENTIAL PROCESS ENERGY TECHNOLOGIES
FOR INDUSTRIAL AND AGRO-INDUSTRIAL SECTORS

	EXISTING PETROLEUM BASED TECHNOLOGIES					POTENTIAL ELECTRIC BASED TECHNOLOGY SUBSTITUTES					
	Steam/Hot Water Boilers	Low Temperature Combustors (100 C)	High Temperature Combustors (100 C)	Internal Combustion Engines-Mechanical Power	Internal Combustion Engines-Electric Generation	Steam/Hot Water Boilers	Resistance Heaters	Heat Pumps	Microwave Systems	Membrane Separators	Electric Grid Expansion
Consumer Goods											
Food Products	•	•	•			•	•	•	•	•	
Coffee Processing	•	•	•			•	•		•	•	
Meat Products	•	•				•	•	•	•		
Dairy Products	•	•				•	•	•	•	•	
Grain Mill Products	•	•	•			•	•	•	•		
Fishery Products	•	•	•			•	•	•	•		
Bakery, Sugar and Confectionary Products		•	•				•	•	•		
Other Food Processing	•	•	•			•	•	•	•	•	
Beverages	•					•	•	•			
Tobacco Manufacturing	•	•				•	•		•		
Clothing	•					•	•				
Footware											
Furniture and Fixtures	•	•				•	•				
Painting and Publishing											
Medicines and Pharmaceutical	•					•	•	•			
Soaps, Perfumes and Cosmetics	•	•				•	•	•			
Transport Equipment				•							
Other Manufacturers	•	•				•	•				
Intermediate Goods											
Textiles	•	•	•			•	•	•	•		
Leather Products	•					•		•			
Wood Products	•	•				•	•				
Paper Products	•	•				•	•	•	•		
Industrial Chemicals	•	•	•			•	•	•			
Paints, Varnish, Lacquer	•					•					
Other Chemicals			•								
Petroleum Refining	•	•				•					
Petroleum and Coal Products	•		•			•					
Rubber Products	•		•			•	•		•		
Plastic Products	•	•	•			•	•		•		
Clay and Porcelain Products			•				•				
Glass Products			•								
Other Non-Metallic Products			•	•							
Iron and Steel			•								
Metal Products			•								
Capital Goods											
Mechanical Machinery											
Electrical Machinery											
Construction and Mining			•	•							
Agro-Industries											
Coffee Beneficiation		•			•		•	•	•		•
Bananas and Fresh Fruits	•			•	•	•					•
Sugar	•			•	•	•		•			•
Rice and Grain Milling		•		•	•		•	•	•		•
Cattle and Relates Activities	•				•	•					•
Fishing					•						•
Crop Sarayinq											
Other	•	•		•	•	•	•	•	•		•

TABLE S-IV

POTENTIAL FOR SUBSTITUTION OF ELECTRICITY FOR PETROLEUM

FUEL PRICE SCENARIO	Case 1	Case 2	Case 3	Case 4	Case 5
• Assumptions:					
– Electricity Tariff[1]	T-4	T-10	T-10	T-10	T-10
– Electricity Price Growth Rate[2]	0	0	0	0	0
– Bunker C Price ($/l)[3]	0.132	0.132	0.132	0.132	0.179
– Petroleum Price Growth Rate[2]	0	0	0.03	.10	.03
SUBSTITUTION OPTIONS					
• Petroleum to Electricity Only					
– Savings of Bunker C in 10^6 BBL	0.0	0.0	0.052	0.432	0.432
– Savings of Diesel and Kerosene in 10^6 BBL	0.261	0.261	0.261	0.261	0.261
– Total Savings of Petroleum in 10^6 BBL	0.261	0.261	0.313	0.693	0.693
– % of Sectoral Petroleum Use	19	19	23	52	52
• Petroleum to Electricity or other Petroleum Options					
– Savings Bunker C in 10^6 BBL	0.0	0.0	0.052	0.432	0.432
– Savings of Diesel and Kerosene in 10^6 BBL	0.181	0.198	0.211	0.261	0.261
– Total Savings of Petroleum in 10^6 BBL	0.181	0.198	0.263	0.693	0.693
– % of Sectoral Petroleum Use	13	14	19	52	52

1) May 1981 electricity unit prices derived from a T-4 or T-10 tariff are equivalent to 3.50 and 1.0 ¢/kWh, respectively.

2) Price growth rates are real relative annual growth rates.

3) May 1981 Costa Rican and Caribbean spot prices are used as initial year prices in the economic analysis.

The results shown in the table are summarized below:

- If present petroleum and electricity price relationships continue in the future, the economic potential for substitution is estimated at between 13 to 19 percent of industrial and agro-industrial use. (Case 1)

- If present industrial electricity tariffs are discounted by about 70 percent (as is representative of the restricted T-10 tariff), then the economic potential for electricity substitution for petroleum ranges between 14 to 52 percent. This range is dependent on the annual real price increase of petroleum products relative to the discounted electricity price:

  - A constant price ratio between petroleum and electricity results in a 14 to 19 percent substitution potential. (Case 2)

  - A three percent annual increase in petroleum prices results in a substitution potential in the range of 19 to 23 percent. (Case 3)

  - A 10 percent annual increase in petroleum prices or a rise in the domestic petroleum prices to May 1981 Caribbean spot prices with a three percent annual petroleum price increase achieves the maximum technical substitution potential of 52 percent. (Case 4 and 5)

Clearly, the two key factors that will impact an industrial electricity substitution program are future increases in petroleum prices and the extent to which electricity price discounts can be extended to the industrial sector without undermining the financial viability of the electricity sector. The T-10 tariff which represents a 70 percent discount over normal industrial electricity tariffs is presently available on a limited time-of-day basis and essentially represents excess power during off-peak periods. The extent to which this or similar tariffs are feasible within the present and future financial structure of the Costa Rican electricity sector has not been addressed in this study. Any commitment to a significant industrial electricity substitution program must first carefully evalute the financial viability of petroleum and electricity pricing structures relative to the health of both the national petroleum and electricity companies as well as to the Costa Rican national economy.

Additional Electricity Required for Maximum Substitution

Under the Case 5 scenario, the maximum substitution of electricity for 52 percent of the industrial/agro-industrial petroleum consumption could be obtained by 1987. Based on industrial growth of 9.1 percent per year, the 52 percent of the projected 12,939 TJ of petroleum consumption amounts to 6,728 TJ of petroleum savings in that year. Based on relative efficiencies of petroleum and electricity use, the electric energy equivalent of this is 1526 GWH. This additional electricity demand implies a 314 MW increase in national electric power requirements from 723 MW to 1037 MW. By 1995, the requirement increases to 624 MW measured from the base case of 1343 MW to the case of maximum industrial electrification of 1967 MW.

The additional electric capacity requirement to 1995 can be obtained by a one to three year acceleration of the hydroelectric projects in the current hydroelectric expansion plans.

Energy Price Constraints to Substitution

The major constraints to substitution of electricity for petroleum in the industrial sector lie in the prices charged for electricity and Bunker C.

Cost of Electricity

The current standard industrial tariff for electricity (T-4) is based on both a demand charge on the maximum peak power that the industry requires and a kWh charge for electricity. A new tariff (T-10) has just recently been instituted which provides industries a significant savings in electricity charges for the months May through January if they are willing to use electricity only during off-peak hours (all hours except 10:00 to 12:30 and 16:30 to 20:00). During the dry months of January through May the T-10 tariff reverts to the T-4 tariff. Simplified summaries of the T-4 and T-10 tariffs are given below:

Tariff	Demand Charge ($/kW)	Energy Charge (¢/kWH)	Equivalent Charge (¢/kWH)
T-4	6.05	1.90	3.50*
T-10	—	1.00	1.00**

*Based on the energy charge plus the demand charge averaged over the number of hours of electricity used in a month. Monthly electricity use is assumed to be 356 hr/mo.

**Assumes electricity use only during off-peak periods resulting in a zero demand charge.

As seen, the T-10 tariff represents about a 70 percent discount to the standard T-4 industrial tariff for electricity. In this study, the T-10 tariff was applied as a potential future electricity price, not so much representing a time-of-day price, but rather as a benchmark for a lower electricity price that would encourage industrial conversion to electricity. The extent to which a T-10 type price discount is financially feasible on a large scale is not evaluated and represents an important potential constraint to the implementation of an industrial electrification program.

Cost of Bunker C

The prices of petroleum products in Costa Rica are given below.

	$(US)/liter*	$(US)/10^9 joules
Bunker C	.132	3.38
Diesel	.365	10.04
Gasoline	.608	18.62
Kerosene	.423	12.27

The analysis in this report shows that, in general, with the standard prices for industrial electricity in Costa Rica, the substitution of electricity for industrial processes now using diesel and kerosene fuels is cost effective. In general, this is not the case for processes using Bunker C. In fact, in the many cases where it is technically feasible, it would be more cost effective to convert existing diesel and kerosene systems to operate on Bunker C rather than electricity.

The present low price of Bunker C in Costa Rica is a result of government subsidization and recent currency devaluation. In May of 1981, bulk prices for Bunker C in the Caribbean market were posted about 36 percent higher than the delivered price to industry in Costa Rica. If the delivered price of Bunker C matched the Caribbean price of $.179/liter, the Case 5 scenario shows the substitution of electricity for Bunker C in industry using the T-10 tariff would be cost effective with petroleum prices increasing at just 3 percent per annum over the cost of electricity.

Consistent with the low cost of Bunker C in Costa Rica, however, is the excess supply of that fuel produced by the Costa Rican RECOPE refinery. This excess supply is currently being re-exported to Caribbean markets. The planned upgrading of the refinery to produce less residuals should ease this situation.

*Costs in this report are given in May 1981 dollars. Costa Rican currency exchange is based on 18.9 colones to the U.S. dollar.

Institutional Constraints to Substitution

The implementation of an industrial electrification program in Costa Rica will require extensive coordination between the national electric company (ICE), the national petroleum company (RECOPE), the energy pricing agency (SNE) and other Costa Rican government offices. Although a coordination body, the National Energy Council and its working arm, the Sectoral Technical Committee are in place and active, the depth and implication of an industrial electrification program and especially any associated energy price incentives require an expanded coordination responsibility for these offices.

New petroleum and electricity pricing structures for Costa Rica may have social-political implications and as such will involve the political institutions of the country.

The industrial sector appears to be institutionally sound and well represented by an effective national organization (Camara de Industrias). If, after an industrial electrification program is determined to be cost effective, and pricing structures are established, then some government educational efforts directed toward industry on the benefits of electrification may be in order.

Financial Constraints to Substitution

The main financial constraint to a substitution program is the shortage of available capital for ICE to undertake an accelerated expansion program. Of secondary concern is the availability of financial resources to industry. Details of potential financial and other constraints are presented in Section 4.

Cost/Benefit Analysis

For the purpose of an initial trial test of the potential economic viability of an industrial electrification program in Costa Rica, MITRE performed a national cost/benefit analysis for the Case 5 scenario presented in Table S-IV. Case 5 was selected, not as a most likely case, but rather as a test case to see if under the energy pricing conditions which permit maximum substitution, the entire investment required, both for industrial conversions and for increased hydroelectric capacity would be cost effective. Assuming only the primary benefits of savings in imported petroleum, the internal rate of return for the total industrial and hydroelectric investment was estimated to be approximately 13 percent. At this rate of return, for the period 1983-1995, discounted benefits of petroleum savings of $220 million match the additional hydroelectric and industrial investment costs of $202 million and $18 million, respectively. As seen, the industrial costs constitute only 8 percent of the total investment required.

The IDB project office conducted a sensitivity analysis on key parameters in the cost/benefit analysis. Of interest to note is that by extending the cost/benefit stream from 1995 through 2015, the internal rate of return increases to approximately 20 percent.

Relative to the guidelines of a minimum of 12 percent rate of return for national development programs, an industrial electrification program based on Case 5 conditions is cost effective. This analysis leaves unanswered whether a relative petroleum and electricity pricing structure equivalent to the Case 5 conditions is a potential reality for Costa Rica.

Recommendations

The analysis and results of this study provide the basis for several recommendations for improving the future of the industrial energy sector in Costa Rica. These recommendations have been prioritized into primary and secondary recommendations.

Primary Recommendations

1. The Government of Costa Rica should institute a policy to encourage the substitution of alternative domestic energy resources for industrial petroleum consumption whenever such substitution is cost effective.

2. The Government of Costa Rica should conduct a comprehensive energy pricing study to consider the optimal relationships between petroleum products, electricity and other alternative sources of energy so as to ensure the efficient use and allocation of energy resources within the sectors of the economy.

3. If the energy pricing study shows that a petroleum/electricity energy price structure can be established in Costa Rica which is consistent with national objectives and provides the economic incentive for industrial electrification, the Government of Costa Rica should institute a policy to encourage the industrial use of electricity while simultaneously accelerating the development of its planned hydro and geothermal facilities to meet the additional demand.

4. The Instituto Costarricense de Electricidad (ICE) should investigate alternative industrial electricity tariffs which encourage the use of off-peak and secondary electric energy.

5. ICE should conduct a study to determine the benefits and costs of extending the electricity grid to consumers in the remote areas of Costa Rica not presently interconnected to the grid. This study should weigh the costs of transmission against the present subsidized cost of transporting diesel fuel for generating electricity in these remote areas.

6. The Government of Costa Rica should identify and actively promote for development those industries beneficial to Costa Rica and which are compatible with the constraints associated with the use of off-peak and secondary electric energy.

7. A central organization, such as the Ministry of Energy, should coordinate the planning and pricing activities of ICE, SNE, RECOPE and OFIPLAN in order to provide a unified, directed and coordinated energy plan for Costa Rica.

Secondary Recommendations

8. The Government of Costa Rica should provide incentives such as exemption from import duties and/or rapid depreciation for equipment using domestic energy resources or providing for energy conservation.

9. The Government of Costa Rica should establish technical advisory centers to promote industrial energy conservation, to assist in assessments of fuel substitution and to identify reliable alternative energy technologies.

10. The Government of Costa Rica should conduct government sponsored seminars to inform industry of the opportunities for converting to alternative domestic sources of energy.

11. The Government of Costa Rica should direct CODESA, the national development organization, to coordinate its industrial investments within the framework of the energy planning objectives of the country. Projects that emphasize conservation and/or use of domestic energy resources, and which fit with the national energy sector development plans, should be given priority.

12. The Government of Costa Rica should initiate government sponsored demonstrations of economically attractive industrial electrical and other alternative (i.e., biomass) technologies to show industry the technical and economic feasibility of these technologies for Costa Rica.

13. The Government of Costa Rica should set equipment and operational standards for new electric and other alternative technologies introduced to Costa Rica in order to minimize diversity, reduce equipment and spare-part incompatibility, and provide a uniform base for servicing and maintenance.

1.0 INTRODUCTION

1.1 Background

As with all of the countries of Central America, Costa Rica suffers from the serious economic penalties resulting from energy dependence on high priced imported petroleum. The approximately 200 million dollar petroleum import bill for Costa Rica in 1979 represents 13 percent of the value of imports and 16 percent of the value of exports in that year (IDB, 1981). Clearly, a cost-effective technique to reduce Costa Rica's dependence on foreign oil would significantly improve this serious financial drain to the Costa Rican economy.

Although Costa Rica has no known petroleum resources, the country is endowed with numerous indigenous energy resources: hydro, geothermal, biomass, wind and other solar resources, as well as potential resources of newly discovered coal. Reduction of foreign oil imports requires that these indigenous energy resources be introduced as substitutes for current uses of petroleum.

Hydro potential stands foremost in Costa Rica's energy resources. More than 8500 MW of hydroelectric potential yielding nearly 37,000 GWh electric energy have been identified in the country (Republica de Costa Rica, 1981). Only 445 MW of this potential capacity are currently developed providing about 98 percent of the 1843 GWh of electricity demand for the country in 1980 (BID, 1980).

On a much smaller scale, geothermal energy for electric generation is also a promising indigenous energy resource for Costa Rica. A total of 80 MW of installed geothermal generation capacity is scheduled for completion in 1986 at the Miravalles site in northwest Costa Rica. Although the total national geothermal potential is not known, a preliminary estimate has been placed at 720 MW (Obiols, 1979).

The question immediately evident is how the large hydro potential might be used effectively to substitute for the many energy end-use needs in Costa Rica now being satisfied by petroleum.

The table below describes direct petroleum consumption by sector in Costa Rica in 1979:

Sector	Energy (TJ)	Percent of National Petroleum Consumption	Percent of Sectoral Energy Consumption
Residential/Commercial	1713	6	7
Transportation	19310	66	100
Industrial and Agro-Industrial	7109	24	44
Other	1088	4	54
	29220	100	

ref: (Republica de Costa Rica, 1980)

Although the transportation sector is the largest consumer of petroleum the technology for substitution of electricity for petroleum in other than rail and urban transit systems is not yet adequate.

The second highest petroleum consuming sector, the industrial and agro-industrial sector, and the target of this study, does present opportunities for substitution of electricity for petroleum. In 1979, electricity accounted for 16 percent while petroleum accounted for 44 percent of the energy consumption in this sector. Electric powered industrial technologies are available on the market today and in many cases can be substituted directly for oil or diesel-fired industrial heating systems. It is the objective of this study to determine to what extent these industrial technologies can be applied in a cost-effective way in Costa Rica.

1.2 Objectives

The formal objectives of this study are listed below:

- identify the primary opportunities for the substitution of electricity for oil in Costa Rica's industrial sector
- determine current estimates of the extent of excess hydro and geothermal electricity supply in the future for Costa Rica
- determine the ranges of costs/prices for fuels, equipment, and capital that make electrical substitutions for oil cost effective in different industrial processes and where impacts of substitution will be significant in Costa Rica
- identify and assess the major policy issues which are likely to curtail or encourage industrial electrification in Costa Rica; identify the requirements, both financial and institutional, to permit and encourage industrial conversion to electricity in Costa Rica
- recommend the steps to be taken to implement an effective national program for industrial conversion to electricity where economically and technically justifiable.

- conduct a cost/benefit analysis of a national program to encourage and provide for industrial use of electricity and conserve industrial use of petroleum.

1.3 Methodology

To accomplish the objectives listed above, the project team initially established a study framework with the support of the staff at the Industrial Economics and Infrastructure Section of the Inter-American Development Bank (IDB). Initial Costa Rican government and industrial contacts were established for the study team by the IDB staff. The project team then conducted an assessment mission to Costa Rica. The team visited with each of the major government institutions with responsibility for energy and industrial planning. The group gathered energy consumption and pricing data, and information and insight on the plans and policies that may affect industrial fuel use in the future. Based on the industrial fuel use information obtained, major oil consuming industries were identified. From this list, the team selected fourteen industries to visit directly. These fourteen industries represented 28 percent of the total industrial diesel consumption and 57 percent of the total industrial Bunker C consumption for the country. Plant visits permitted an identification and observation of the petroleum based technologies in operation and an indication of the specific end use energy needs that might be satisfied by conversion to electrical technologies in each of these industries.

The information obtained from the survey and general industrial process information data were then integrated to provide an estimation of the national end use industrial energy needs for Costa Rica. This information was presented in the form of matrices comparing process needs across industrial production categories. These matrices formed the basis for identifying the sectors and technologies appropriate for conversion to electricity and the measure of ultimate national conversion potential.

Based on recent MITRE investigations in electric technologies, MITRE selected a family of electric technologies commercially available and most suitable for potential conversion of industrial petroleum based equipment in Costa Rica. Through direct contacts with vendors, the team determined the current price and performance information for each of these electric powered industrial technologies. In addition, the team evaluated a newly available biomass gasification system capable of being retrofitted onto existing small petroleum combustion systems. The biomass gasification system is particularly appropriate in remote rural applications in Costa Rica where abundant wood, wood wastes and other biomass resources are available.

A number of significant energy, economic and institutional policy issues affecting Costa Rica have direct impact on the feasibility of expanded use of electricity in the industrial sector of that country. Many of the main issues involve fuel and energy pricing structures. Therefore, the comparative technology analysis incorporates a range of potential fuel prices and provides a basis to evaluate the pricing policy options that Costa Rica will likely face in the future.

The contribution of this study is in the technical and economic analysis comparing the effectiveness of petroleum and electricity technologies for industry. The project team initially constructed a conversion matrix which identified the potential conversions between existing petroleum technology and new electric powered technologies. A subset of these conversions were selected for an economic analysis. For each comparison a life cycle cost analysis was performed for both the existing and the new technology. Each comparison was made across a range of potential future fuel price increases and inflation rates.

Finally, the project team compiled the results of the technology specific analysis and applied it to the entire industrial sector of Costa Rica. Conclusions on the potential substitution of electricity for petroleum consumption in the industrial sector of Costa Rica were derived under five energy pricing scenarios. For the fifth scenario, a national cost/benefit assessment was performed to determine the expected rate of return for the industrial and hydroelectric investments required in an industrial electrification program.

2.0 INDUSTRIAL SECTOR: ECONOMIC AND ENERGY PROFILE

2.1 Background

In the last two decades, the industrial sector* of Costa Rica has grown, to become the largest productive sector in the Costa Rican economy. Between 1960 and 1979, the relative contribution to the gross domestic product (GDP) of the industrial sector grew from 14 to 22 percent (IDB, 1981). Statistics for 1979 indicate that manufactured products accounted for 24 percent of the total value of exports (IDB, 1981). The industrial sector also provided for approximately 15 percent of total employment in Costa Rica (World Bank, 1980a).

An equally important sector is the agricultural sector,** representing 18 percent of GDP and accounting for 71 percent of the value of total exports in 1979 (World Bank, 1980b). The relative contribution of the agricultural sector to GDP has been declining over the past two decades from 26 percent in 1960 to 18 percent in 1979 (IDB, 1981).

Energy consumption in the agricultural sector is significant, especially for coffee beneficiation, crop irrigation, fresh fruit (especially banana) packing, sugarcane processing, grain drying and milling and a few other related processes. These activities in the

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*The industrial sector is defined to include manufacturing, mining and construction but not to include electricity, gas and water utilities.

**The agricultural sector is defined to include agriculture, forestry, hunting and fishing.

agricultural sector are referred to, in this study, as the agro-industrial sector and are considered along with the industrial sector because of their importance to the Costa Rican economy and the magnitude of their total energy consumption.

The central valley in and around the capital city of San Jose and the provincial capitals of Cartago and Alajuela contains the majority of industry in Costa Rica. Electricity for industry in this region is supplied by the existing national electric grid (see Figure 2-1). RECOPE (Refinadora Costarricense de Petroleo, S.A.), which maintains its main storage tank farm between Cartago and San Jose, is the sole national petroleum supplier. Refined petroleum products are shipped via a dual pipeline from RECOPE's refinery and port facilities in Moin near Limon on the Atlantic coast.

Many of the agro-industrial operations, especially the banana packers, are located in the remote northeast and southwest sectors of Costa Rica where, presently, there is no electricity grid. In these areas, diesel fuel is being used to generate electricity for crop irrigation, fresh fruit processing, packing, employee consumption and other related activities.

2.2 Energy Consumption Patterns

Both the industrial and agro-industrial sectors are major energy consumers in Costa Rica (as seen in Table 2-I). The two account for approximately 27 percent (16,092 TJ) of the 1979 total

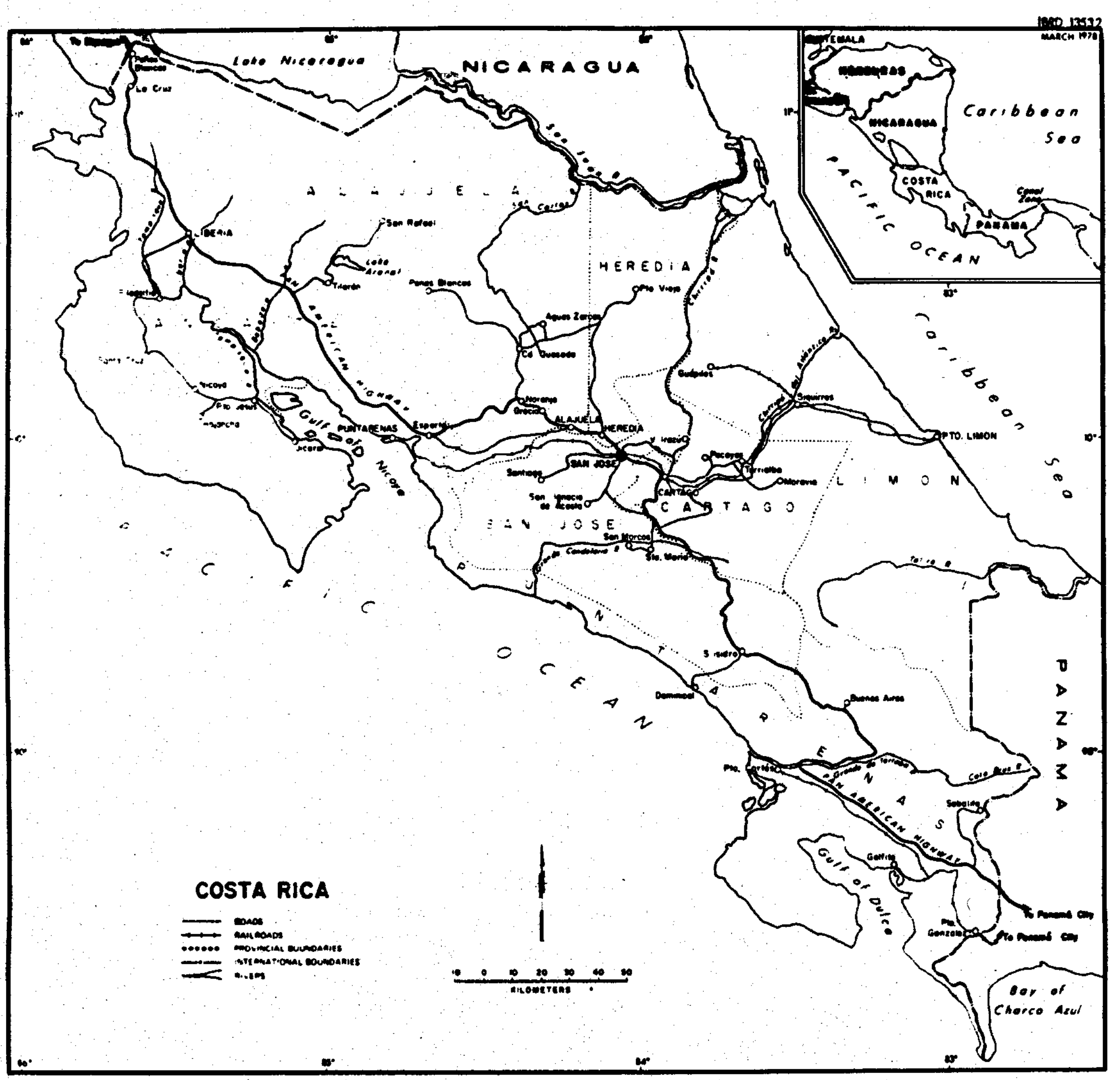


FIGURE 2-1
MAP OF COSTA RICA

TABLE 2-I

SECTORAL ENERGY CONSUMPTION IN COSTA RICA - 1979

(In 10^{12} Joules)

Energy	Sector: Residential and Commercial	Transportation	Industrial and Agro-Ind.	Others	Total*
Electricity	3,717	38	2,528	167	6,450
Petroleum:	1,713	19,310	7,109	1,088	29,220
Gas Liquids	867	-	92	-	959
Gasoline	-	6,438	-	-	6,438
Kerosene and Jet Fuel	846	921	193	-	1,960
Diesel	-	11,951	1,633	50	13,634
Bunker C	-	-	5,191	1,038	6,229
Wood	17,426	-	791	-	18,217
Biomass	-	-	5,651	-	5,651
Charcoal	360	-	-	-	360
Coke	-	-	13	-	13
Feed Material	-	-	-	758	758
Total*	23,216	19,348	16,092	2,013	60,669
% of Total	38.3	31.9	26.5	3.3	

*May not add due to conversion round off.

Costa Rican energy consumption (Republica de Costa Rica, 1980). Imported petroleum is the key fuel for these sectors amounting to 44 percent (7,109 TJ) of their total energy consumption. The petroleum products consumed are almost entirely Bunker C and diesel representing 73 and 23 percent, respectively, of the total petroleum consumed. Of the remaining 56 percent of energy consumption in the industrial and agro-industrial sector, biomass fuels account for 40 percent (6,442 TJ) and electricity 16 percent (2,528 TJ). The pie-charts shown in Figure 2-2 summarize this information.

Figure 2-3 indicates the growth rates and relative shares of commercial energy* consumption by economic sector in Costa Rica. After transportation, the industrial and agro-industrial sector is the second largest commercial energy consuming sector in Costa Rica.** Its share of the total commercial energy consumption has declined slightly from 41 percent in 1965 to 37 percent in 1979. However, the magnitude of commercial energy consumed has increased by 2.8 times from 5,417 TJ in 1965 to 15,300 TJ in 1979 (Republica de Costa Rica, 1981).

*Commercial energy consumption accounts for only that portion of energy directly purchased by the sector. It does not include any energy resources generated and consumed within the sector.

**While the residential and commercial sector is the largest total energy consuming sector, commercial energy in this sector accounts for only 25 percent of consumption. Approximately 75 percent of energy consumption in this sector is wood that is not accounted for commercially (Republica de Costa Rica, 1981).

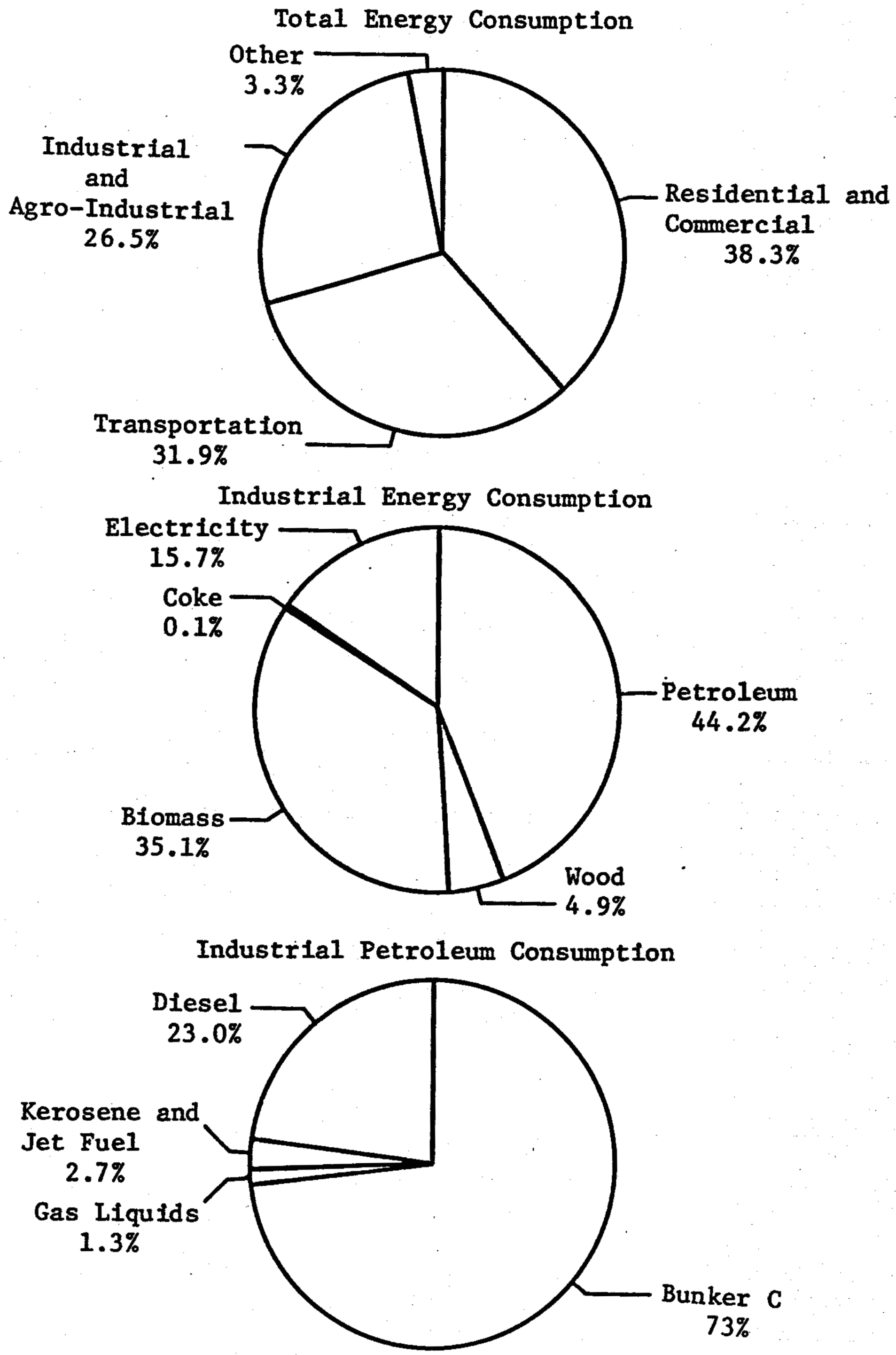
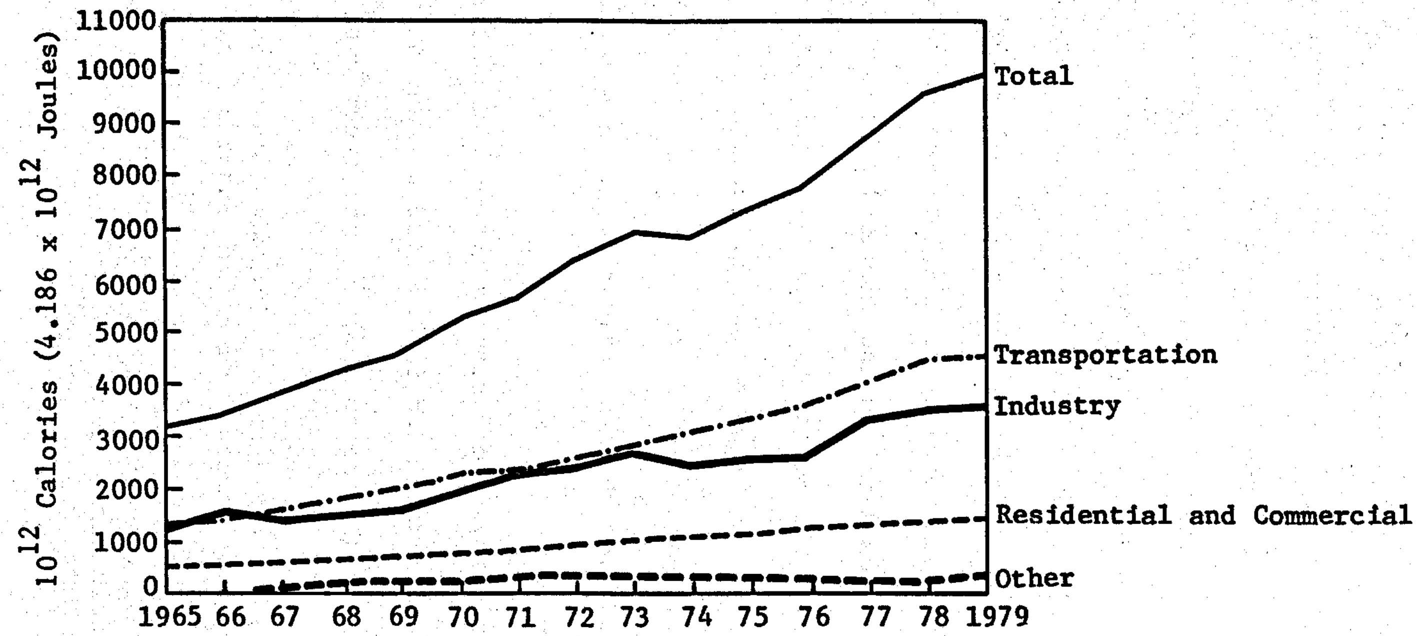


FIGURE 2-2
1979 ENERGY CONSUMPTION IN COSTA RICA



SOURCE: República de Costa Rica

FIGURE 2-3
HISTORICAL CONSUMPTION OF COMMERCIAL ENERGY IN COSTA RICA

Table 2-II and Figure 2-4 present historical data on the types of commercial energy consumed in the industrial and agro-industrial sector. The data indicate that the total consumption of commercial energy has increased at the average annual rate of 7.5 percent per annum. However, the different types of fuel have experienced varying growth rates over this period. Bunker C and electricity have increased fairly steadily growing at annual average rates of 8.5 percent and 12 percent, respectively. Biomass fuel use has been increasing at an average rate of 6 percent over the period 1965 to 1979. The use of biomass fuels actually declined between 1973 and 1975. The consumption of diesel oil in the industrial sector has fluctuated considerably over the period 1965 to 1979. Figure 2-4 shows the dramatic increases and decreases during this period. Major price increases for diesel in February of 1974 and again in August of 1979 help explain the shifts in diesel consumption.

2.3 Industrial Structure

The food products industry* dominates the industrial sector of Costa Rica. These sectors accounted for over 50 percent of the gross value of industrial production in 1977.** The contribution

*Food products industry is defined here to include industries listed under the CIIU (Clasificacion Industrial Internacional Uniforme) codes 311 thru 313.

**The most recent disaggregated data available for the industrial sector was for 1977 (World Bank, 1980a).

TABLE 2-II

INDUSTRIAL AND AGRO-INDUSTRIAL ENERGY CONSUMPTION: 1965 THRU 1979

(In 10^{12} Joules)

Year	ENERGY							
	Electricity	Liquid Gas	Kerosene	Diesel	Bunker C	Coke	Biomass*	Total
1965	493	11	-	748	1,647	5	2,519	5,423
1967	621	23	-	217	1,846	6	3,147	5,860
1969	782	35	-	388	2,229	7	3,483	6,924
1971	1,112	65	-	1,822	2,599	9	3,739	9,347
1973	1,317	92	-	2,391	3,026	12	4,712	11,549
1975	1,412	122	-	1,345	3,580	11	4,647	11,118
1977	1,780	138	-	2,263	4,553	14	5,050	13,797
1979	2,528	92	193	1,633	5,191	13	5,650	15,300

*Includes only commercial biomass fuels.

SOURCE: República de Costa Rica, 1981.

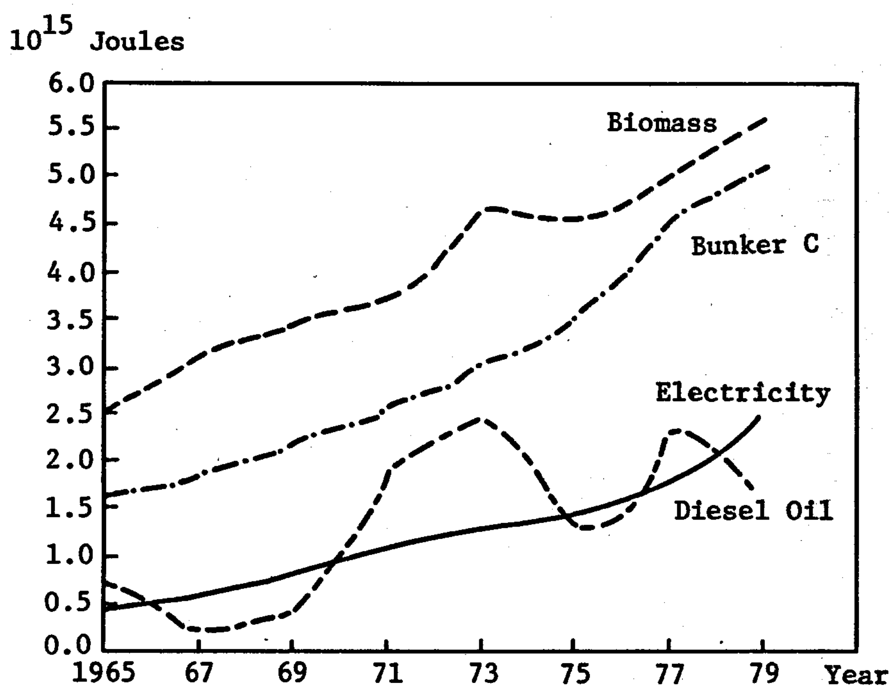


FIGURE 2-4
INDUSTRIAL AND AGRO-INDUSTRIAL ENERGY CONSUMPTION: 1965 THROUGH 1979

of the remaining sectors is well distributed with no single sector exceeding five percent of the gross value of industrial production. Heading this list are textiles and clothing. Table 2-III presents a list of the primary industrial sectors and their 1977 gross value of production.

The food products industry, because of its size, diversity and importance to the Costa Rican economy is further sub-divided for this study into the following major sub-sectors:

- Coffee products
- Meat products
- Dairy products
- Grain mill products
- Fishery products
- Bakery, sugar and confectionary products
- Other food products

The agro-industrial sector is also an important sector of the Costa Rican economy accounting for 18 percent of GDP. The major agro-industries considered are:

- Coffee beneficiation
- Banana and fresh fruit crop irrigation and packing
- Sugar processing
- Rice and grain milling
- Cattle and related activities

TABLE 2-III

1977 GROSS VALUE OF PRODUCTION IN COSTA RICAN INDUSTRY

CIIU	INDUSTRY	1977 GROSS VALUE OF PRODUCTIONS
	Consumer Goods	10,551.7
311-312	Food Products	7,371.3
313	Beverages	838.4
314	Tobacco Manufacturers	269.7
322	Clothing	530.8
324	Footwear	109.1
332	Furniture and Fixtures	283.3
342	Printing, Publishing	218.4
3522	Medicines and Pharmaceuticals	306.0
3523	Soaps, Perfumes, Cosmetics	181.7
284	Transport Equipment	393.5
39	Other Manufacturers	49.5
	Intermediate Goods	4,381.1
321	Textiles	633.6
323	Leather Products	76.8
331	Wood Products	500.4
341	Paper Products	425.5
351	Industrial Chemicals	519.9
3521	Paints, Varnish, Lacquer	103.2
3529	Other Chemicals	101.3
353	Petroleum Refining	495.8
354	Petroleum and Coal Products	4.8
355	Rubber Products	245.0
356	Plastic Products	314.1
361	Clay and Porcelain Products	22.3
362	Glass Products	28.1
369	Other non-metallic Minerals Products	338.6
371	Iron and Steel	127.5
381	Metal Products	414.2
	Capital Goods	571.7
382	Mechanical Machinery	170.0
383	Electrical Machinery	401.7
	TOTAL	15,504.5

Source: (World Bank, 1980a)

- Fishing
- Crop spraying

2.4 Current Petroleum Use - By Sub-sector and Process Energy

One of the major objectives of this study was to identify primary opportunities for substitution of electricity and other alternative energy sources for petroleum use in Costa Rica's industrial sector. In order to determine the primary opportunities, an initial assessment of the magnitude and purpose (i.e., process energy need) of petroleum use in Costa Rica's industrial sector was required. A literature survey, prior to initiation of this study, revealed that data were available for industrial petroleum use only at the sectoral level. No data were available at the industrial sub-sector level or disaggregated by industrial process energy need. Therefore a primary task of this study was to estimate industrial petroleum consumption by industrial sub-sector and by process energy need. The section below describes how this task was accomplished. The results are presented in matrix form in Section 2.4.4.

2.4.1 Methodology

The methodology used for determining Costa Rica's industrial petroleum consumption by industrial sub-sector and by process energy needs is briefly outlined below.

- Obtain annual industrial petroleum consumption data at the sub-sector level of disaggregation.

- Identify the major petroleum consuming industrial sub-sectors.

- Identify the industrial sub-sectors of major economic importance to Costa Rica.

- Map the industrial sub-sectors that are both major petroleum consumers and economically important to Costa Rica.

- Select specific industries within this map of industrial sub-sectors for a preliminary survey of current energy use patterns and process energy needs.

- Conduct on site visits and/or questionnaire surveys of those industries identified.

- Gather additional literature on industrial energy processes for all other industries representative of Costa Rica.

- Finally, synthesize the data obtained from the industrial survey and the literature with the industrial sub-sector consumption data to estimate the process energy needs that correspond to current petroleum energy use. Present this information in an industrial petroleum use matrix that correlates petroleum product consumption to industrial process energy needs.

2.4.2 Data Sources

In order to obtain most of the data required by the above methodology, the study was initiated with a two week data gathering mission to Costa Rica. During these two weeks the study team contacted over 15 government and industrial institutions and 14 specific industries (see Appendix A for the list of institutions and industries contacted). The 14 industries contacted represented 28 percent of total industrial diesel consumption and 57 percent of total industrial Bunker C consumption. A brief discussion of the key data and sources obtained for this study is presented below.

Accurate data on total petroleum use in Costa Rica is available from RECOPE, the sole national petroleum importing, refining and distributing authority. Therefore, all petroleum consumed in Costa Rica passes through RECOPE's accounts. RECOPE provides monthly and annual petroleum consumption data, at varying levels of disaggregation, for the following petroleum products:

- gasoline
- diesel
- kerosene
- jet fuel
- aviation gas
- Bunker C
- liquefied petroleum gas (LPG)
- asphalts

This data is presented for the following sectors:

- Public sector (i.e., direct government purchases)
- Pumps (i.e., retail pumping stations)
- Transportation sector (i.e., direct transport industry purchases)
- Agriculture, agro-industrial and fishing sector (i.e., direct purchase)
- Industrial sector (i.e., direct industry purchases)
- Commercial sector (i.e, direct purchases)
- Retailers (i.e., not included in pumping stations)
- Others (i.e., not included elsewhere)

As the data reflect direct purchases from RECOPE by sector, the data are not a true accounting of sectoral energy consumption. For example, it was determined from the industrial survey that almost all gasoline and a portion of diesel purchases in the industrial sector are used for transportation. Similarly, some industrial firms purchase small quantities of diesel and kerosene, which are credited to the categories of retailers and pumps. For the purposes of this study, all gasoline purchases by industry were assumed to be used for transportation. Transportation use of industrially purchased diesel was estimated based on data obtained in the industrial survey.

RECOPE reports monthly petroleum consumption for its direct sales to each specific industry in the industrial and agro-industrial sector. This accounts for more than 95 percent of the total Costa Rican industrial petroleum consumption.* RECOPE data for 1980 was used for this study.

Specific industries in the RECOPE data base were allocated to the industrial sub-sectors (listed on Table 2-III) based on information obtained from the Industrial Directory of Costa Rica (Camara de Industrias, 1980). Through a cross-referencing index in this directory, specific industries were matched to their associated Clasificacion Industrial Internacional Uniforme (CIIU) number. In addition, the staff of the Ministry of Minerals and Energy

*The remaining 5 percent of industrial consumption is assumed to be included in the retailers and pumps category.

investigated and provided classifications for the approximately 10 percent of industries listed in the RECOPE data base but not listed in the industrial directory.

Data on energy process needs (i.e., steam, hot water, process heat, etc.) within each industrial category were obtained from two main sources: the industrial survey conducted as part of this study; and the literature available in the United States for industries similar to those in Costa Rica. The industrial survey, as indicated, represented 28 percent of industrial diesel consumption and 57 percent of industrial Bunker C consumption. Examples of the questionnaire and data collected by this survey are shown in Appendix B. Published data on industrial process needs were obtained primarily from the following sources:

- "Energy Analysis of 108 Industrial Process," Drexel University, 1979
- "Energy Use in the Food System," Booz-Allen and Hamilton, Inc., 1976
- "Energy-Saving Techniques for the Food Industry," M.G. Casper, 1977
- "Agriculture and Energy," William Lockeretz, 1977

2.4.3 Disaggregated Consumption

The total 1980 petroleum consumption in the industrial and agro-industrial sector amounted to 8.058 x 10^3 TJ (1.34 x 10^6 BBL). Of this, the industrial sector accounted for 81 percent and the agro-industrial sector for the remaining 19 percent.

This section presents data, derived in this study, on the petroleum consumed by the sub-sector industries within the industrial and agro-industrial sectors. From this disaggregated data, and with information gathered in an industrial survey, estimates of the process use of petroleum fuels (i.e., for steam generation, low or high temperature process heat, etc.) were derived. These estimates are presented in Section 2.4.4.

Industrial Sector

Table 2-IV presents the 1980 industrial petroleum consumption at the three and four digit CIIU level. This results in a disaggregation of the data into 30 sub-sectors. The top ten petroleum consuming sub-sectors are listed in order of decreasing consumption in Table 2-V. In total, they account for 93 percent of the sector's consumption.

In 1980, as in the past, the major petroleum product used in the industrial sector was Bunker C. Bunker C consumption reached 740.8×10^3 BBL in 1980, equivalent to 68 percent of the total industrial petroleum consumption. Diesel consumption was the next highest at 266.8×10^3 BBL. Only 9 percent of industrial petroleum consumption was made up by gasoline, kerosene, jet fuel and asphalts.

CIIU 369 (other non-metalic mineral products) is the largest petroleum consuming industrial sub-sector accounting for 348.6×10^3 BBL or equivalently 32 percent of the 1980 industrial petroleum

TABLE 2-IV

1980 INDUSTRIAL SECTOR PETROLEUM CONSUMPTION
(IN BBL)

CIIU#	Industry	Fuel					
		Gasoline	Diesel	Bunker C	Kerosene	Other	Total
	Consumer Goods						
311	Food Products	3,866	65,259	102,391	14,906	—	186,420
313	Beverages	1,429	16,572	36,021	—	—	54,022
314	Tobacco Mnfg.	120	—	4,995	—	—	5,115
322	Clothing	—	2,486	5,528	—	—	8,014
324	Footwear	—	—	—	—	—	—
332	Furniture and Fixtures	—	888	2,356	—	—	3,244
342	Printing and Publishing	—	—	—	—	—	—
3522	Medicines and Pharmaceuticals	—	1,291	—	—	—	1,291
3523	Soaps, Perfumes, Cosmetics	—	432	—	599	—	1,031
384	Transport Equipment	—	—	—	—	—	—
39	Other Manufactures	—	3,570	—	24	—	3,594
	Intermediate Goods						
321	Textiles	—	9,179	31,877	—	1	41,057
323	Leather Products	—	311	5,829	—	—	6,140
331	Wood Products	—	4,985	11,936	—	—	16,921
341	Paper Products	740	5,119	37,374	—	—	43,233
351	Industrial Chemicals	—	302	752	—	—	1,054
3521	Paints, Varnish, Lacquer	—	2,928	144	—	12	3,084
3529	Other Chemicals	216	2,369	61,014	1,478	—	65,077
353	Petroleum Refining	—	—	—	—	—	—
354	Petroleum and Coal Products	—	—	—	—	—	—
355	Rubber Products	144	2,400	17,311	—	—	19,855
356	Plastic Products	—	965	143	—	—	1,108
361	Clay and Porcelain Products	—	9,510	5,168	285	—	14,963
362	Glass Products	—	561	44,966	14,881	—	60,408
369	Other Non Metallic Mineral Products	336	14,126	334,177	—	—	348,639
371	Iron and Steel	—	—	2,356	—	—	2,356
381	Metal Products	624	7,848	30,481	—	—	38,953
	Unknown	384	1,490	816	—	44	2,734
	Capital Goods						
382	Mechanical Machinery	—	—	—	—	—	—
383	Electrical Machinery	264	1,327	—	—	—	1,591
500	Construction and Mining	2,935	102,888	5,145	—	49,559	160,527
	TOTAL	11,058	256,806	740,780	32,173	49,616	1,090,433

TABLE 2-V

TOP TEN PETROLEUM CONSUMING INDUSTRIAL SUB-SECTORS

CIIU	Industry	1980 Petroleum Consumption in 10^3 BBL	Cumulative Percent of Industrial Consumption
369	Other non-Metalic Mineral Products	348.6	32%
311	Food Products	186.4	49%
500	Construction and Mining	160.5	64%
3529	Other Chemicals	65.0	70%
362	Glass Products	60.4	75%
313	Beverages	54.0	80%
341	Paper Products	43.2	84%
321	Textiles	41.1	88%
381	Metal Products	38.9	92%
355	Rubber Products	19.9	93%

consumption. This sub-sector is dominated by two cement industries which account for 96 percent of the total consumption. They are:

- Industria Nacional de Cemento, S.A. 296.4×10^3 BBL
- Cemento del Pacifico, S.A. 37.9×10^3 BBL

Industria Nacional de Cemento is the single largest industrial petroleum consumer in Costa Rica. It consumed 291.7×10^3 BBL of Bunker C, 4.3×10^3 BBL of diesel, and 0.3×10^3 BBL of gasoline in the process of producing 430.0×10^3 tonnes of cement products in 1980.

The food products sub-sector is the second largest petroleum consuming sub-sector accounting for 186.4×10^3 BBL or 17 percent of 1980 industrial consumption. Table 2-VI presents petroleum consumption data for the major categories in this subsector. The dairy products industry is the largest energy consumer within this sub-sector accounting for 41 percent of the petroleum consumption. The meat products, grain mill products and fishery products industries are also major energy consumers. Like the non-metalic mineral products industry, a few large consumers dominate the food products industry. The five largest petroleum consumers account for 65 percent of the sub-sector consumption. The remaining petroleum is consumed by approximately 45 smaller industries.

Construction and mining is the third largest petroleum consuming industrial sub-sector accounting for 160.5×10^3 BBL of

TABLE 2-VI

1980 FOOD PRODUCTS SUB-SECTOR PETROLEUM CONSUMPTION
(IN BBL)

Food Production Sub-Sector	Fuel				
	Gasoline	Diesel	Bunker C	Kerosene	Total
• Coffee Processing	0	3,920	2,796	24	6,740
• Meat Products	467	1,938	25,175	0	27,580
• Dairy Products	3,085	23,147	50,394	-	76,626
• Grain Mill Products	-	3,672	6,033	14,882	24,587
• Fishery Products	-	23,085	3,144	-	26,229
• Bakery, Sugar & Confectionary Products	-	2,279	-	-	2,279
• Other Food Processing	312	7,218	14,849	-	22,379
• Total	3,864	65,259	102,391	14,906	186,420

petroleum consumption. However, 50×10^3 BBL of this consumption are asphalts with no practical energy value. In addition, diesel represent 64 percent of its total petroleum consumption, much of which is used to operate heavy transport, construction and mining equipment. This sub-sector has approximately 25 individual industries and is not dominated by a few large petroleum consumers.

CIIU 3529, other chemical, is the fourth largest petroleum consuming industrial sub-sector. It is dominated by a fertilizer manufacturer, Fertilizantes de Centro America (Fertica) S.A., located in Puntarenas, near the Pacific coast. In 1980, Fertica consumed 63.4×10^3 BBL of petroleum accounting for 97 percent of the petroleum consumed in this sub-sector. Bunker C accounted for 61.0×10^3 BBL of the petroleum consumed by Fertica and was utilized to produce 270,000 tonnes of fertilizer products.*

The glass products industry is the fifth largest petroleum consuming industrial sub-sector. It is also dominated by a single industry, Vidriera C.A., S.A., which accounts for 98 percent of the petroleum consumption in this sub-sector. Bunker C accounts for 74 percent and kerosene for 25 percent of the total petroleum consumed in this sub-sector.

*Fertica also consumes 68,500 tonnes of imported ammonia (derived from natural gas) in the process of producing fertilizers (estimate provided by Ing. Manuel E. Arias A., Gerente General, Fertilizantes de Centro America [Costa Rica] S.A., San Jose, Costa Rica).

The top five petroleum consuming industrial sub-sectors account for 75 percent of the total industrial petroleum consumption. The next five account for an additional 18 percent. Thus, of the total thirty industrial sub-sectors the remaining twenty industrial sub-sectors account for only 7 percent of the total industrial petroleum consumption.

Agro-Industrial Sector

Table 2-VII presents the 1980 petroleum consumption data for the major sub-sector industries in the agro-industrial sector. Eight sub-sector industries are identified. Total 1980 petroleum consumption in this sector was 252.8×10^3 BBL or equivalent to 1.46×10^{15} J. Diesel was the major petroleum fuel consumed in this sector accounting for 82 percent of the total. Bunker C accounted for 10 percent with gasoline, kerosene and jet fuel accounting for the remaining 8 percent.

The largest petroleum consuming sub-sector in the agro-industrial sector is the banana and fresh fruit producers. Total consumption in this sub-sector accounted for 137.8×10^3 BBL or 54 percent of the total sector consumption. The majority of petroleum consumed was diesel used for powering electric generators. Many of the banana and fresh fruit producers are located in remote areas of the country not presently serviced by the electricity grid. They require electricity for irrigation, washing and packing operations

TABLE 2-VII

1980 AGRO-INDUSTRIAL SECTOR PETROLEUM CONSUMPTION
(IN BBL)

Agro-Industry	Fuel					
	Gasoline	Diesel	Bunker C	Kerosene	Av. Gas	Total
Coffee Beneficiation*	5,032	34,412	2,510	-	-	41,954
Bananas and Fresh Fruit Producers	9,236	112,498	16,018	24	24	137,800
Sugar Producers	2,249	37,933	1,371	-	-	41,553
Rice and Grain Milling		5,976	-	-	-	5,976
Cattle and Related Activities	-	1,876	4,119	-	-	5,995
Fishing	-	5,858	-	-	-	5,858
Crop Spraying	-	-	-	-	4,450	4,450
Other	-	9,152	142	-	-	9,294
Total	16,517	207,705	24,160	24	4,474	252,880

*Coffee beneficiation is defined here to include all activities from pulping, fermenting, washing, drying, storage and husking. It does not include roasting, grinding and instant coffee production which are activities allocated to the food-products sub-sector of the industrial sector.

and for employee residential consumption. With diesel prices increasing in Costa Rica, these producers are investigating the costs of connecting to the electricity grid.

Coffee beneficiators* and sugar producers** each consumed approximately 42×10^3 BBL of petroleum. Again, the majority of this consumption was for diesel fuel. A significant portion (4.5×10^3 BBL) of aviation fuel was also consumed in 1980 in the agro-industrial sector for crop spraying activities. Grain milling, cattle raising, fishing and other agro-industrial related activities accounted for 27.1×10^3 BBL or approximately 11 percent of the agro-industrial sector consumption in 1980.

2.4.4 Petroleum-Process Energy Matrices

Petroleum derived fuels, like other fuels, are consumed to provide working forms of energy such as heat, mechanical energy or chemical energy. Fuels, such as petroleum, natural gas, coal, solar

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*Activities up to coffee beneficiation are allocated to the agro-industrial sector while coffee roasting, instant coffee production, etc., are allocated to the food products sub-sector of the industrial sector. An industry engaged in both sets of activities is allocated to the sector of its most dominant activity.

**Sugar producers include industries engaged in the growing, harvesting and collection of the sugar cane. Sugar refining is allocated to the food products sub-sector of the industrial sector.

biomass, or electricity* are generally substitutable for generating a particular end-use energy form. In each case, a specific fuel is selected because of inherent economic and technical advantages. As economic and technical conditions change, so will fuel use patterns.

The objective of this study, because of recent changes in fuel prices in Costa Rica, is to determine the technical and economic feasibility of converting industrial petroleum use in Costa Rica to electricity or other alternative fuels. An estimate of the present use of petroleum fuels is a precursor to this determination. In this section, data are presented on estimates of the process energy needs met by petroleum use in the industrial and agro-industrial sector. The methodology and data sources used to derive these estimates are outlined in Sections 2.4.1 and 2.4.2, respectively. The data presented here must be considered as preliminary but it does provide, for the first time, reasonably accurate estimates of petroleum use in the industrial and agro-industrial sectors of Costa Rica.

Process energy needs are categorized as follows:

- Steam
- Hot water
- Low temperature process heat (less than 100°C)
- High temperature process heat (greater than 100°C)

*Electricity, though strictly not a fuel, is included in the general list of fuels because it can be converted to provide the same working forms of energy as conventional fuels.

- Mechanical energy
- Transportation*
- Electricity generation

A matrix of the 1980 petroleum consumption and resulting process energy needs or energy products for the industrial and agro-industrial sector is shown in Table 2-VIII (in TJ/yr) and Table 2-IX (in 10^3 BBL/yr).

The conversion to high temperature process heat represents the largest consumption of petroleum fuels accounting for 3.4×10^3 TJ or 42 percent of the energy value of the petroleum fuels consumed in the sector. Approximately 90 percent of the petroleum used to generate this high temperature process heat is Bunker C, the majority of which is used by the cement industry in Costa Rica.

Steam raising for industrial processes represents the second largest consumption of petroleum in the industrial and agro-industrial sector (23 percent of the total). Again, Bunker C accounts for the majority (approximately 80 percent) of the total energy value of petroleum used to generate steam.

Approximately 11 percent of the petroleum purchased is used for transportation purposes. This included 26 percent of the total

*Transportation as a process energy need should not be included in the industrial or agro-industrial sector but should be attributed to the transportation sector. However, many industries that purchase directly from RECOPE use part or all of their gasoline and diesel purchases to operate their vehicles for transportation.

TABLE 2-VIII

1980 ENERGY PRODUCT MATRIX FOR THE INDUSTRIAL AND AGRO-INDUSTRIAL SECTOR (IN TJ)

Petroleum Consumption in TJ/yr	Gasoline	Diesel	Bunker C	Kerosene	Av. Gas	Asphalts	Total	Percent of Sector Total
Steam	--	367	1,472	--	--	--	1,839	22.8
Hot Water	--	19	130	--	--	--	149	1.8
Low Temperature Process Heat	--	195	140	85	--	--	420	5.2
High Temperature Process Heat	--	259	3,001	91	--	--	3,351	41.6
Motors	--	407	--	--	--	--	407	5.1
Transport	143	686	--	--	24	--	853	10.6
Electricity	--	751	--	--	--	--	751	9.3
Other	--	--	--	--	--	287	287	3.6
Total	143	2,685	4,743	176	24	287	8,058	100

TABLE 2-IX
1980 ENERGY PRODUCT MATRIX FOR THE INDUSTRIAL AND AGRO-INDUSTRIAL SECTOR
(IN 10^3 BBL)

Petroleum Consumption in 10^3 BBL/yr	Gasoline	Diesel	Bunker C	Kerosene	Av. Gas	Asphalts	Total
Steam	--	63.4	237.5	--	--	--	300.9
Hot Water	--	3.3	20.9	--	--	--	24.2
Low Temperature Process Heat	--	33.8	22.5	15.5	--	--	71.8
High Temperature Process Heat	--	44.8	484.1	16.6	--	--	545.5
Motors	--	70.4	--	--	--	--	70.4
Transport	27.6	118.8	--	--	4.5	--	150.9
Electricity	--	130.0	--	NEG	NEG	--	32.2
Other	--	--	--	--	--	49.6	49.6
Total	27.6	464.5	765.0	32.1	4.5	49.6	1,343.3

diesel purchases in the sector and all of its gasoline and jet fuel purchases.* Over 9 percent of the sector's petroleum consumption is used to generate electricity almost exclusively by the use of diesel. Of the remaining petroleum consumption in industry, 5 percent is used for low temperature process heat, another 5 percent for stationary mechanical energy, 2 percent for generating hot water and approximately 4 percent for non-energy feed materials such as asphalts.

Tables 2-X thru 2-XV present the data on petroleum consumption versus process energy needs for various levels of disaggregation. Key observations from this data are summarized below:

- High temperature process heat and steam raising are the major uses for petroleum in the industrial sector accounting for 51** and 26 percent of the total petroleum consumption respectively.

- Steam raising and low temperature process heat are the predominant uses for petroleum in the food products sub-sector accounting for 58 and 21 percent of the total petroleum consumption respectively in that sub-sector.

- Transportation accounts for 15 percent of the petroleum purchases in the food products sector.

- Diesel use for electricity generation accounts for 51 percent of the petroleum use in the agro-industrial sector.

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*The energy balance data published for Costa Rica (Republica de Costa Rica, 1980) allocates all industrial purchases of gasoline and jet fuel to the transportation sector but does not account for any diesel consumption for transportation. The industrial survey conducted for this study, however, revealed that some industrial diesel purchases are used for transportation.

**Of the 545.5 x 10^3 BBL/yr of petroleum consumption for high temperature process heat, 59 percent is accounted for by two cement industries and 11 percent by one glass products industry.

- Transportation accounts for 30 percent of the petroleum purchases in the agro-industrial sector.

- Steam and low temperature heat requirements consume 18 percent of the petroleum use in the agro-industrial sector.

TABLE 2-X
1980 ENERGY PRODUCT MATRIX FOR THE INDUSTRIAL SECTOR
(IN TJ)

Petroleum Consumption in TJ/yr	Gasoline	Diesel	Bunker C	Kerosene	Av. Gas	Asphalts	Total	Percent of Sector Total
Steam	--	367	1,363	--	--	--	1,730	26.2
Hot Water	--	19	104	--	--	--	123	1.9
Low Temperature Process Heat	--	58	124	85	--	--	267	4.1
High Temperature Process Heat	--	259	3,001	91	--	--	3,351	50.8
Motors	--	407	--	--	--	--	407	6.1
Transport	57	361	--	--	--	--	418	6.3
Electricity	--	13	--	--	--	--	13	0.2
Other	--	--	--	--	--	287	287	4.4
Total	57	1,484	4,592	176	0	287	6,596	100

TABLE 2-XI
1980 ENERGY PRODUCT MATRIX FOR THE INDUSTRIAL SECTOR
(IN 10^3 BBL)

Petroleum Consumption in 10^3 BBL/yr	Gasoline	Diesel	Bunker C	Kerosene	Av. Gas	Asphalts	Total
Steam	—	63.4	219.9	—	—	—	283.3
Hot Water	—	3.3	16.9	—	—	—	20.2
Low Temperature Process Heat	—	10.1	20.0	15.5	—	—	45.6
High Temperature Process Heat	—	44.8	484.1	16.6	—	—	545.5
Motors	—	70.4	—	—	—	—	70.4
Transport	11.1	—	—	—	—	—	11.1
Electricity	—	2.2	—	—	—	—	2.2
Other	—	—	—	—	—	49.6	49.6
Total	11.1	256.7	740.9	32.1	—	49.6	1,090.4

TABLE 2-XII
1980 ENERGY PRODUCT MATRIX FOR THE FOOD PRODUCTS SUB-SECTOR
(IN TJ)

Petroleum Consumption in TJ/yr	Gasoline	Diesel	Bunker C	Kerosene	Av. Gas	Asphalts	Total	Percent of Sector Total
Steam	--	179.7	462.0	--	--	--	641.7	57.6
Hot Water	--	--	48.6	--	--	--	48.6	4.4
Low Temperature Process Heat	--	29.2	124.2	81.7	--	--	235.1	21.1
High Temperature Process Heat	--	13.2	--	--	--	--	13.2	1.2
Motors	--	--	--	--	--	--	0.0	0.0
Transport	20.1	142.2	--	--	--	--	162.3	14.6
Electricity	--	12.9	--	--	--	--	12.9	1.1
Other	--	--	--	--	--	--	0.0	0.0
Total	20.1	377.2	634.8	81.7	0.0	0.0	1.113.8	100

TABLE 2-XIII
1980 ENERGY PRODUCT MATRIX FOR THE FOOD PRODUCTS SUB-SECTOR
(IN 10^3 BBL)

Petroleum Consumption in 10^3 BBL/yr	Gasoline	Diesel	Bunker C	Kerosene	Av. Gas	Asphalts	Total
Steam	--	31.1	74.5	--	--	--	105.6
Hot Water	--	--	7.8	--	--	--	7.8
Low Temperature Process Heat	--	5.1	20.0	14.9	--	--	40.0
High Temperature Process Heat	--	2.3	--	--	--	--	2.3
Motors	--	--	--	--	--	--	--
Transport	3.9	24.6	--	--	--	--	28.5
Electricity	--	2.2	--	--	--	--	2.2
Other	--	--	--	--	--	--	--
Total	3.9	65.3	102.3	14.9	0.0	0.0	186.4

TABLE 2-XIV
1980 ENERGY PRODUCT MATRIX FOR THE AGRO-INDUSTRIAL SECTOR
(IN TJ)

Petroleum Consumption in TJ/yr	Gasoline	Diesel	Bunker C	Kerosene	Av. Gas	Asphalts	Total	Percent of Sector Total
Steam	--	--	109	--	--	--	109	7.5
Hot Water	--	--	25	--	--	--	25	1.7
Low Temperature Process Heat	--	137	16	--	--	--	153	10.5
High Temperature Process Heat	--	--	--	--	--	--	--	--
Motors	--	--	--	--	--	--	--	--
Transport	86	325	--	--	24	--	435	29.8
Electricity	--	738	--	--	--	--	738	50.5
Other	--	--	--	--	--	--	--	--
Total	86	1,200	150	--	24	--	1,460	100

TABLE 2-XV
1980 ENERGY PRODUCT MATRIX FOR THE AGRO-INDUSTRIAL SECTOR
(IN 10^3 BBL)

Petroleum Consumption in 10^3 BBL/yr	Gasoline	Diesel	Bunker C	Kerosene	Av. Gas	Asphalts	Total
Steam	--	--	17.6	--	--	--	17.6
Hot Water	--	--	4.1	--	--	--	4.1
Low Temperature Process Heat	--	23.6	2.5	--	--	--	26.1
High Temperature Process Heat	--	--	--	--	--	--	--
Motors	--	--	--	--	--	--	--
Transport	16.5	56.3	--	--	4.5	--	77.3
Electricity	--	127.8	--	NEG	NEG	--	127.8
Other	--		--	--	--	--	
Total	16.5	207.7	24.2	NEG	4.5	--	252.9

3.0 CONVENTIONAL INDUSTRIAL ENERGY TECHNOLOGIES AND POTENTIAL ELECTRIC SUBSTITUTES

This section briefly describes the conventional petroleum-based energy production systems which are currently being used in the industrial and agro-industrial sectors of Costa Rica. The information presented here to a large extent, is based on the preliminary industrial survey conducted during the in-country field trips. However, general descriptions of some standard industrial energy supply systems are also included to illustrate their operation. In addition, brief descriptions of electric technologies which can be potentially substituted for the conventional energy production systems are also included.* Finally, based on the technical feasibility, the maximum potential of substituting electricity for petroleum-derived fuels in both the industrial and agro-industrial sectors is estimated. The economic feasibility of such substitutions is estimated for a number of selected systems in Section 5.0.

3.1 Existing Industrial/Agro-Industrial Energy Technologies

The brief survey of industries in Costa Rica indicated that petroleum-derived fuels are primarily consumed to produce usable forms of energy such as process steam/hot water, low and high temperature process heat, mechanical power and on-site electricity

*The information on potential electric technology substitutes is based on several previous MITRE studies (see Harlow, 1976; Lord, 1978; Muradaz, 1980; Barbier, 1976; Ettlinger, 1979; Borko, 1978; and Ouellette, 1981).

generation. Detailed statistical data on the consumption of petroleum-derived fuels by industrial sub-sectors and type of application (i.e., energy form produced) are given in Section 2.0.

The manner in which petroleum-derived fuels like diesel or Bunker C oil are used to produce required process energy is generally similar among industrial sectors. The quantities and types of petroleum derived fuels used, however, vary for different industrial sectors (see Section 2.0). For example, the non-metallic mineral products sector essentially consumes Bunker C oil for the production of high temperature process heat used in cement manufacturing. In contrast, the food products sector uses a combination of diesel and Bunker C oil to produce low temperature process heat and steam/hot water for supplying its process energy needs. The use of diesel fuel for producing on-site mechanical and electrical power is predominant in the construction and mining sub-sector and through the agro-industrial sector.

A summary of typical petroleum fuel uses and resulting process energy characteristics for 14 major oil consuming industries that were surveyed in Costa Rica is given in Table 3-I. As shown in Table 3-I, petroleum fuels like, Bunker C, diesel oil, and kerosene are used to supply process steam/hot water, process heat and mechanical and/or electric power. The petroleum-fired technologies most commonly used for producing these energy forms can be grouped as follows:

TABLE 3-I

SUMMARY OF ENERGY USE INFORMATION FROM VISITS TO INDUSTRIES

COMPANY	BOILERS			OTHER USES		
	BHP (Units)	FUEL Type	FUEL 10^3 GJ/YR	Application (Units)	FUEL Type	FUEL 10^3 GJ/YR
1. Subproductora de Café[1]				Air Dryer[a] (Combustor)	Bunker	157
2. Demasa	60 (1)	Kerosene	28	Air Dryers[b] (Combustors)	Kerosene	111
				Cooking (Combustor)	Kerosene	18
3. Cooperativa de Leche	100 (6) 150 (1) 80 (2)	Bunker	82			
4. Compañía Bananera Costaricense	30 (2) 350 (4)	Bunker Palm Residue	14 221	Electrical Generation	Diesel	345
5. Cooperativa de Café (2)				Air Dryers (20)	Wood[e]	62
6. Coopemontecillos	200 (3) 400 (2) 500 (1)	Bunker	93			
7. TICA-TEX	300 (4)	Bunker	96			
8. STANDARD FRUIT	250 (2)	Bunker	28	Electrical Generation	Diesel	57
9. NUMAR	150 (1) 200 (1) 1,100 (1)	Bunker[3]	189	Dowtherm Heaters[c] (Combustors)	Bunker	37
10. CONSEJO NACIONAL DE PRODUCCION				Air Dryers (14)	Diesel	441
11. INDUSTRIA NACIONAL DE CEMENTO	75 (1)	Bunker		Cement Kilns (2) (Combustors)	Bunker	1924[d]
12. ZELEDON Y CIA[1]				Air Dryers (25)	Diesel Wood (5)	2 9
13. FERTILIZANTES DE CENTRO AMERICA	(4)	Bunker	354	Air Dryers	Bunker	59
14. BEEF PRODUCTS CO., Ltd.		Electric				

Notes: (a) Seasonal operation for four months only.

(b) Seasonal operation for four months only. Currently installing a coffee hull dryer with enough output to substitute all oil used at present.

(c) Average demand is 600 BHP.

(d) Includes 75 BHP consumption.

(e) Assumed wood at 495 MJ/m^3

- oil-fired boilers for steam and hot water
- oil-fired combustors for low (less than 100^oC) and high (greater than 100^oC) temperature process heat.
- internal combustion engines for on-site mechanical power and/or electricity.

Brief descriptions of these technologies follow. In addition, a brief description of the synthesis of a natural-gas and/or petroleum-based feedstock for ammonia production is also included. Costa Rica imports all of its ammonia which is produced from natural gas. However, the technology to produce ammonia via electrolysis produced hydrogen exists.

3.1.1 Oil-Fired Boilers

The most common industrial oil-fired energy conversion technology seen in Costa Rica is the conventional hot water or steam boiler. In MITRE's survey of 14 major oil consuming industries in Costa Rica, a total of 32 separate boilers were identified. These boilers range in size from 30 HP to 1100 HP with a median size of 200 HP. The majority of these boilers were fired by Bunker C with a few using diesel or kerosene.

A steam boiler is essentially a container into which water is continually fed and converted into steam by the application of heat. In oil-fired boilers the required heat is provided by burning a petroleum-derived liquid fuel in a combustion chamber, i.e., the furnace of a boiler. The standard furnace for small industrial boilers consists of a refractory-lined combustion chamber enclosed in a metal casing. Liquid fuels are first atomized, i.e., divided into minute particles, to provide proper mixing with the combustion air. Small oil-fired boilers generally use mechanical or air atomizers. The Bunker C oil, because of its high viscosity, requires pre-heating prior to fuel atomization. On most boilers, automatic devices control fuel feed rates to maintain a certain boiler header pressure and to fully proportion the fuel and air mixture to maintain efficient combustion.

Boilers can be broadly categorized into two types: (a) fire-tube, and (b) water-tube. In the fire-tube design, hot combustion gases pass through the tubes and heat transfers to the water surrounding the tubes on the shell side. In the water-tube design, heat from the hot combustion gases in the combustion chamber transfers to the water within the tubes.

Fire-tube boilers produce steam on the shell side. These boilers are limited to low steam pressures (less than 300 psig), quality (dryness), and capacities (less than 15,650 Kg [or 1000 HP] of stream per hour) because of the large diameters of the shell. Water-tube boilers in contrast eliminate these quality and capacity restrictions but are more expensive than fire-tube boilers. However, for most of the industrial applications in Costa Rica, fire-tube boilers can provide a better match with respect to steam demand and quality. Therefore, the majority of boilers currently operating in the industrial sector of Costa Rica are of fire-tube design.

In Costa Rica, typical process steam uses from boilers are for pasteurization of milk; processing of cheese; scalding, washing, and rendering of animal carcasses; leather tanning and drying; brewing of beer; processing soft drinks, and textile spinning, weaving, and finishing.

A list of typical temperature requirements for process energy applications in Costa Rican industries is shown in Table 3-II.

3.1.2 Oil-Fired Combustors (Heaters)

Hot combustion gases or hot air are required in many industrial applications. These combustion systems can be classified according to temperature requirements:

- Combustors for low temperature (less than 100°C) process heat, and
- Combustors for high temperature (more than 100°C) process heat.

As indicated in Table 3-I, the survey identified a total of 68 separate combustors. Almost all of them are used to provide hot air for direct drying applications. The most common burner capacity in Costa Rica is about 2.1 GJ per hour (2 MMBtu/hr). Many of these combustors use Bunker C or diesel fuel. In the case of diesel comcombustors, conversions to Bunker C or other alternate fuels is currently being contemplated. In the coffee industry there is an on-going conversion of the coffee bean driers to wood and coffee hull residue firing. These conversions will reduce consumption of

TABLE 3-II

LIST OF TYPICAL COSTA RICAN INDUSTRIAL PROCESS HEAT APPLICATIONS AND TEMPERATURE REQUIREMENTS

CIUU Number	Industry*	Temperature Requirement °C
311-312	FOOD PRODUCTS	
	MILK (3)	
	Pasteurization	75
	Evaporation-Drying	70-200
	Cheese (Condensing)	40-93
	Cleaning	60
	COFFEE (BENEFICIO) (4)	
	Bean Drying	85
	MEAT (5)	
	Scalding, Carcass washing and clean-up	60
	Singeing	260
	Rendering	93
	Cooking	68
323	LEATHER	
	Tanning	29-54
	Drying	43
321	TEXTILES (7)	
	Spinning	<100
	Weaving	<100
	Finishing	100
369	CEMENT (8)	
	Drying	150
	Calcining	1300

*Numbers in parentheses refer to the list of companies in Table 3-I.

liquid fuels currently being used to generate hot air for the coffee bean drying process.

A major industrial consumer of kerosene for process heat is a tortilla manufacturer. Kerosene is used for both grain drying and tortilla cooking. In the tortilla cooking process, vaporized kerosene is combusted in small individual flames placed in close proximity to the tortilla conveyor. The tortilla cooking takes place at 270^{o}C with a residence time of about 35 sec.

A typical combustor usually consists of a burner with auxiliary fuel and air handling systems and a combustion chamber where hot gases are generated. In direct drying applications, hot gases are subsequently diluted with the proper amount of air to obtain the required process temperature blown directly either in parallel or countercurrent with the flow of material. In other applications where the combustion gases might be detrimental to the quality of product, ambient air is heated indirectly by means of heat exchangers and passed over the process material.

The calcining kilns used in the portland cement manufacturing industry in Costa Rica are one example of high temperature process heat combustors. These kilns are direct-fired with Bunker C. The hot combustion gases pass counter current to the cement clinker (i.e., finely ground limestone and clay mixture) and heat transfers to the constituent materials to promote the cement formation reactions. The highest temperatures reached in the kilns range between

1400-1500°C. The cement industry is the single largest petroleum consuming industry in Costa Rica.

3.1.3 Internal Combustion Engines

Internal combustion (IC) reciprocating engines burn a fuel/air mixture to produce mechanical work. The mixture is first compressed in a cylinder by a moving piston and then ignites (or is ignited) and expands to push the piston and supply mechanical energy. IC engines are commonly divided into two types:

- spark ignition (SI) or otto cycle engines, commonly fueled with gasoline
- compression ignition (CI) or diesel cycle engines, commonly fueled with diesel.

In the SI engine a premixed fuel/air mixture is introduced into the cylinder, compressed by the piston, and ignited by a spark plug as the piston nears the top of its stroke. In diesel (CI) engines, the fuel is injected directly into the cylinder just as the piston nears the top of its stroke. The fuel ignites from the heat of the compressed air in the cylinder. In most cases no ignition devices are used so the fuel must be one which will self-ignite under these conditions.

Stationary engines of both types can be used to provide mechanical power for operating different industrial equipment. These engines can also be hooked to electric generators to produce electricity.

The stationary diesel engines are most commonly used to generate electricity in remotely located industrial and commercial facilities in Costa Rica. For example, diesel generated electricity is predominant in the southwest province of Puntarenas and the northeast provinces of Heredia, and Limon. In 1979 these three provinces alone accounted for 37.92 GWh, or 96 percent of the private diesel generated electricity in Costa Rica. The primary reason for this regional predominance is the lack of an interconnected grid in these remote provinces. Also, some industries which are connected with the utility electricity grid, use stationary diesel engine-generators to provide emergency stand-by power.

The larger diesel engine-generators used for the on-site electricity generation in the remote regions of Costa Rica are generally rated to produce about 1000 kW of electric power. These engine generators can be found in large banana plantations, where they provide electricity for irrigation, mechanical power to run packing equipment, and lighting and other residential needs of the plantation employees.

Another predominant use of diesel engines is to provide mechanical power in the construction and mining industries. For example, stationary diesel engines like grinders and conveyors were observed in the sand and gravel and construction industries in Costa Rica. In addition, diesel engine pumps and concrete mixers are also used by the construction industry. The total diesel consumption for stationary mechanical power is estimated at approximately 5 percent of the total industrial petroleum consumption.

3.1.4 Synthesis of a Natural Gas or Petroleum-Derived Feedstock for Ammonia Production

In the survey of the Costa Rican industrial base, ammonia was identified as a potential chemical feedstock which can be produced by an electrolysis-based synthesis technology.

Ammonia, derived from natural gas, is currently being imported from Mexico by the fertilizer industry in Costa Rica. Ammonia is used as a feedstock in producing mixed nitrogen fertilizers, primarily ammonium nitrate and phosphate. Substitution of imported ammonia by electrolysis produced ammonia will indirectly displace natural gas or petroleum imports currently embodied in the imported ammonia.

In the conventional ammonia synthesis process, a proper mixture of hydrogen and nitrogen is passed over a catalyst at high pressure and temperature to produce ammonia. The hydrogen required for this synthesis is usually derived from natural gas or from petroleum fractions. On a limited scale, coal is also used as a source of hydrogen for ammonia plants. However, with the growing scarcity of petroleum and natural gas resources, the use of coal for ammonia production will be enhanced. The nitrogen requirements of a conventional ammonia synthesis plant are supplied by an air separation plant.

3.2 Potential Electric Substitutes

The conventional petroleum-based energy conversion technologies described in the previous section may technically be substituted by several different electric technologies. Some of these electric technologies may be classified as direct substitutes for the existing petroleum-based systems. Direct substitute electric systems supply the same energy products (i.e., process steam/hot water or hot air) as the petroleum-based system and require no change to the overall industrial process. For example, consider a food drying operation where steam produced from an oil-fired boiler is currently used to accomplish the drying. An electric boiler can supply the required steam with no change to the drying operation.

Certain electric technologies can be classified as indirect substitutes for existing petroleum systems. Indirect substitutes replace both the pletroleum-based energy production system and the existing industrial processs. For example, a microwave heating system may be used to replace the conventional steam-based food drying operation mentioned in the above example. The use of a microwave system completely replaces the steam-based process equipment.

As an initial step in evaluating the potential for substitution of electric technologies for existing industrial petroleum-based technologies in Costa Rica, MITRE identified the set of electric technologies that are potentially substitutable. Using the above definitions, these technologies are grouped as direct and indirect substitutes. The direct substitutes are:

- Electric boilers
- Electric heaters
- Heat pumps
- Electric Distribution Grid Expansion (applied only for on-site electricity generation in remote areas).

The indirect substitutes are:

- Microwave systems
- Electric membrane separators
- Electrolysis-based ammonia production.

Electric technologies like arc and plasma heating are not included because the Costa Rican industrial sub-sectors (i.e., mainly steel and other metals production) suitable for their application are not large enough to be considered for electric conversion. However, plasma technology in theory can be used to supply the calcination heat to the cement kilns, which consume a sizable portion (about 30 percent) of the total industrial Bunker C consumption. The technical feasibility of converting a commercial cement kiln to plasma heating is not yet established (Sood, 1981). Therefore this conversion possibility is not explored in this study.

A conversion matrix relating the potential technical substitution of the existing petroleum-based technologies with these electric technologies is shown in Table 3-III. For the purposes of the economic analysis, MITRE has selected six petroleum to electricity

TABLE 3-III

TECHNOLOGY CONVERSION MATRIX

Existing Petroleum-based Technologies	Direct Electric Substitutes: Electric Boilers/ Hot Water Generator	Direct Electric Substitutes: Electric Heaters	Direct Electric Substitutes: Heat Pumps	Direct Electric Substitutes: Grid Expansion	Indirect Electric Substitutes: Microwave System	Indirect Electric Substitutes: Electric Membrane Separators	Indirect Electric Substitutes: Electrolysis-based Ammonia
Steam/hot water Boilers	◉	◉	◉		●	●	
Combustors (>100°C)		◉	●		●		
Combustors (<100°C)		●			◉		
Internal Combustion Engines				◉			
Conventional Ammonia Synthesis							●

● Potential conversion

◯ Conversion selected for detailed analysis.

conversion possibilities. These are shown in Table 3-III. These conversion possibilities were selected because they represent:

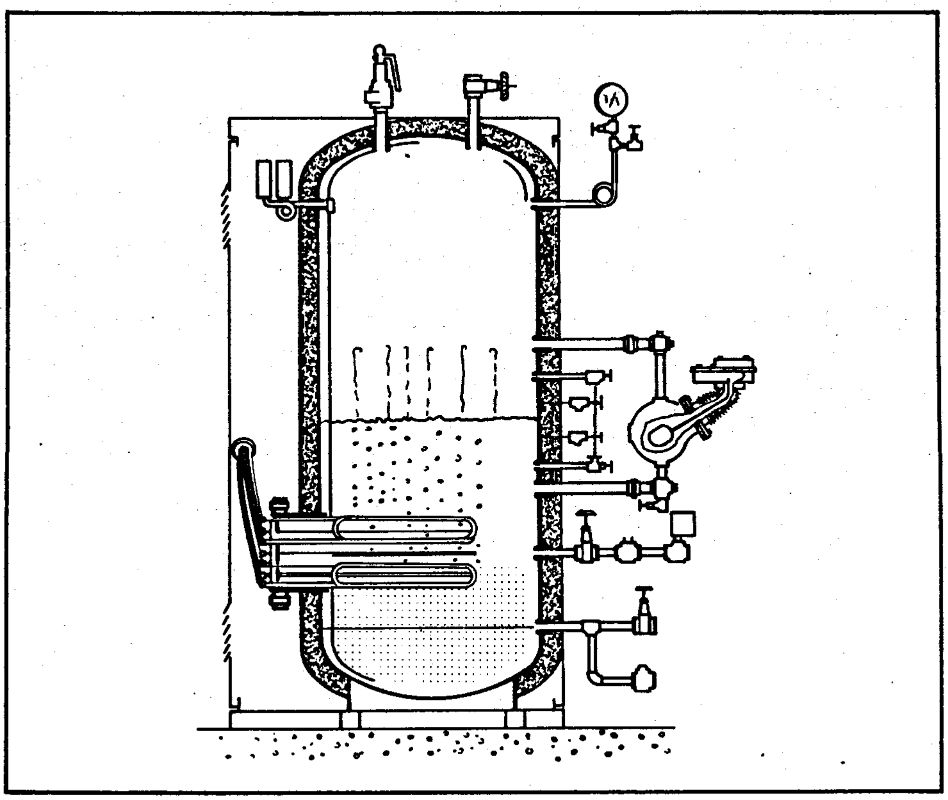
- a large portion of current petroleum consumption in Costa Rica industry; and
- potentially substitutable electric technologies that are technically advanced and commercially proven.

The economic competitiveness of the six selected conversion possibilities is assesed in Section 5.0. The technical descriptions of all the potential electric technologies identified in Table 3-III are given below.

3.2.1 Electric Boilers/Hot Water Generators

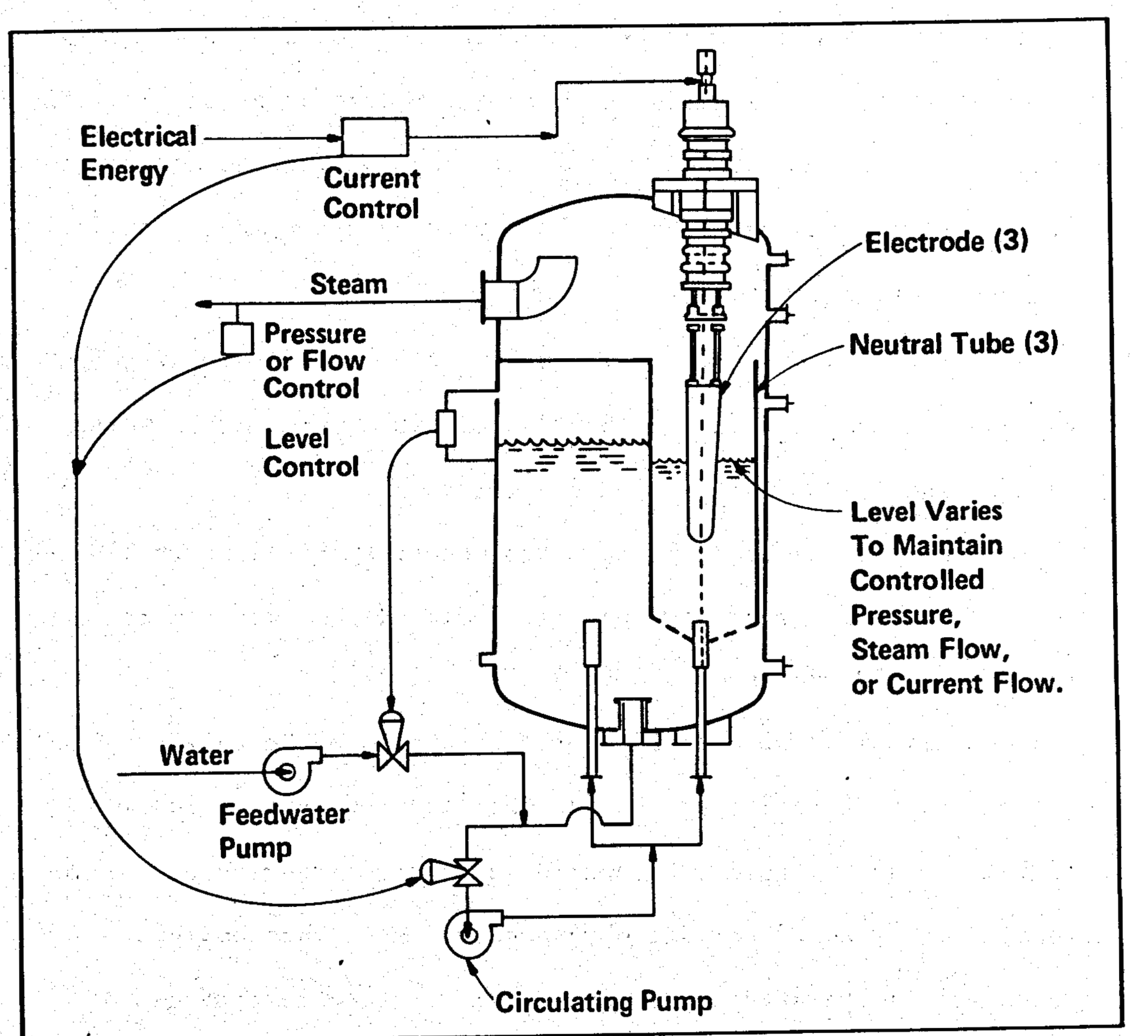
Electric boilers and hot water generators are commercially available. The recent oil and gas price increases and stricter environmental regulations are making them economically attractive for producing steam and hot water in many industrial plants in the United States (Schwieger, 1978).

There are two types of electric boilers and hot water generators: immersion (or resistance) boilers and electrode boilers. The immersion boiler is basically a pressure vessel with resistance type heating elements submerged in water. Figure 3-1 shows a schematic of an immersion or resistance type boiler. The electrode boiler consists of a pressure vessel in which the water itself is used as a heating element. The electrodes can either be immersed in the water or be impinged by the circulation of water jets. Figure 3-2 shows a schematic of an electrode boiler.



Source: Heil, Terence J., Charles H. Leatham, Jr., Electric Boilers up to 175,000 lb/hr - Available Designs and Applications, Gilbert/Commonwealth, Jackson, Miss., Presented to the American Power Conference, April 19, 1977.

FIGURE 3-1
SCHEMATIC DIAGRAM OF IMMERSION BOILER



Source: Heil, Terence J., Charles H. Leatham, Jr., Electric Boilers Up to 175,000 lb/hr - Available Designs and Applications, Gilbert/Commonwealth, Jackson, Miss., Presented to the American Power Conference, April 19, 1977.

FIGURE 3-2
SCHEMATIC DIAGRAM OF COATES HIGH VOLTAGE ELECTRODE BOILER

Immersion boilers are generally restricted to smaller steam capacity. These boilers are economical only in sizes up to 2000-2600 kW (3200-4300 kg/hr of saturated steam at 100°C or 200 to 250 HP.) At capacities larger than the above range, a host of electrical components (i.e., contacts, and fuses) are required for the immersion boiler, thus making the electrode boiler cheaper and more practical at higher steam outputs.

Electrode boilers are available for both low-voltage (600 V or less) and high voltage (2.3 - 15 kV) operations. Steam pressures range between 12-500 psig (184-3,547 kPa).

Low voltage electrode boilers are generally rated up to 2500 kW. However, the capacity of high voltage electrode boilers can reach up to 50 MW (79,450 kgS/hr or 5100 HP) (Heil, 1977).

The efficiency of electric boilers is between 98 to 99 percent as compared to 78 to 85 percent for oil-fired boilers.* The immersion boilers are virtually automatic, and do not require excessive attention other than periodic observation. Electrode boilers also require little operating attention. Fully automatic controls of the boiler and feedwater system can eliminate constant operator attendance as in the case with fuel-fired boilers.

Electrical boilers avoid many of the environmental and operational problems associated with fuel-fired boilers. With electricity

*Does not account for the efficiency of electricity production.

as the fuel, there are no emissions or other products of combustion and no need for stacks, or noisy air handling equipment. Hazards associated with combustion are eliminated as is maintenance to remove combustion residue. Since heat is generated directly in the water itself, no part of the boiler is at a temperature higher than the steam or water.* When maintenance is required an electrode boiler both cools and restarts faster for reduced downtime. With fewer moving parts and less instrumentation, reliability is increased and requirements for spare parts and maintenance personnel are lowered substantially.

The electric boilers, particularly electrode type boilers, have a narrower tolerance to changes in feed-water quality than do oil-fired boilers. For electrode boilers it is necessary to control water conductivity within a narrow range, not too low (about 500 micromhos-cm or less), or the boiler will not work; nor too high (about 3,000 micromhos-cm or more), or high arcing between the electrodes will occur.

The installation of high voltage electrode boilers requires special electrical considerations. These boilers require Wye-connected, 3-phase, four wire service, and the neutral and the boiler shell must be solidly grounded (Schweiger, 1978). Another important factor to be considered in the selection of an electrode boiler is the voltage

*The combustion chamber of fuel-fired boilers are generally several hundred degrees higher than the steam produced.

available from the utility distribution grid. Higher voltage reduces the size of the pressure vessel for a given output. Also smaller feeders are required to carry a specified amount of power. Finally, if a nominal voltage of 13.8 kV is directly available from utility distribution lines, no stepdown transformers are required.* This will reduce capital costs and transformer losses.

Electric boilers can be technically substituted for a large number of oil-fired boilers in the industrial sector of Costa Rica. This is particularly true for the food products, and textile subsectors (see Table 3-II), where medium pressure saturated steam can satisfy the process needs.

3.2.2 Electric Resistance Heaters

Electric heating is produced when current is forced through a high resistance conductor. The advantages of electric heating are convenience, control, and the elimination of combustion products. A schematic of a typical installation of a process air duct heater is shown in Figure 3-3. In general, the metal sheath tubular elements consist of a corrosion/oxidation resistant sheath (e.g., Incoloy), a high purity magnesium oxide refractory which is well compacted to ensure maximum thermo-conductivity and electrical insulation resistance, and finally the heating element which is usually a nickel-chromium low watt density resistance wire. These are high

*Electricity to industry in Costa Rica is normally available from the grid at 34.5 kW.

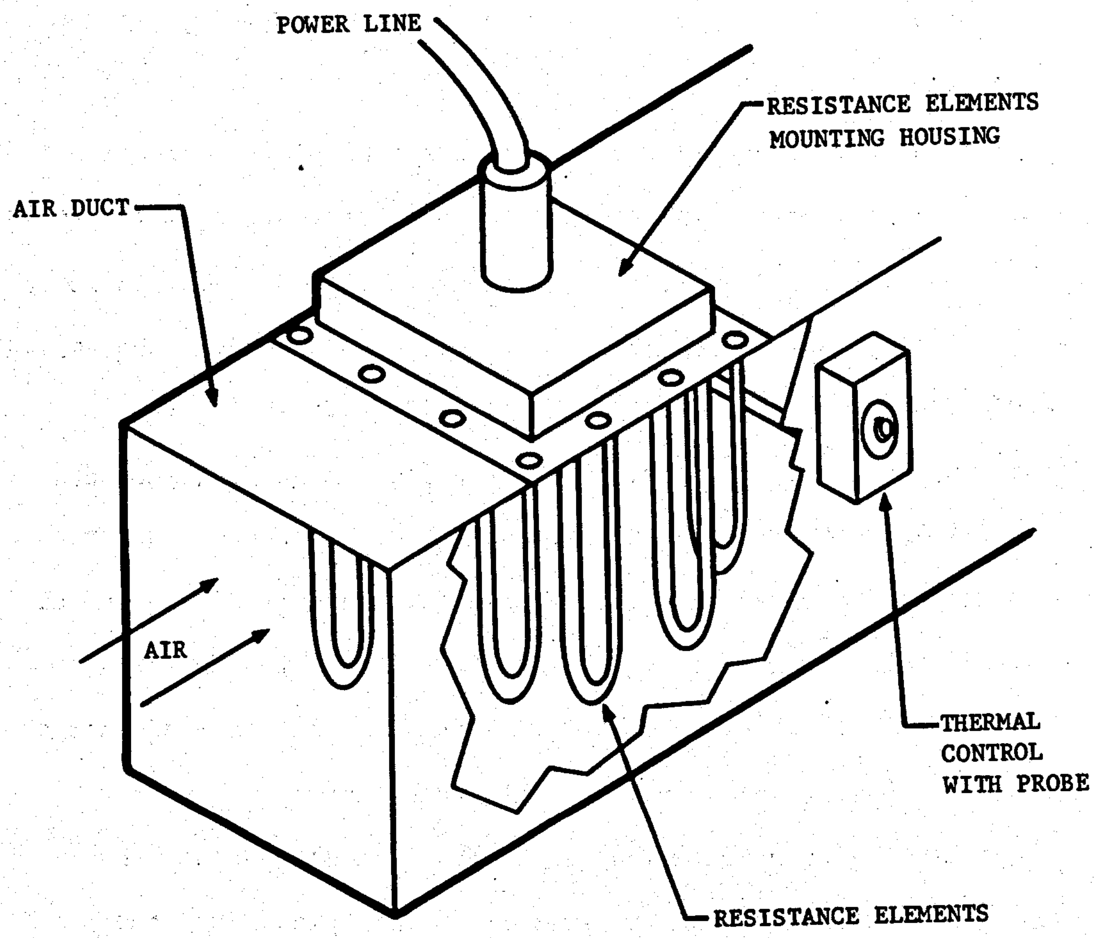


FIGURE 3-3
SCHEMATIC OF PROCESS AIR DUCT RESISTANCE HEATER

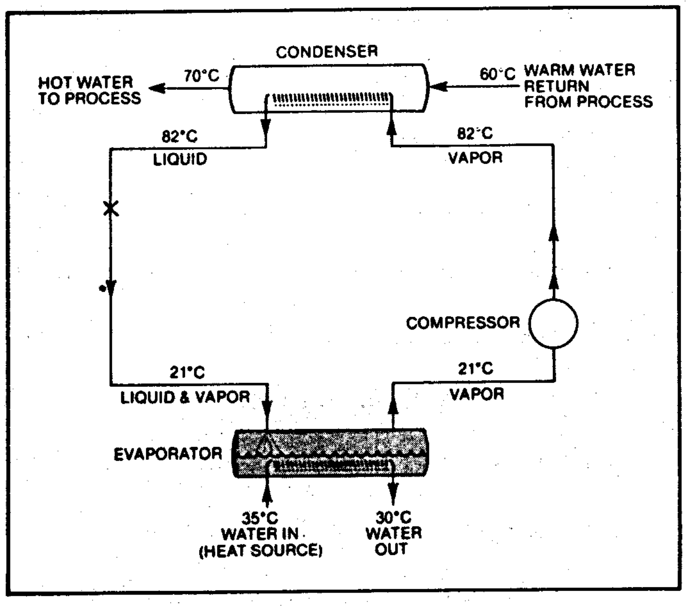
efficiency elements where all power input is converted to thermal energy. One manufacturer supplies modular elements ranging in capacity from 5 to 300 kW, and allowing output air temperatures up to 649°C (1200°F).

3.2.3 Heat Pumps

The value of industrial heat pumps is beginning to be recognized in U.S. industry primarily because of the success of Westinghouse in developing their Templifier* (Westinghouse, 1978). This pump is capable of raising the temperature of a waste source from the region 21-49°C (70-129°F)to about 82-104°C (180-220°F). This limit is imposed by currently available refrigerants. As new refrigerants are developed, the temperature limitation is expected to increase to about 204°C (400°F). In most applications a unit of electrical energy can extract 2 to 5 units of waste heat. This implies that a coefficient of performance (COP), defined as the ratio of energy output to electric energy input, is between 3 and 6.

Figure 3-4 shows a typical schematic flow diagram of a heat pump. In this example, waste water at 35°C is piped into the evaporator where the heat is absorbed by the refrigerant. The compressor raises the temperature of the refrigerant (21°C) to a higher temperature (82°C) and pressure before it goes into the

*Reference to specific manufacturers is not the result of a deliberate selection process nor does it constitute an endorsement of the manufactured products.



Source: Westinghouse Air Conditioning Intl., Templifier Heat Pump, Specifications Sheet TPE-A1, April, 1978.

FIGURE 3-4
SCHEMATIC DIAGRAM OF TEMPLIFIER HEAT PUMP

condenser. There the delivery water (60°C) picks up heat and is then delivered to another plant process at 70°C.

Heat pumps range in capacity from 40 to about 5000 kW. Each unit is completely factory assembled and shipped ready to operate when connected to power and water sources.

A prerequisite for industrial heat pump application is the availability of a moderate temperature (less than 50°C) waste heat source. If a waste heat source is available, the industrial heat pumps can be used for a wide variety of processes across different industrial sub-sectors. The food products sector in Costa Rica can readily use the heat pump technology to supply hot water for some process needs or to pre-heat the boiler feed water of the existing oil-fired system. In either case, the heat pump technology is not capable of displacing the existing oil-fired systems completely. It would supplement existing systems by reducing the overall fuel consumption.

3.2.4 Utility Electric Distribution Grid Expansion

The expansion of the existing utility distribution grid will make electric power more accessible to remote agro-industrial operations, particularly the ones which are located in the Southwest province of Puntarenas and the Northeast provinces of Heredia, and Limon. Thus, grid electricity can serve as a potential substitute for diesel-generated electricity.

3.2.5 Microwave Systems

Microwave energy is a form of electromagnetic energy similar to radio signals. Microwave energy can be used to heat any substance in which there are free polar molecules (e.g., water). When high frequency microwaves pass through materials containing polar molecules, the resulting alternating electrical field oscillates the polar molecules about their axes creating inter-molecular friction. This produces a volume or internal heating effect.

The most important medium for microwave heating is water. The greater the concentration of water in the material, the larger the dielectric loss factor and the faster the product will heat up (Ouellette, 1981).

Microwave energy is attractive for use in the air dehydration of most foods because of the speed of moisture removal. One of the major advantages of microwave heating when compared to conventional methods is its ability to penetrate heat to the interior of the material to be dried. Even at the high frequency of 2.45 GHZ, heat penetration depths for foods range from one to several centimeters (Ouellette, 1981). This ability of microwave energy to produce heat deep within food products rather than at the surface is responsible for the short processing time. On the contrary, conventional drying methods depend solely on the surface area contact which require longer processing times. The deep heat penetration achieved by microwave energy, however, is responsible for a lack of surface effects such as browning, which may be a disadvantage in roasting or baking but is an advantage in operations like grain drying, potato chip or tortilla manufacturing, or fruit processing.

The capital costs of microwave equipment are high. However, a dramatic increase in throughput due to the short processing time reduces the size and capacity requirements of support equipment thus providing for almost equivelant costs of microwave systems when compared to equivelant petroleum systems. Some applications of microwave system in the food products industry have resulted in 100 percent increases in productivity (Ouellette, 1981).

It is difficult to offer a quantitative comparison between the use of conventional heat and microwave energy. The parameters that need to be measured for a comparison are a function of the specific process that is being considered. Previous detailed economic estimates, comparing conventional and microwave bread baking systems have indicated that microwave systems offer a slight economic advantage.

The use of microwave heating systems can be considered for the food products sub-sector in Costa Rica. Specifically, the application of microwave energy systems will be suitable for various food drying applications. Some of the typical applications currently in use in the U.S. include finish drying of pasta, finish baking of biscuits, and finish drying of potato chips. Also, microwave systems have been developed in France, which use microwaves in a vacuum tunnel to dry a great variety of solid and liquid food items. Other efforts in testing of large scale microwave applications include microwave-vacuum drying of grain and microwave curing of rubber for the automobile tire industry. The results of these experimental testing programs indicate marginal economic advantages for microwave systems when compared to conventional systems.

3.2.6 Separation Technologies

Advanced membrane separation processes like reverse osmosis and ultrafiltration are capable of separating dissolved substances and/or finely dissolved particles from solutions. These advanced processes use electricity as the main energy input and are capable of concentrating many dilute water solutions.

Reverse Osmosis and Ultrafiltration

In reverse osmosis and ultrafiltration, water diffuses through a selectively permeable membrane from a more to a less concentrated solution. The driving force for such a transfer is a pressure difference across the membrane in excess of the difference in osmotic pressure. Ultrafiltration utilizes pressures of 1 to 10 atmospheres (101 to 1013 kPa), while reverse osmosis utilizes pressures of 33 to 75 atmospheres (3343 to 7597 kPa).

These advanced concentration or water separation processes consume substantially less energy and have lower operating costs when compared to conventional steam-based evaporation processes (Ouellette, 1981). These processes can also be used for preconcentration of dilute solutions before concentration by conventional methods, thus effecting a capacity increase in existing plants and reducing energy consumption.

The membrane separation technologies can be used in the Costa Rican food products, and especially the milk products industry for converting conventional water removal, concentration, and other separation processes. Presently, water removal and concentration processes across the food products industry generally use steam produced from oil-fired boilers. The substitution of advanced membrane separation technologies for conventional steam separation processes can reduce the oil consumption for producing process steam.

The most significant current commercial use of reverse osmosis and ultrafiltration in the U.S. food processing industry is in the treatment of cheese whey (Ouellette, 1981). Whey is a by-product of the conversion of milk into cheese. Ten pounds of whole milk will produce about one pound of hard cheese and nine pounds of whey. About 30 billion pounds of whey are produced annually in the United States, and about half of it is disposed as waste. Because of its high biological oxygen demand (BOD), it can not be disposed without further treatment. However, the whey has high nutritional value, and after drying or concentrating, it can be added to a great many food products. Reverse osmosis and ultrafiltration are being commercially used in the U.S. to concentrate and fractionate cheese whey. These methods of concentrating cheese whey have proven to be more cost effective than conventional evaporation methods.

The advanced membrane separation technologies are not free of technical problems. The usual problems encountered in membrane concentration include membrane fowling, concentration polarization, shear damage to food substances, loss of some aromatics, and less sensitivity to the separation of sugar and salts than might be desired.

3.2.7 Ammonia from Electricity

Production of ammonia from cheap hydroelectricity is commercially being practiced in countries like Egypt and India. The scheme of producing ammonia from electricity is shown in Figure 3-5. This scheme is based on commercially proven hardware. Basically, electricity is used to split water into its primary components hydrogen and oxygen. The hydrogen thus produced is mixed with pure nitrogen obtained from an air separation plant. The stoichiometric mixture of hydrogen and nitrogen (one mole nitrogen to three moles of hydrogen) is compressed to high reaction pressures, e.g., 13790 kPa (2000 psia), and passed over an iron-based catalyst in an ammonia synthesis reactor.

The major consumer of electricity is the water electrolysis process, which consumes approximately 88 percent of the total electric input to the plant. The ammonia synthesis loop consumes about 6 percent of the total electric input. The rest is distributed among air

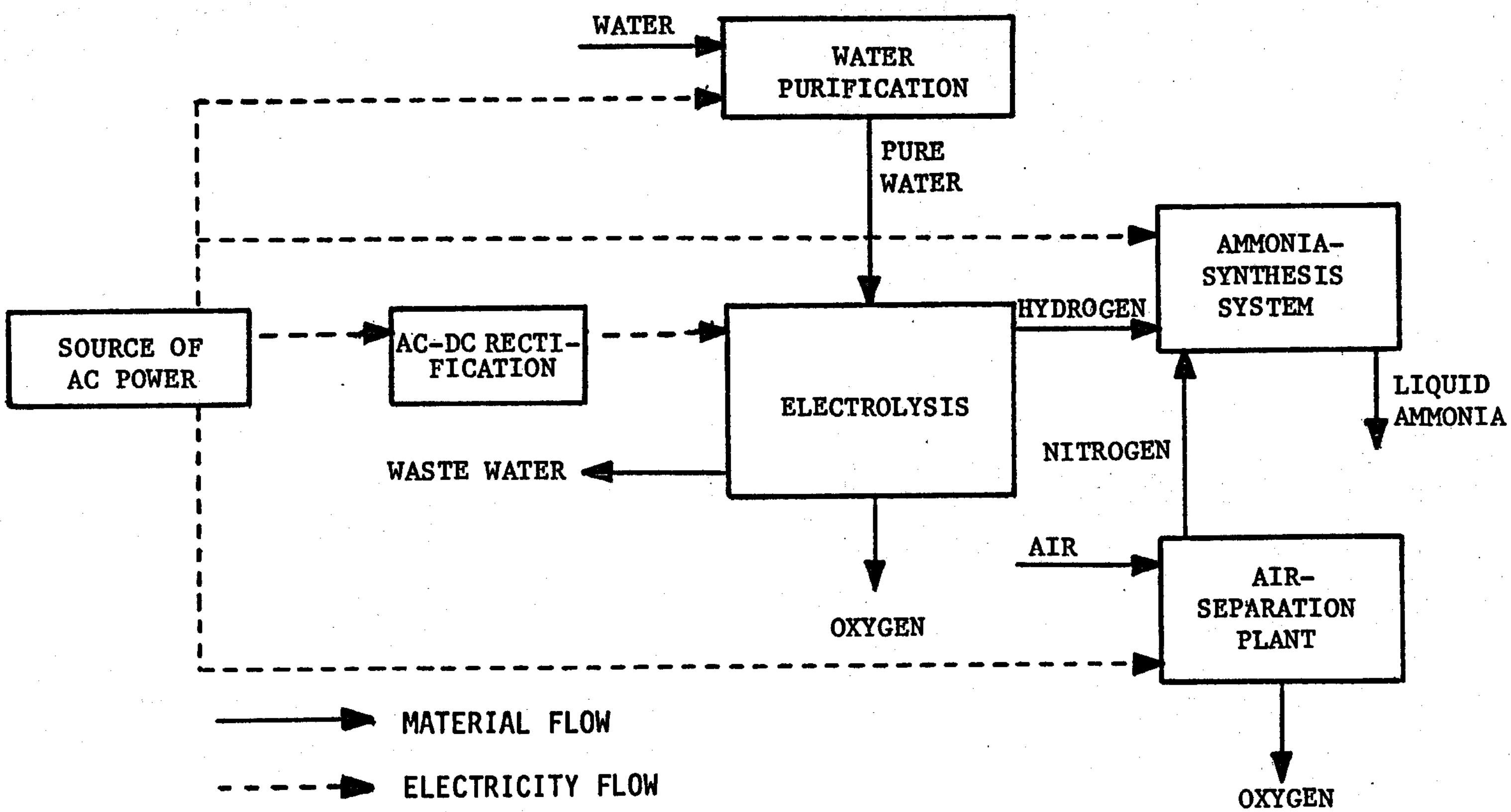


FIGURE 3-5
LIQUID-AMMONIA PRODUCTION–GENERAL FLOW SCHEMATIC

separation plant and ac-dc rectification losses. A 100 MW electric input is capable of producing approximately 262 tons of liquid ammonia per day. The cost of ammonia production via electrolysis is very sensitive to the price of electricity. An economic feasibility study conducted in 1976 had estimated that at 10 mills/kWh, the ammonia production cost will be about $210/tonne for 100 MW electric plant, and $188/tonne for 500 MW electric plant. The lower production cost at higher plant capacity is due to the economics of scale in plant investment. As the cost of electricity increased to 20 mills/kWh, the respective ammonia production costs changed to $296/tonne and $276/tonne (Konopka, 1976). However, since the time of that study, significant advances have been made in water electrolysis technology which have improved the economics of electricity-based ammonia production processes. Given these advances and the fact that imported ammonia in Costa Rica costs $200/tonne (May, 1981), the competiveness of electricity-based ammonia with the natural gas-based imported ammonia needs to be assessed in greater depth.

3.3 Maximum Potential for Electricity Substitution in the Industrial Sector of Costa Rica

A maximum potential for electricity substitution in the industrial sector of Costa Rica is estimated based on the technical feasibility of using electric technologies in place of conventional petroleum-fired systems. The economic factors are then superimposed on this maximum potential to estimate the actual potential for such substitution. The economic assesment is presented in Section 5.0.

On a strictly technical basis, all the petroleum used by the industrial and agro-industrial sector to produce steam, hot water, low temperature process heat, stationary mechanical power and electricity can be replaced by centrally generated electricity. With the exception of the cement and glass industries, petroleum used for high temperature process heat can also be replaced by electricity. Electric plasma and arc heaters are in the experimental stage for use in the cement and glass industries. However, at this stage, they are not technically feasible for industrial use. While the technology for small electric vehicles is available, petroleum used for transport in the industrial and agro-industrial sector is considered not technically substitutable by electricity. From the industrial and agro-industrial energy product matrices presented in Table 2-VIII and 2-IX and the technically feasible electric alternatives outlined above, the potential for substitution of electricity for petroleum was estimated. Tables 3-IV and 3-V present the results of this analysis.

The maximum technically substitutable potential (i.e., not taking economics, institutional or site specific factors into consideration) is about 52 percent of the total 1980 industrial and agro-industrial petroleum consumption or 14 percent of the total 1980 national petroleum consumption. The technologies that represent this conversion potential are steam and hot water boilers, low and high temperature process heaters and diesel electric generators.

TABLE 3-IV

MAXIMUM TECHNICALLY SUBSTITUABLE POTENTIAL OF ELECTRICITY FOR PETROLEUM IN
THE INDUSTRIAL AND AGRO-INDUSTRIAL SECTOR - 1980
(IN TJ)

Energy Product	Petroleum Product						
	Gasoline	Diesel	Bunker C	Kerosene	Av. Gas	Asphalts	Totals
Steam		367	1472				1839
Hot Water		19	130				149
Low Temperature Process Heat		195	140	85			420
High Temperature Process Heat		77/ 182	939/2062	9/82			1025/2326
Motors		407					407
Transport	143	686			24		853
Electricity		751					751
Other						287	287
Total	143	1409/1275	2681/2062	94/82	24	287	4184/3874

The underlined figures represent cases which are technically feasible for substitution with electricity.

TABLE 3-V

MAXIMUM TECHNICALLY SUBSTITUTABLE POTENTIAL OF ELECTRICITY FOR PETROLEUM IN THE INDUSTRIAL AND AGRO-INDUSTRIAL SECTOR - 1980
(IN 10^3 BBL)

Energy Product	Petroleum Product						
	Gasoline	Diesel	Bunker C	Kerosene	Av. Gas	Asphalts	Totals
Steam		63.4	237.5				300.9
Hot Water		3.3	20.9				24.2
Low Temperature Process Heat		33.8	22.5	15.5			71.8
High Temperature Process Heat		13.4/ 31.4	151.4/332.7	1.7/14.9			166.5/379.0
Motors		70.4					70.4
Transport	27.6	118.8			4.5		150.9
Electricity		130.0					130.0
Other						49.6	49.6
Total	27.6	243.9/220.6	424.3/332.7	17.2/14.9	4.5	49.6	693.4/649.9

The underlined figures represent cases which are technically feasible for substitution with electricity.

Steam and hot water boilers account for the largest portion or 47 percent of the total conversion potential of 693,400 BBL. Of the 693,400 BBL of petroleum, 424,300 BBL is Bunker C, 243,900 BBL is diesel and 17,200 BBL is kerosene.

The industries that utilize potentially convertible petroleum technologies can be determined from the data presented in Table S-III. However, as shown in Table 3-VI, seven key industries represent 65 percent (or 448,000 BBL) of the total convertible petroleum consumption. Within these seven industries, 60 percent of the petroleum consumption is used to generate steam or hot water, 23 percent to generate electricity and 17 percent to provide low or high temperature process heat.

It should be recognized that the data on the technically substitutable potential of electricity for petroleum presented in Tables 3-IV, 3-V and 3-VI are estimated based on the simplifying assumption that all technically feasible substitutions could be implemented. It does not consider any institutional, economic or site-specific constraints which may eliminate some techically feasible substitutes from further consideration. A discussion of some key institutional factors is presented in Section 4.0. Economic factors are evaluated in Section 5.0. Site specific constraints were not evaluated because of the general scope of this study.

TABLE 3-VI

KEY INDUSTRIES WITH POTENTIALLY CONVERTIBLE PETROLEUM CONSUMPTION

Industry	Convertible Petroleum Consumption (1000 BBL)	Percent of Total Industrial Convertible Petroleum Consumption
• Food products*	158	23
• Fresh fruit producers**	106	15
• Beverages	49	7
• Paper products	42	6
• Textiles	41	6
• Coffee beneficiators***	33	5
• Rubber products	19	3
	448	65

*The key energy consuming industries within the food products industries are: dairy products; meat products; grain mill products and coffee processing.

**Diesel for electricity generation is the primary source of petroleum consumption by fresh fruit producers.

***Petroleum is presently used by coffee beneficiators primarily to dry coffee beans and in some cases generate electricity. With regard to drying coffee beans, electric resistance heaters are a technical possibility. However, biomass options are also available and should be considered as a primary substitute.

4.0 NATIONAL POLICY ISSUES AND INSTITUTIONAL FACTORS

Decisions on Costa Rican national policy will have a significant impact on the potential for industrial electrification in that country. In this section we present and discuss the major national policy issues affecting electrification along with some of the institutional factors that need to be considered in parallel.

4.1 Energy Pricing

Energy prices in Costa Rica have undergone significant changes over the past decade. Costa Rica imports all of its petroleum and therefore is vulnerable to externally initiated price increases. Current refinery capacity in Costa Rica is sufficient to meet approximately 50 percent of domestic needs with major short falls in diesel and gasoline production. Demand for these light petroleum products is met by spot purchases on the Caribbean market thereby increasing the external influence on petroleum prices.

The prices of all commercial fuels are set by the government of Costa Rica. At the time of the analysis presented in this report, with a major devaluation of the Colon in progress, all petroleum prices were frozen at their May 1981 levels.

Table 4-I describes the pricing structure for electricity and petroleum products for 1972, 1976, 1980 and May of 1981. The top of the table presents vendor fuel prices using units of measure typical

TABLE 4-I

COSTA RICA ELECTRICITY AND PETROLEUM PRICES

	Industrial Electricity	Gasoline	Diesel	Bunker C	Kerosene
	(Colones/KWH)	(Colones/Liter)	(Colones/Liter)	(Colones/Liter)	(Colones/Liter)
1972	.13	.92	.38	.15	-
1976	.35	2.20	1.03	.75	1.02
1980	.45	6.11	2.56	.98	-
1981 - May	.45(.024US$)	11.50(.608US$)	6.90(.365US$)	2.50(.132US$)	7.99(.423US$)
	$Colones/10^9 J$	$Colones/10^9 J$	$Colones/10^9 J$	$Colones/10^9 J$	$Colones/10^9 J$
1972	35.5	28.2	10.4	3.9	-
1976	96.2	67.4	28.3	19.2	29.6
1980	125.0	187.1	70.4	25.1	-
1981 - May	125.0(6.61US$)	352.2(18.62US$)	189.8(10.04US$)	64.1(3.38US$)	231.8(12.27US$)

Ref: (República de Costa Rica, 1981)

for the sale of each fuel. The lower portion describes the energy prices of these fuels. As can be seen, in 1972, petroleum prices were significantly lower than electricity on an energy basis. By May of 1981, energy prices of gasoline, diesel, and kerosene exceeded that of electricity with Bunker C running about half that of electricity.

Table 4-II describes the posted product prices of petroleum products for May, 1981 in the Caribbean region compared against the May 1981 market prices of these fuels in Costa Rica. The imbalance in the prices of Bunker C is quite evident. The posted price of Bunker C in the Caribbean is 36 percent above the Costa Rica market price. In addition, this increment does not include the costs of Costa Rica storage and delivery which should be subsumed in the Costa Rica market price.

One of the problems behind the artificially low price of Bunker C in Costa Rica is excess supply. Table 4-III compares the Costa Rica refinery production for gasoline, diesel and Bunker C against the direct imports and national demand for those products in 1979. Because of the size of the refinery, the nature of the reconstituted crude imported as the feedstock to the RECOPE refinery, and the limitations on the product slate of the refinery itself, the refinery is unable to satisfy the gasoline and diesel needs of the country. In addition, the reduction in the demand for petroleum for electricity

TABLE 4-II

COMPARISON OF COSTA RICA AND CARIBBEAN MAY 1981
PETROLEUM PRICES

	Gasoline ($/Liter)	Diesel ($/Liter)	Bunker C ($/Liter)	Kerosene ($/Liter)
Caribbean Posted Product Prices	.247	.246	.179	.263
Costa Rica Market Price	.608	.365	.132	.423

Ref: Petroleum Economist - May 1981

TABLE 4-III

GASOLINE, DIESEL, AND BUNKER C SUPPLY AND DEMAND IN 1979 (TJ)

	Gasoline	Diesel	Bunker C
Refinery Production	3,098	3,579	7,171
Imports	3,366	11,591	0
Electricity Demand	0	3,412	1,268
End Use Demand	6,438	13,634	6,229

Note: Supply need not equal demand because of losses and changes in inventory

Ref: (República de Costa Rica, 1980).

generation* in 1980 resulted in an over supply of Bunker C. This excess has had to be reexported for sale in the Caribbean.**

The potential for industrial electrification in Costa Rica, is strongly dependent on the relative prices of petroleum and electricity. In order to promote efficient utilization of petroleum products within the Costa Rican economy, domestic petroleum prices ought to be equal to their CIF import values plus transport and handling to point of consumption. This also implies that the relative prices of individual petroleum products should be balanced among themselves. The price subsidy of one petroleum product results in not only increased imports of that product, but also a longer term dependence on that product as individuals and industries invest in fuel-specific capital equipment.

Other developing countries in the world have resolved the Bunker C price problem by pricing residual fuels closer to their energy content values, which, in effect, places an import duty on these fuels. The greatest penalty of such actions in Costa Rica would be on those industries for which fuel is the major component of product expense (e.g., cement, fertilizers, etc.).

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*As noted before, 98 percent of electric power in 1980 was generated from hydro resources.

**Plans are underway to upgrade the RECOPE refinery to produce less residuals.

However, in the international market, Bunker C, which is the real contendor to electricity for industry, will likely continue to have an equilibrium price which is lower than the price of crude oil. Presently, the price of Bunker C is about 70 percent of the price of the comparable crude from which it is extracted. New refinery cracking technology is currently being built throughout the Caribbean to take advantage of this low price to extract more light products from distillery residuals. In the long run, this new technology will cause the equilibrium price of residual fuels to rise. It has been estimated that a future equilibrium price for Bunker C will be at 80 to 85 percent of the price of crude (Shell, 1981).

4.2 Electricity Prices

Electric generation in Costa Rica is now nearly totally dependent on hydropower. Stand-by generators are either oil-fired steam turbines or oil-fired gas turbines. The latter are used for peaking power needed for high demand periods occurring during evening hours when industrial and commercial use overlaps with high residential use of electricity and hydro capacity is inadequate to meet this demand. This condition is usually seasonal.

Costa Rica, as all of Central America, has a well defined wet (winter) and dry (summer) season. The dry season begins in November and continues to March or April; the wet season runs from April through October. With daily rains in the rainy season, the Costa

Rican streams are usually uniformly full. Many of the hydroelectric facilities in Costa Rica are run of the river units which take advantage of this flow. These hydrofacilities have virtually no reservoir capacity but depend entirely on the uniformity of the stream flow during the wet seasons. These facilities become less and less able to supply electricity to the grid as the dry season progresses. Newer hydro facilities with large dams and reservoirs are then required to meet electricity demand. In very dry seasons, these facilities may also become inadequate to meet demand and electricity must be generated by thermal plants burning imported oil.

This sequence of daily demand and seasonal supply variations provides a very wide spectrum of marginal costs for electricity. The cost of run of river hydro plants is very low; hydroelectricity from large dam-reservoir systems has medium cost; electricity from oil-fired steam and peaking turbines has the highest cost.

The tariffs charged for electricity in Costa Rica are basically an average of these generation costs. However, within this framework, the electric company of Costa Rica, ICE, assigns 11 separate tariffs. Basically, residential tariffs are less costly than industrial and commercial tariffs.

The two tariff structures relevant to large industrial consumers are called T-4 and T-10. The details of these tariff structures are presented in Appendix C. Tariff T-4 applies to high voltage industrial consumers of greater than 20,000 kWh per month for more than six months of the year.

T-10 is a marginal cost and incentive tariff set up for industry to encourage the use of off-peak electricity. This tariff requires that electricity only be used during the off-peak hours, specifically any hours except 10:00 AM -12:30 PM and 4:30 PM - 8:00 PM. The T-10 tariff is limited to customers with more than 20,000 kWh monthly consumption.

The structure for both these tariffs is summarized below.

T-4

Demand Charge	Colones
First 27 kW or less	2030.40/month
Next 40 kW at	75.20/kW/month
Each additional kW at	114.35/kW/month
Energy Charge	
First 20,000 kWh or less	979.70/month
Each additional kWh at	0.3586/kWh

T-10

From May 21 to January 20

Demand Charge

Maximum demand registered for any 15 minute period during the hours of 10:00 AM to 12:30 PM and 4:30 PM to 8:00 PM except holidays and weekends is charged at the T-4 rate.

Energy Charge

Energy used in excess of previous year average will be charged at the following rate:

	Colones
Between 8:00 PM and 10:00 AM	0.1600/kWh
Between 10:00 AM and 8:00 PM	0.1938/kWh

Note that the T-10 tariff has no demand charge. During the dry months of January 21st to May 20th, the T-10 tariff automatically reverts to the T-4 tariff. At any time the time of day requirements for electricity consumption are violated, the demand charges revert back to T-4.

Use of the T-10 tariff benefit requires rescheduling of industrial processes. In some cases this may be impractical. In the food processing industry, it was reported to the MITRE team that delivery of raw food feedstocks is done by individual farmers at the beginning of the work day. To prevent spoilage, the firm must process all of the food deliverd in the same work day. In other industries rescheduling should not be as difficult. From a social and labor aspect, the traditions of a given work schedule may be difficult to overcome and must be studied carefully before the commitment of an industry to a schedule which matches the T-10 tariff.

The transmission grid of Costa Rica ties the entire country into one system. There are plans now to provide both Nicaragua and Panama the opportunity to tie to the Costa Rican grid to purchase future excess power. The transmission connection to Nicaragua is under construction now.

The transfer agreement between Costa Rica and Nicaragua stipulates that Nicaragua will pay Costa Rica for electricity at a price midway between the cost of generation in Costa Rica and the cost of generation in Nicaragua that the purchased electricity replaces. In other words, the two countries split the benefit.

From a policy viewpoint, although Costa Rica does obtain a benefit from this transfer, the electric company policy is to provide electricity to Costa Rican consumers. The transfer to Nicaragua is made only when there is an excess of power. An increased industrial demand would be met even if it were more cost effective to transfer electricity out of the country.

According to reports obtained in Costa Rica, the electric tie with Panama is still in the negotiation stage.

Relative to electricity pricing, one final point needs to be made. The funding for virtually all of the standard electric development projects in Costa Rica comes largely from the large development banks: Inter-American Development Bank, the World Bank, the Central American Bank for Economic Integration, etc. The loan agreements made by these institutions require that loan payments be made in dollars. As many of the new hydroelectric facilities have 50 percent or more funding from external sources, future electricity tariffs may require significant upward adjustment to meet dollar debt payment requirements. Although the generation of electricity may be based completely on Costa Rican energy resources, there still may be foreign price dependence through monetary constraints. It is likely, however, the dependence on world inflation rates is much preferable to the dependence on the price of imported petroleum.

4.3 Institutional Factors

A number of institutional factors need to be mentioned that may have an impact on the feasibility or the implementability of a program of substitution of industrial petroleum consumption with electricity.

Nearly all commercial energy supply in Costa Rica comes under the direct control of the Costa Rican government. The Instituto Costarricense de Electricidad (ICE) is responsible for the national electric system; the Refinadora Costarricense de Petroleo (RECOPE) is responsible for national petroleum supplies including the operation of the one petroleum refinery, and an independent government organization, the Servicio Nacional de Electricidad (SNE), is responsible for pricing of both electricity and petroleum.

Other governmental organizations, less directly involved now but which likely would become involved as a substitution program is initiated, include the Oficína de Planificacion Nacional y Politica Economica (OFIPLAN), with responsibility for national economic planning, and the Corporacion Costarricense de Desarrollo (CODESA), a national development organization which in the past has been a source of funding for special energy programs in the national interest.

In an effort to focus and to coordinate the energy activities in Costa Rica, in 1980, a Ministry of Energy was defined along with a National Energy Council made up of ministers and executive presidents of the organizations involved with national energy activities. This council has the responsibility for coordination of energy activities in addition to defining objectives and priorities in the energy sector.

The working body of this organization is the Sectoral Technical Committee headed by the Executive Secretary of Energy Planning and consists of the heads of the planning offices of each of the government organizations involved with energy matters.

A national effort to encourage the substitution of electricity for petroleum would require an immense coordination between organizations in Costa Rica. An accelerated hydroelectric expansion program can only be successful if the new demand for industrial electricity is realized. The new demand will depend on a whole range of factors including national economic growth, capital availability, and petroleum and electricity pricing structures. New petroleum and electricity pricing structures will not only require extensive coordination between ICE, RECOPE, and SNE but will involve all of the government of Costa Rica.

Although a structure for the required coordination is in place, the authority and depth of implication of that coordination responsibility will need to be significantly expanded if an industrial electrification program is to proceed effectively.

Energy pricing in Costa Rica besides being a critical factor relating to the economics of an industrial electrification program, is also a political-social problem. Because virtually all of commercial energy is nationally controlled, the goverment has the responsibility for establishing energy prices consistent with national objectives. Because of political and social pressures, there has been a tendency in Costa Rica in the past to set some energy prices below cost and to delay energy price increases. The effect has been to weaken the financial posture of both the national energy industries and the country itself.

A national program for industrial electrification will likely require some innovative pricing measures, which may not match traditional pricing practises within the separate energy institutions. Moreover the pricing structures will have to be agreed upon within the political framework of the country. In short, the needs for coordination along with the political-social aspects of energy pricing questions suggests that strong high level leadership in the Costa Rican government will be essential for the success of such a program if implemented.

The institutional aspects of Costa Rican industry itself appear to be sound. Plant managers and engineers in the major industries are generally well-versed on energy matters and willing to take advantage of cost effective new opportunities relating to energy. The Costa Rican industrial trade organization, the Camara de Industrias, is active and would be useful in the organization and information dissemination for an electrification program.

4.4 Financial Constraints

The main financial constraint to a substitution program is the shortage of available capital for ICE to undertake an accelerated expansion program. An industrial electrification conversion program would require ICE to accelerate its present capacity addition plans by one to three years. This in turn would require the one to three year accelerated acquisition of the funds required to finance construction of the new hydroelectric facilities. Assuming the funds for an accelerated program are available, then the investment costs of the program are simply the additional interest costs associated with earlier borrowing. At a discount rate of 9 percent, these additional costs have a present value of $210 million dollars. Additionally, given Costa Rica's 1980 gross investment of $836 million, the implications of an accelerated electricity investment program on the availability of investment capital for the rest of the economy is serious and must be carefully evaluated.

Of secondary concern is the availability of financial resources to industry. Although small in comparison to the investment requirements for an accelerated hydroelectric program, the funds required for conversion of industrial equipment will provide additional competition for the already scarce financial resources currently available to industry.

5.0 ECONOMIC ANALYSIS

To determine the economic potential for converting industrial petroleum consumption to electricity in Costa Rica, six generic case studies are defined which compare the economics of existing petroleum based technologies against potential alternative electric technologies. These case studies are:

Case A. Petroleum versus high-voltage electrode 800 HP steam boilers.

Case B. Petroleum versus low-voltage resistance 250 HP steam boilers.

Case C. 2.11 GJ (2.0 MMBtu)/hr petroleum versus electric resistance low temperature process heaters.

Case D. 2.11 GJ (2.0 MMBtu)/hr petroleum versus low-voltage resistance and electric heat pumps hot water boilers.

Case E. 2.11 GJ (2.0 MMBtu)/hr petroleum versus electric microwave food oven-drier system.

Case F. 1 MW petroleum electric generator versus purchased grid electricity.

The application in Costa Rica of the existing petroleum technologies and the selection of the competing electric technologies presented above is discussed in Section 3.0.

In addition to the six cases outlined above, a case evaluating a newly available retrofit biomass gasification technology for 250 HP and smaller petroleum boilers is evaluated against maintaining existing petroleum boilers. The biomass gasification technology offers the unique opportunity of replacing only the oil burner portion of a petroleum boiler system with the biomass gasifier/burner. The economic analysis of this alternative, presented in Case G, was requested by the IDB project officer who was informed of the potential of this technology, during the progress of this study. Thus, a complete analysis of this technology is beyond the scope of this study. However, Case G provides a preliminary analysis.*

5.1 Methodology

Given the technical feasibility of alternative energy systems, the ultimate selection criteria, within a profit-making industry, must be based on maximizing its profit while minimizing all risks. Thus, the lowest initial cost alternative may not result in the greatest economic return because of the systems annual operating and maintenance costs, reliability and expected life. When several alternatives are available, the selection criteria is standardized in order to compare alternatives against each other.

With respect to risk, a comparison of technology reliability, performance, operation, expected life and other non-quantifiable factors must be accounted for and evaluated. For all monetarily quantifiable factors, the importance of the time value of money (i.e., the opportunity costs) must be accounted for when evaluating

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*A detailed analysis of the economies of retrofit wood gasification technologies is presented in: "An Assessment of Wood Gasification/Combustion Systems for Retrofit or Replacement of Small Oil-Fired Boilers in Papua New Guinea," Matthew S. Mendis and Abu Talib, The MITRE Corporation, WP-81W578, October, 1981.

alternatives from an investment perspective. Several discounting methods for investment analysis exist in the literature.* The most commonly used methods include:

- Rate of return on investment
- Payback period
- Net present cost
- Life cycle cost
- Uniform annual costs

Each of these methods has its advantages and disadvantages and, in some cases, may not result in similar conclusions for a given set of alternatives. Thus, the investment analysis method selected must carefully reflect the overall priorities of the decision-maker. For example, a payback analysis will favor alternatives with large incomes in early years while a net present worth or uniform annual costs analysis will account for the income generated throughout the life of a project.

In a dynamic economy there are two types of investment decisions: capacity expansions and capacity replacements. Capacity expansions relate to the addition of new capacity where none previously existed, and investment decisions in this realm are based upon comparisons of the capital and operating costs of each proposed system. Alternately, capacity replacement is the displacement with

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*See Grant, 1970; Van Horne, 1978; Barish, 1978.

a new, more economic system of an existing system with a remaining productive life. Although the analysis required to evaluate capacity expansion decisions and replacement decisions is quite similar, the criteria used are quite different.* A key factor in replacement decisions is that the sunk capital costs of the existing system is not relevant to the analysis. Only the salvage value and operating costs of the existing system and the capital and operating costs of the new system are relevant. A brief outline of the criteria used in this study to evaluate capacity expansion and capacity replacement decisions is presented below.

Capacity Expansions

The basis used for evaluating the economics of competing energy systems for capacity expansions is the life cycle cost (LCC) of a unit of process energy (i.e., kg of steam, GJ of process heat, kWh of electricity). The primary assumption is that competing energy systems have similar productive lives and only affect costs without affecting gross revenues. Therefore, the system with the lowest LCC will yield the highest return on investment.

The LCC of a unit of process energy for a given system is determined by dividing the discounted present worth (PW) of the capital, fuel, operating and maintenance costs incurred over the life of the

*For discussions on replacement analysis see Gsellman, 1981 and Taylor, 1964.

system by the total process energy output over the life of the system. In mathematical terms this is expressed as:

(1) $$LCC^A = PW^A_{i^*,n} / TPEO^A$$

Where:

LCC^A = the life cycle cost per unit of energy of alternative A

$PW^A_{i^*,n}$ = the present worth of the total cash outlays of alternative A over n years (the life of the alternative discounted at the rate of i*)

$TPEO^A$ = the total process energy output of alternative A

(2) $$PW^A_{i^*,n} = TCI^A_o + \sum_{t=1}^{n} [FC^A_o (1 + F_f)^n + OMC^A_o (1 + F_m)^n] PWF^{i^*}_t - CB^A_n \cdot PWF^{i^*}_n$$

Where:

TCI^A_o = total initial capital investment of A

FC^A_o = initial (or base year) annual fuel cost of A

OMC_o = initial (or base year) annual operating and maintenance costs of A

F_f = average annual real rate of increases in fuel prices

F_m = average annual real rate of increases in operating and maintenance costs

$PWF^{i^*}_t$ = the present worth factor for discount rate i* in year t

CB^A_n = the cash balance of alternative A of the end of n years due to recovery of working capital and equivalent salvage value

(3) $PWF_t^{i*} = 1/(1+i*)^t$

<u>Capacity Replacements</u>

The "payback" period (PP) for an investment is an initial decision criteria normally used in capacity replacement decisions. Mathematically this can be stated as:

PP = NCI/ASC

Where:

NCI = the net capital investment for the replacement technology*

ASC = the annual savings in costs from implementing the replacement technology

The maximum acceptable payback period varies according to perceived opportunity costs and project risks. For industry in Costa Rica, the maximum acceptable payback period for small industrial replacement energy systems is approximately two to three years.

Given an acceptable payback period, the more important element in capacity replacement decisions is the timing of the decision. The timing of the replacement of the existing oil-fired system with a new alternative system must be accomplished while minimizing the net present cost (NPC) or uniform annual costs (UAC) to the industry.

Consider a planning horizon of time period L. Figure 5-1 illustrates the possible cash flow over the period L. The existing

*The net capital investment is defined to be the total capital investment (TCI) of the replacement alternative less the working capital of the existing technology.

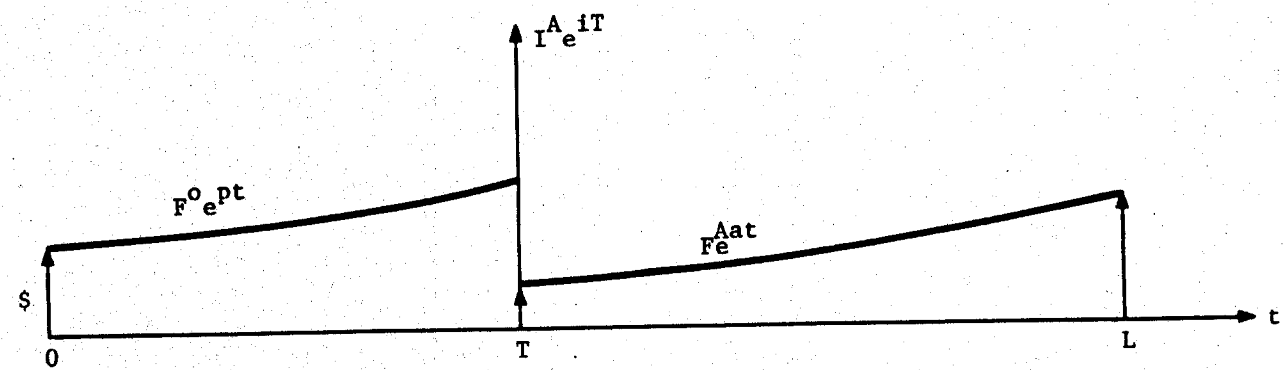

FIGURE 5-1
CASH FLOW OVER PLANNING HORIZON L

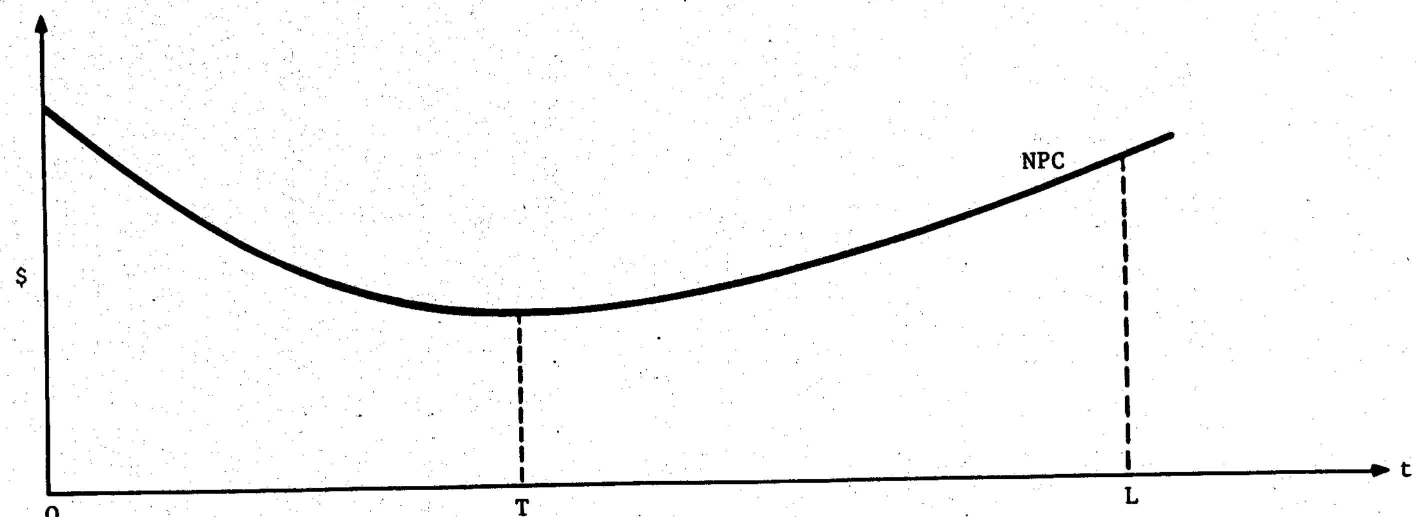

FIGURE 5-2
NET PRESENT COST (NPC) AS A FUNCTION OF THE TIMING OF THE REPLACEMENT INVESTMENT

oil-fired system has an annual operating and maintenance costs in time t given as:

(4) $F^o(t) = F^o e^{pt}$

Where:

F^o = the O&M costs for the oil-fired system in year zero,

p = the O&M price escalation for the oil fired system

Similarly the new alternative has an initial investment and an O&M cost given by:

(5) $I^A(t) = I^A e^{it}$

Where:

I^A = the total capital investment measured in year zero

i = the annual price increase in capital equipment

(6) $F^A(t) = F^A e^{at}$

Where:

F^A = the O&M costs for the alternative system in year zero

a = the O&M price escalation for the alternative system

The objective of the replacement analysis is to identify the time, T, of the alternative investment such that the NPC of the cash flow over the planning horizon, L, is minimized as shown in Figure 5-2. Mathematically, this can be represented as:

(7) Minimize $NPC = \int_0^T F^o e^{pt} e^{-rt} dt + I^A e^{iT} e^{-rT} + \int_T^L F^A e^{at} e^{-rt} dt$

Where:

r = the acceptable discount rate

This can be solved by evaluating the above equation and solving for the value of T which results in:

$$(8) \quad \frac{\partial\, NPC}{\partial\, T} = 0$$

The above two equations yield a closed form solution for the special case where:

$$(9) \qquad i = a \neq p$$

This is the case where the price escalation for petroleum and the alternative fuel is disimilar.

Assuming the conditions in equation (9) hold, then the solution for T is given as:

$$(10) \qquad T^{*} = \frac{1}{(p-i)} \ln \left[\left((r-i)\ I^{A} + F^{A} \right) / F^{o} \right]$$

Equation (10) can be used for an initial estimate of the value of T.

Define:

$$(11) \qquad p' = p-i$$

$$(12) \qquad r' = r-i$$

The value p' represents the relative price escalation of petroleum and r' the relative discount rate. Equation (10) can then be written as:

$$(11) \quad T^{*} = \frac{1}{p'} \ln \left[\left(r' \quad I^{A} + F^{A} \right) / F^{o} \right]$$

The term in the brackets simply represents the ratio of the annualized cost of the new alternative over the annualized cost of the existing oil-fired technology. The optimum replacement time T^{*} is a function of this ratio and the petroleum price escalation rate: A plot of T* for varying annualized cost ratios and petroleum price escalation rates is presented in Figure 5-3. This plot is used to determine the approximate replacement life for the existing oil-fired technologies evaluated in this study.

5.2 Assumptions

Energy Prices

Current (i.e., May 1981) energy prices are selected as a basis for the economic analysis of competitive energy systems. The effects of general inflation on future energy prices are factored out of the analysis and only relative real increases in energy prices are considered. Similarly, the effects of the highly unstable exchange rate for the Colon are avoided by considering all future energy prices in dollars. The implications of changes in the exchange rate, especially as it affects domestic electricity prices through fixed asset revaluation is highly complex and subject to extensive negotiations between international financial institutions, ICE, and other offices of the Government of Costa Rica.

Table 5-I presents current and projected petroleum prices used in this analysis. Price projections for medium and high real price increases are presented. These correspond to annual real price increases of three and ten percent, respectively.

As presented in Section 4.0, industrial electricity prices in Costa Rica are based on two tariff structures, T-4 and T-10. Present electricity consumption in most industries in Costa Rica are at the

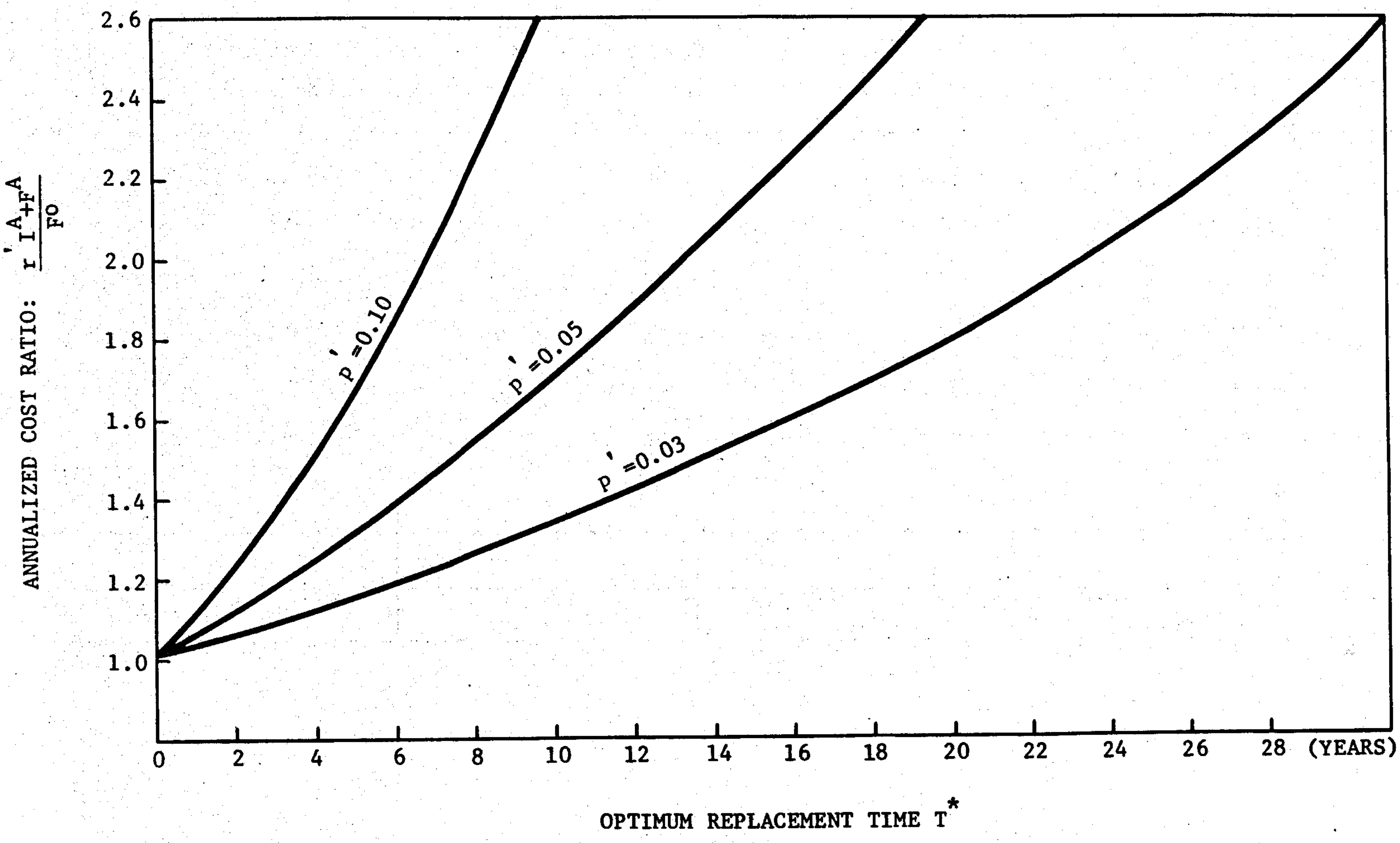

FIGURE 5-3
PLOT OF OPTIMUM REPLACEMENT TIME T*

TABLE 5-I

PETROLEUM PRODUCT PRICES

Products	Unit	May 1981 Actual		Projections 1985		Projections 1990	
		Colones	$	Medium $	High $	Medium $	High $
Petroleum:							
Crude Oil	BBL	623.70	33.000	37.014	48.032	43.006	77.081
Bunker C	liter	2.50	0.132	0.149	0.193	0.172	0.311
Diesel	liter	6.90	0.365	0.411	0.534	0.476	0.861
Gasoline	liter	11.50	0.608	0.684	0.890	0.793	1.434
Kerosene	liter	8.00	0.423	0.476	0.619	0.552	0.997
Ammonia:	Tonne	3780.00	200.000	225.010	292.082	260.095	471.059

Medium = 3 percent per annum real price increases

High = 10 percent per annum real price increases

U.S.$1 = ₡18.9

maximum rate bases given in these tariffs. Given this assumption, the price of additional electricity for substitution of petroleum is as follows:

Tariff	Demand Charge/Time of Day		Energy Charge/Time of Day	
T-4	₡114.35 x kW	0.00 to 24.00	₡0.3586/kWh	0.00 to 24.00
T-10	₡114.35 x kWp	10.00 to 12.30 and 16.30 to 20.00	₡0.1938/kWh	10.00 to 20.00
	₡ 0.00	all other times	₡0.1600/kWh	20.00 to 10.00

Where:

kW = the highest average load in kW for any 15 minute interval during the month

kWp = the highest average load in kW for any 15 minute interval during the month that is registered between 10.00 and 12.30 hours or between 16.30 and 20.00 hours

kWh = the total kWh registered in a month

For this analysis, real price increases in electricity are assumed to occur uniformly across tariffs for both demand and energy charges. Thus, projected tariff increases are determined by adjusting the constant terms in the equations above for T-4 and T-10.

Discount Rate

A discount rate (i*) of 20 percent is assumed to reflect a reasonable measure of the opportunity costs of money to industry in Costa Rica. Since general inflationary effects are factored out of this analysis, the discount rate represents the minimum acceptable real rate of return to industry. This discount rate is higher than the rate of 12 percent normally used by the IDB for large national projects. A sensitivity analysis on the discount rate is presented to provide a measure of its impact on capital budgeting decisions.*

Project Life

A project life of 10 years is assumed for all new equipment.** This is a conservative estimate but considered adequate for the general level of this analysis. In practice, equipment life for most industrial process energy systems vary considerably depending on the level of use, maintenance practices, fuel characteristics, surrounding environment and several other factors. No salvage value is attached to the equipment for the purposes of this analysis.

Total Capital Investment

The total capital investment of each energy system is estimated based on the fixed capital investment (FCI) and working capital (WC) required. The FCI is estimated from equipment costs (EC) quoted by vendors. A list of vendors contacted is presented in Appendix D. The FCI includes standard cost estimating factors (Peters, 1980) for installation (IN), engineering (EN) and contingencies (CN) plus

*The lower the discount rate the more favorable is the economic position for those technologies that result in fuel and operating cost savings.

**The project life of 10 years does not indicate the actual life of the equipment but is selected to provide an adequate cash flow period for analysis. Disbursements made after 10 years discounted at 20 percent have a present worth factor of less than 0.13 and therefore have little or no effect on the outcome of a discounted life cycle cost analysis.

quoted estimates for shipping costs (SH) from the U.S. to Costa Rica. In mathematical terms, FCI is represented as:

FCI = EC + IN + EN + CN + SH

Where:

IN = 0.2 x EC

EN = 0.15 x (EC + IN)

CN = 0.05 x (EC + IN + EN)

Working capital is estimated at 10 percent of the baseline fuel plus operating and maintenance costs.

Total Annual Non-Fuel O&M Costs

Non-fuel O&M costs are estimated as the sum of equipment maintenance, manpower and auxiliary power costs. These costs are assumed constant (i.e., no real price increases) over the analysis period. Annual equipment maintenance costs are estimated at 10 percent of the fixed capital investment (FCI). Manpower costs are estimated based on observed practices in Costa Rica for operation of similar equipment. Wages plus fringes are assumed at $2000/yr for general labor and $5000/yr for skilled labor. Auxiliary power, in the form of electricity required for operating pumps and fans associated with the petroleum- and wood-fired systems, is priced at the average May 1981 T-4 electricity price of $0.035/kWh (C0.67/kWh).

5.3 Results

Results of the economic analysis for the seven case studies considered are presented in this section. Each case study is briefly described, followed by a presentation of the cash flow data (i.e., capital investments and annual fuel and operating costs) and process energy life cycle costs (LCC). A summary of the main observations of the analysis concludes the presentation of each case study.

A sensitivity analysis of key variables is presented at the end of Case A. This analysis provides a basis for evaluating the sensitivity of the results to key variables for the remaining six cases.

<u>Case A</u>: 800 HP petroleum versus high-voltage electrode steam boilers.

The 800 HP boilers are representative of a few large industrial steam generating facilities in Costa Rica. However, their size and generally high annual utilization factor* (assumed to be 50 percent) results in a significant quantity of fuel consumed for industrial steam generation. Boilers in this size range are estimated to account for between 10 to 30 percent of the petroleum consumed for industrial steam.

Table 5-II presents the cash flow data for the 800 HP diesel, Bunker C and electrode boilers. The FCI differ by about 18 percent between boilers. However, annual fuel costs are significantly higher for boilers using diesel or T-4 electricity while boilers using Bunker C or T-10 electricity have annual fuel costs that are 50 to 65 percent lower.

*Annual utilization factor is defined as the ratio of the annual output of the system divided the total maximum annual capacity of the system.

TABLE 5-II

CASE A: BASE YEAR CASH FLOW FOR 800 HP BOILERS

	Fuel System Alternatives			
	Oil-Fired Boiler		Electrode Boiler	
Cost Components $\$ \times 10^3$	Diesel	Bunker C	T-4 Electricity	T-10 Electricity
• Total Capital Investment	276.8	197.6	278.0	215.7
Fixed Capital Investment	128.8	142.6	151.8	151.8
Working Capital	148.0	55.0	126.2	63.9
• Total Annual Non-Fuel O&M Costs	22.0	26.5	16.6	16.6
Maintenance	12.9	14.3	15.3	15.3
Manpower	3.0	3.0	1.3	1.3
Auxiliary Power	6.1	9.2	0.0	0.0
• Total Annual Fuel Costs	1,458.3	523.0	1,245.7	622.3

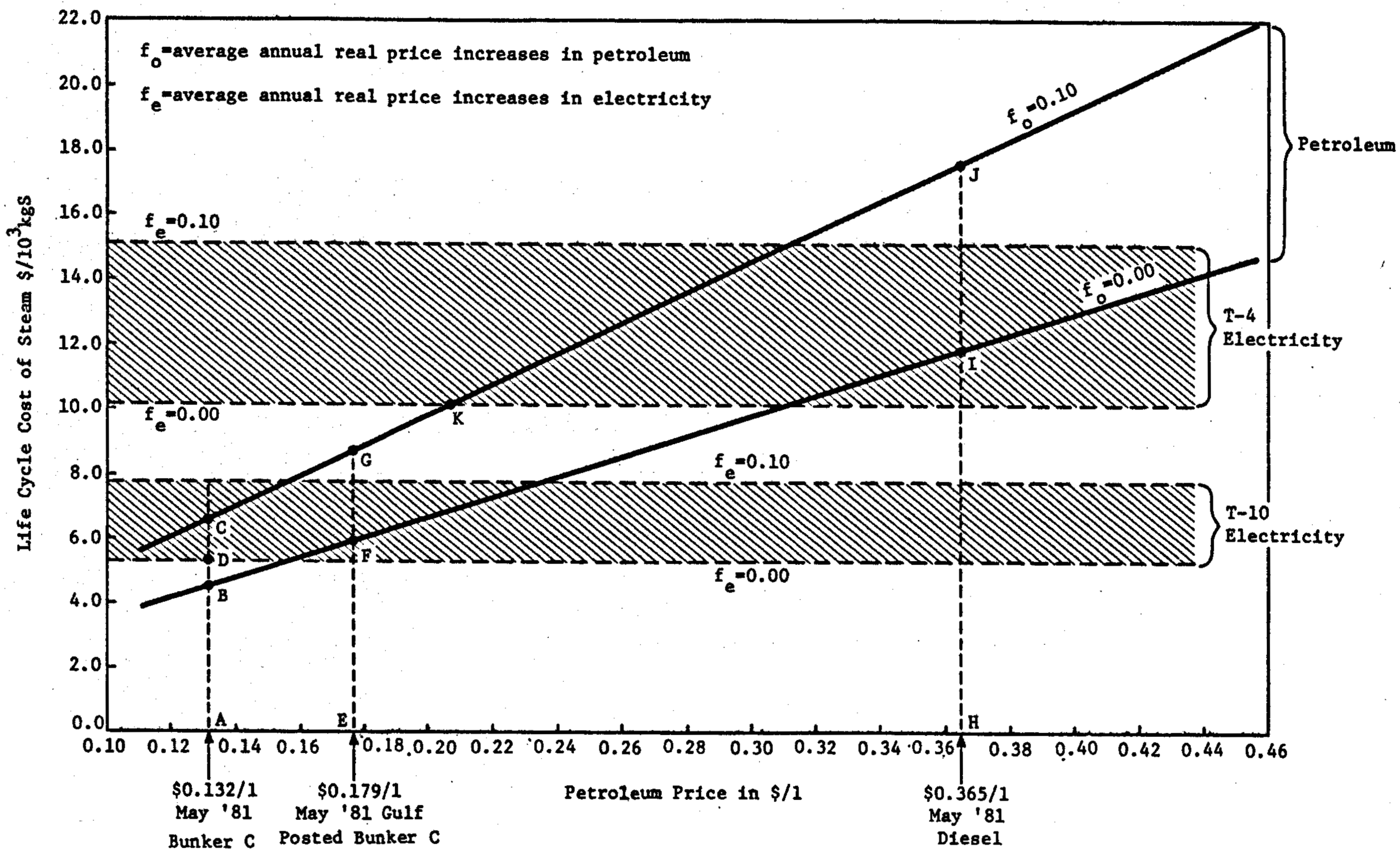

FIGURE 5-4
CASE A: LIFE CYCLE COST OF STEAM VERSUS FUEL COSTS—
800 HP BOILERS

Figure 5-4 presents the life cycle cost (LCC) analysis for steam generated by either petroleum or electricity. The solid lines map the range of the LCC per 10^3 kg of steam(kgS) generated by petroleum boilers as a function of petroleum prices and average annual real fuel price increases. The dashed lines map the range of the LCC per 10^3 kgS generated by electrode boilers as a function of electricity tariff structures, T-4 or T-10, and average annual real electricity price increases.

Line AB represents the LCC of steam ($4.6/$10^3$ kgS) from a Bunker C boiler for Bunker C priced at $0.132/l (May 1981 price) and with no expected increase in the real price of Bunker C over the next 10 years. Line AC represents an expected 10 percent annual average real increase in Bunker C prices. The LCC in this case rises to $6.6/$10^3$ kgS, a 43 percent increase over the stable real price case. The line BC represents the range between zero and a 10 percent average annual real price increase. If the price of Bunker C is increased in the base year (n=o) to $0.179/l, the Gulf Coast spot price, then line EF ($5.9 thru $8.7/$10^3$ kgS) represents the range of the LCC of steam from Bunker C boilers.

The data in Figure 5-4 illustrates that diesel boilers, which at current prices have a LCC for steam in the range of $11.8 thru $17.6/$10^3$ kgS, are highly uncompetitive when compared to electrode and especially Bunker C boilers. Under present conditions, electrode boilers are competitive with Bunker C boilers only if electricity is purchased at the T-10 rate. Implied in the T-10 rate are the operational time constraints for achieving the minimum charge discussed in Section 5.2. Electrode boilers operating with T-4 electricity rates and assuming no annual real price increase have a LCC of steam of $\$10.1/10^3$kg. An increase in base year Bunker C prices of 60 percent (to $0.21/1) and an expected average annual real price increase of 10 percent per year will yield a similar LCC for steam from Bunker C boilers (point K).

Table 5-III presents the results of the replacement analysis for the 800 HP boilers. Simple payback periods were calculated by adjusting the total capital investment needed for the alternative technology by the working capital of the existing oil-fired technology. Optimum replacement times, T*, were calculated for discount rates of 12 and 20 percent and petroleum escalation rates of 3 and 10 percent.

The results indicate that the immediate replacement of diesel systems with electrode boilers is economic under almost all conditions tested. Replacement of Bunker C systems with electrode boilers powered by T-4 electricity is not economic within a planning horizon of 10 years unless Bunker C prices escalate at an average rate of 10 percent per year. Even in this case, replacement of existing boilers with substantial lives is not economic until the ninth year. Replacement of existing Bunker C boilers with electric boilers using T-10 electricity is economic in the 2 to 7 year time frame depending on the assumed discount rate and petroleum price escalation rate.

TABLE 5-III

REPLACEMENT ANALYSIS FOR 800 HP BOILERS

REPLACEMENT OPTION	PAYBACK PERIOD (IN YEARS)	REPLACEMENT TIME, (IN YEARS)		
		r=0.12 p=0.03	r=0.20 p=0.03	r=0.20 p=0.10
Diesel System Replaced By:				
T-4 Electricity	0.6	0	0	0
T-10 Electricity	0.1	0	0	0
Bunker C System Replaced By:				
T-4 Electricity	*	28	28	9
T-10 Electricity	*	6	7	2

r = discount rate
p = petroleum price escalation rate
* = the savings from the replacement option are negative.

Case B: 250 HP petroleum versus low-voltage resistance boilers.

The 250 HP steam boilers are representative of a large majority of the steam boilers in Costa Rica which fall in the range of 60 HP to 400 HP. While boilers in this size range are numerous in Costa Rica, their smaller size and generally lower utilization factor (assumed at 0.3) results in a much lower fuel consumption per boiler, than do the large boilers. Boilers under 400 HP in size are estimated to account for between 60 to 80 percent of the petroleum consumed for producing industrial steam.

Table 5-IV presents the cash flow data for the 250 HP diesel, Bunker C and low-voltage resistance boilers. As in the case of the 800 HP boilers, the FCI between boiler types differ only slightly while fuel costs are the major variable.

Figure 5-5 presents the LCC analysis for steam generated by either petroleum or electricity. The LCC of steam generated by low-voltage resistance boilers at T-4 rates is in the competitive range of small diesel boilers. The competitive advantage will increase if there is any increase in diesel prices in the base year. Small Bunker C boilers are competitive against resistance boilers with T-10 electricity. An increase of 44 percent in the base year Bunker C prices, to $0.190/l, results in a LCC of steam from Bunker C boilers that is in the equivalent range for resistance boilers operating with T-10 electricity. Under present conditions, there is a strong economic incentive for all diesel boiler consumers to switch to

TABLE 5-IV

CASE B: BASE YEAR CASH FLOW FOR 250 HP BOILERS

	Fuel System Alternatives			
	Oil-Fired Boiler		Electrode Boiler	
Cost Components $ x 10^3	Diesel	Bunker C	T-4 Electricity	T-10 Electricity
• Total Capital Investment	96.2	85.9	107.7	91.3
Fixed Capital Investment	67.7	75.0	76.2	76.2
Working Capital	28.5	10.9	31.5	15.1
• Total Annual Non-Fuel O&M Costs	10.4	11.4	8.9	8.9
Maintenance	6.8	7.5	7.6	7.6
Manpower	3.0	3.0	1.3	1.3
Auxiliary Power	0.6	0.9	0.0	0.0
• Total Annual Fuel Costs	274.1	98.2	306.2	142.3

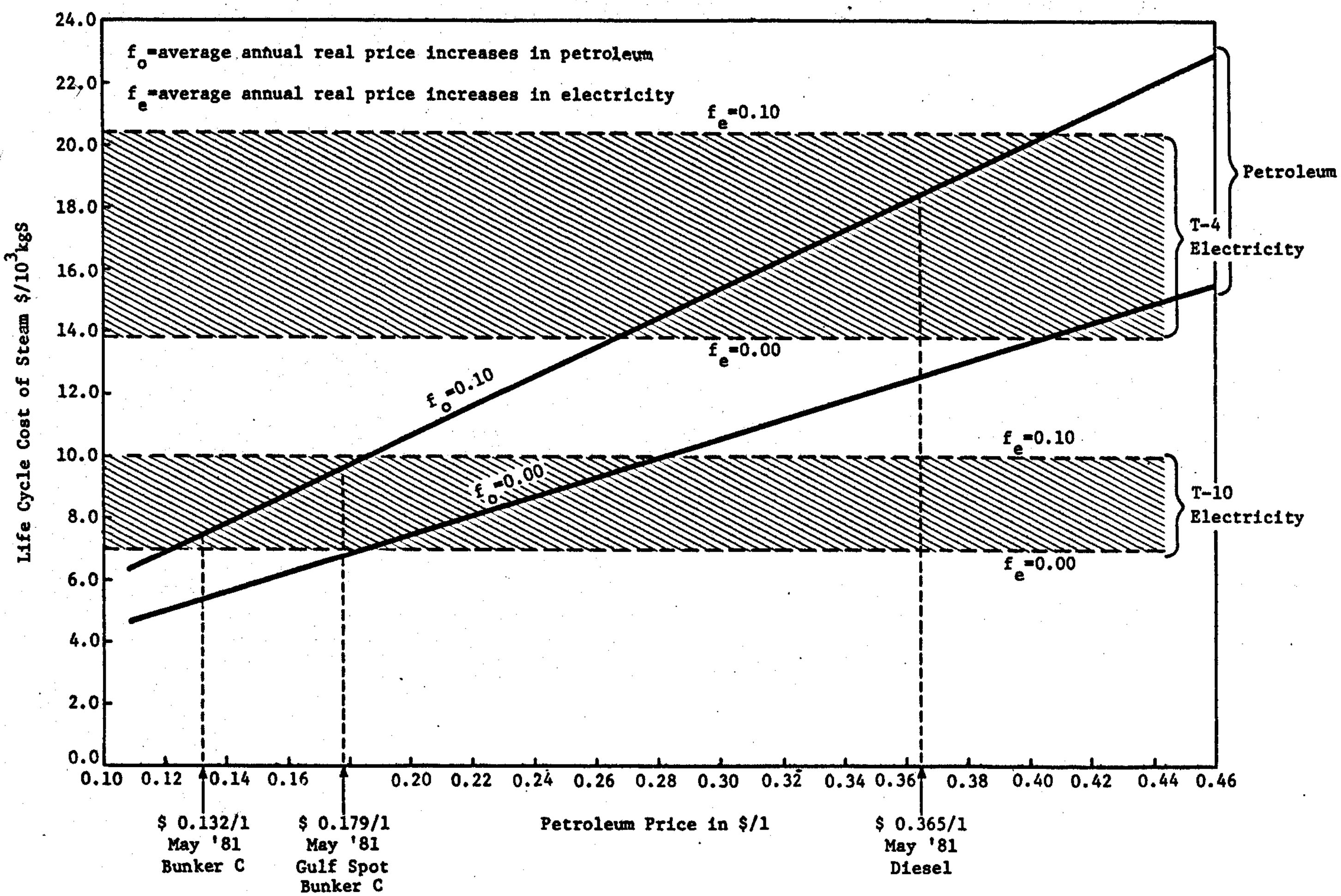

FIGURE 5-5
CASE B: LIFE CYCLE COST OF STEAM VERSUS FUEL COSTS— 250 HP BOILERS

Bunker C. The cost of retrofitting a diesel 250 HP boiler to burn Bunker C is estimated at under $12,000 in capital cost or equivalently an additional $\$0.23/10^3$kgS to the LCC of Bunker C (assuming a five year life for the retrofit).

Table 5-V presents the results of the replacement analysis for 250 HP boilers. Optimum replacement times were calculated only for discount rates of 20 percent and petroleum price escalation rates of 3 percent. The results indicate that it is economic to replace existing diesel boilers immediately with electrode boilers powered by T-10 electricity. If T-4 electricity is used, the optimum replacement time shifts to five years. Replacement of existing Bunker C boilers with electrode boilers powered by either T-4 or T-10 electricity is uneconomic if the baseline assumptions of this analysis persist. A shift up in the Bunker C price to the Gulf spot market price of $0.179/l will make replacement of existing Bunker C boilers with T-10 electrode boilers economic in five years.

Case C: 2.11 GJ (2.0 MMBtu)/hr petroleum versus electric resistance low temperature process heaters.

Petroleum low temperature process heaters are predominant in the food processing industry in Costa Rica. Size ranges for these process heaters vary considerably but in general are in the smaller size ranges represented by the 2.11 GJ (2.0 MMBtu)/hr system evaluated in this case study. Utilization factors for these systems also vary considerably from less than 0.3 for users such as coffee

TABLE 5-V

REPLACEMENT ANALYSIS FOR 250 HP BOILERS

REPLACEMENT OPTION	PAYBACK PERIOD (IN YEARS)	REPLACEMENT TIME (IN YEARS)	
		r=0.20 p=0.03	r=0.20 p=0.03 BC=$0.179/ℓ
Diesel System Replaced By:			
T-4 Electricity	*	5	5
T-10 Electricity	0.5	0	0
Bunker C System Replaced By:			
T-4 Electricity	*	37	28
T-10 Electricity	*	14	5

r = discount rate
p = petroleum price escalation rate
BC = May 1981 Bunker C Gulf Spot price
* = the savings from the replacement option are negative.

beneficiators to greater than 0.6 for industrial processors. A utilization factor of 0.5 is assumed in this analysis.

Table 5-VI presents the cash flow data for the diesel, Bunker C and electric resistance low temperature process heaters. The FCI for the electric system is approximately twice as much as that for the petroleum systems. Total annual fuel costs in the base year are highest for the diesel and lowest for the Bunker C system. An electric resistance system on a T-4 tariff has a 15 percent lower base year fuel costs than does the diesel system. Base year annual fuel costs for the electric resistance system on a T-10 tariff is $46,700, approximately 27 percent higher than that for the Bunker C system.

Figure 5-6 presents the LCC analysis for process heat generated by either the petroleum or electric systems. Assuming no major shift in current Bunker C prices, the Bunker C system is the most competitive. However, if base year Bunker C prices are allowed to move up to the Gulf spot price of $0.179/1, electric resistance systems under a T-10 tariff are equally competitive. Electricity systems under a T-4 tariff are competitive with diesel systems given current diesel prices.

The replacement analysis for 2.0 MMBtu/hr low temperature heaters is presented in Table 5-VII. It is economic to replace existing diesel powered systems immediately by electric systems powered either by T-4 or T-10 electricity. However, replacement of Bunker C systems with T-10 powered electric systems are only economic in five years.

TABLE 5-VI

CASE C: BASE YEAR CASH FLOW FOR 2.11GJ(2.0 MMBTU)/HR LOW TEMPERATURE PROCESS HEATERS

Cost Components $\$ \times 10^3$	Fuel System Alternatives			
	Oil-Fired Process Heaters		Resistance Process Heaters	
	Diesel	Bunker C	T-4 Electricity	T-10 Electricity
• Total Capital Investment	44.1	40.4	74.9	70.3
Fixed Capital Investment	32.5	35.8	64.8	64.8
Working Capital	11.6	4.6	10.1	5.5
• Total Annual Non-Fuel O&M Costs	6.9	8.7	7.8	7.8
Maintenance	3.3	3.6	6.5	6.5
Manpower	1.3	1.3	1.3	1.3
Auxiliary Power	2.3	3.8	0.0	0.0
• Total Annual Fuel Costs	109.2	36.8	93.4	46.7

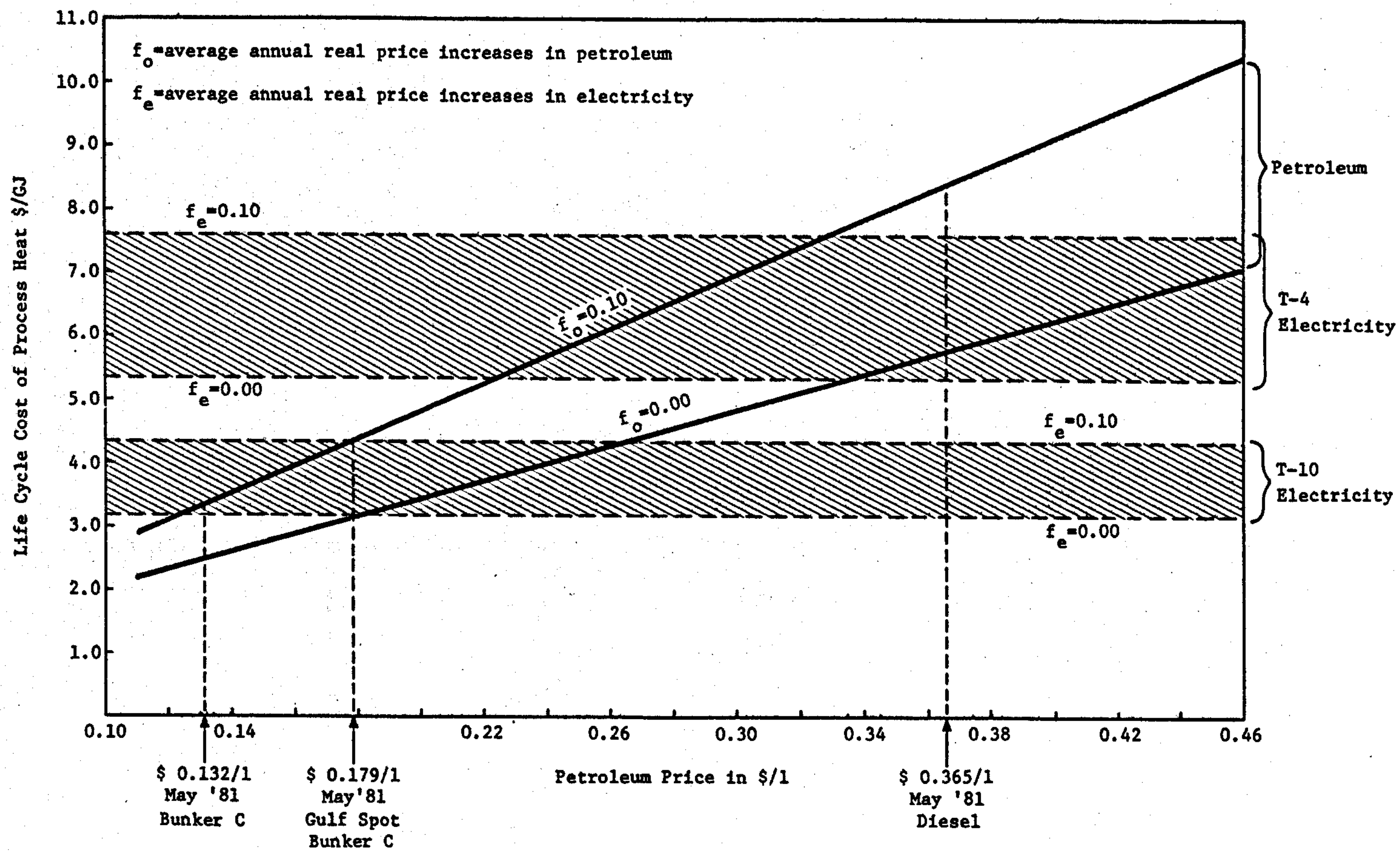

FIGURE 5-6
CASE C: LIFE CYCLE COST OF PROCESS HEAT VERSUS FUEL COSTS—
2.11 GJ (2.0 MMBTU)/HR PROCESS HEATERS

TABLE 5-VII

REPLACEMENT ANALYSIS FOR 2.0 MMBTU/hr

LOW TEMPERATURE PROCESS HEATERS

REPLACEMENT OPTION	PAYBACK PERIOD (IN YEARS)	REPLACEMENT TIME (IN YEARS)	
		r=0.20 p=0.03	r=0.20 p=0.03 BC=$0.179/ℓ
Diesel System Replaced By:			
T-4 Electricity	5.7	0.7	0.7
T-10 Electricity	1.0	0	0
Bunker C System Replaced By:			
T-4 Electricity	*	31	22
T-10 Electricity	*	13	5

r = discount rate
p = petroleum price escalation rate
BC = May 1981 Bunker C Gulf Spot price
* = the savings from the replacement option are negative

<u>Case D:</u> 2.11 GJ (2.0 MMBtu)/hr petroleum hot water boilers versus low-voltage resistance boilers and electric heat pumps.

Hot water is used in several industrial processes in Costa Rica especially in the food and beverage industry. In most cases, the hot water is derived from steam boilers but in some instances it is generated directly from hot water boilers. In either case, if hot water is the process energy needed, then electric resistance boilers and electric heat pumps can be considered as potential substitutes.

The electric heat pump is particularly appropriate when there is a high temperature waste stream available from which the heat pump can extract heat. To obtain process water temperatures of about 160 F from waste stream temperatures of about 100 F, the coefficient of performance (COP) for the heat pump is about 4. In the absence of such a waste stream and assuming ambient temperatures, the heat pump has a COP of about 2.0 and is not particularly efficient for producing hot water. The analysis in this case assumes the availability of a 110 F waste stream to produce a 180 F process hot water stream, and that the COP for the heat pump is 3.6.* A utilization factor of 0.5 is also assumed for all the hot water boiler systems considered in this case.

*The COP of 3.6 implies that 3.6 units of energy are derived from the waste heat source by using one unit of equivalent electrical energy.

TABLE 5-VIII

CASE D: BASE YEAR CASH FLOW FOR 2.11GJ(2.0 MMBTU)/HR HOT WATER BOILERS

Cost Components ($\$x10^3$)	Fuel System Alternatives					
	Oil-Fired Boiler		Low Voltage Resistance Boilers		Electric Heat Pump	
	Diesel	Bunker C	T-4 Electricity	T-10 Electricity	T-4 Electricity	T-10 Electricity
• Total Capital Investment	35.1	30.8	29.5	24.8	116.4	113.0
Fixed Capital Investment	23.8	26.5	19.8	19.8	113.0	113.0
Working Capital	11.3	4.3	9.7	5.0	3.4	2.3
• Total Annual Non-Fuel O&M Costs	3.8	4.2	3.3	3.3	12.6	12.6
Maintenance	2.4	2.7	2.0	2.0	11.3	11.3
Manpower	1.3	1.3	1.3	1.3	1.3	7.3
Auxiliary Power	0.1	0.2	0.0	0.0	0.0	0.0
• Total Annual Fuel Costs	109.2	39.1	93.4	46.7	21.2	10.6

Cash flow data for diesel, Bunker C, electric boilers and for electric heat pumps are presented in Table 5-VIII. Capital cost estimates for the heat pumps are about five times greater than the conventional petroleum or electric boilers. Annual fuel costs, however, are about one-fifth to one-tenth that of the conventional boilers.

The LCC analysis for hot process water generated by conventional petroleum or electric boilers and by heat pumps is presented in Figure 5-7. Heat pumps at either a T-4 or T-10 electricity tariff are competitive with Bunker C boilers. Conventional electric boilers with a T-10 electricity tariff are competitive with Bunker C and diesel boilers and at a T-4 tariff are competitive only with diesel boilers. As with, steam boilers, diesel hot water boilers are convertible to Bunker C for a relatively small capital investment.

The replacement analysis for 2.0 MMBtu/hr hot water boilers is presented in Table 5-IX. Immediate replacement of existing diesel systems by either low voltage resistance boilers or heat pumps is economic for almost all cases. Replacement of Bunker C systems with T-10 powered heat pumps become economic in one year. T-10 powered low voltage resistance boilers are economic replacements for existing Bunker C systems only after seven years.

Case E: 2.11 GJ (2.0 MMBtu/hr) petroleum versus electric microwave food oven systems.

Food oven systems are used extensively in Costa Rica for high temperature process heat in baking and other food processing. These

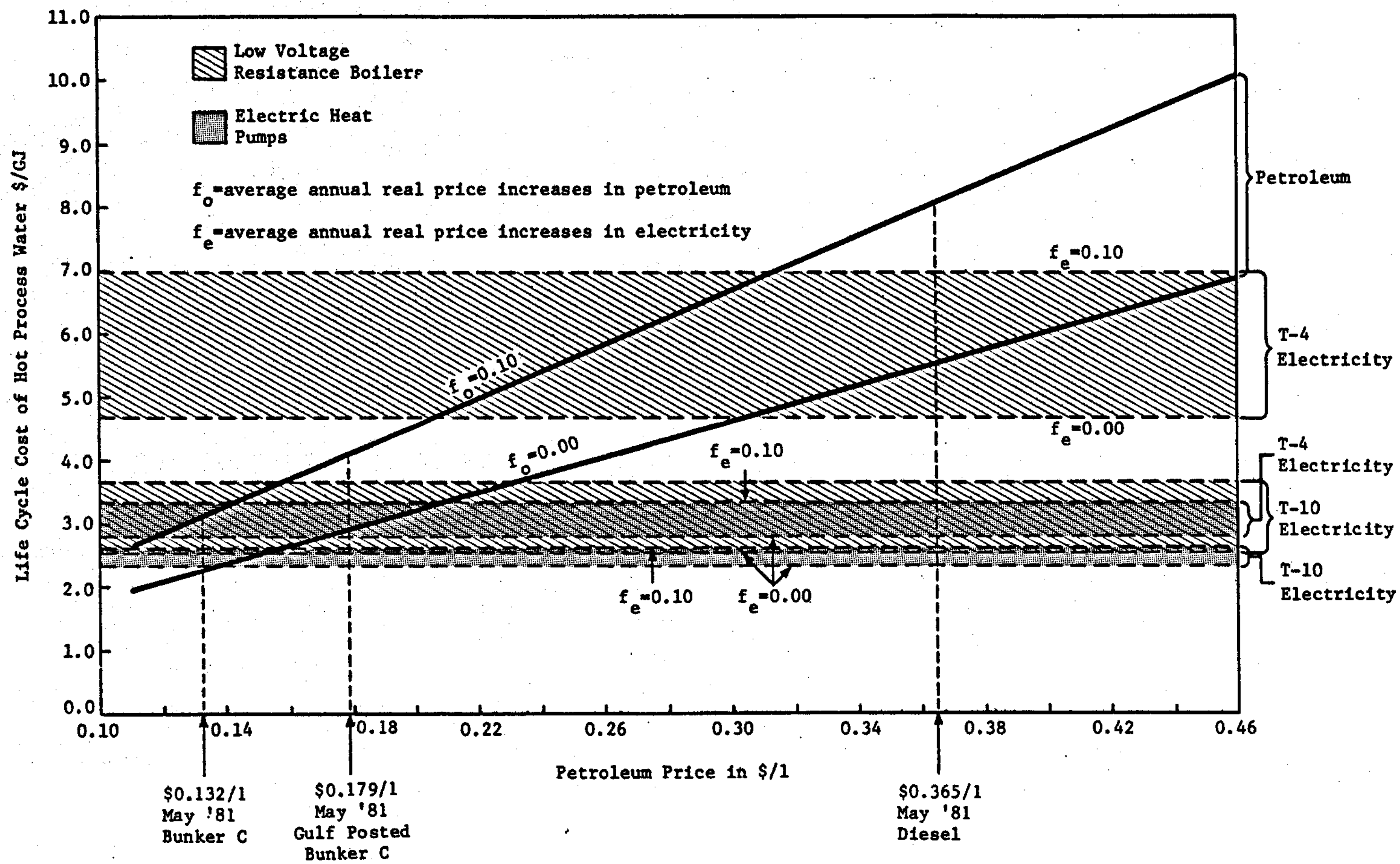

FIGURE 5-7
CASE D: LIFE CYCLE COST OF HOT PROCESS WATER VERSUS FUEL COSTS—2.11 GJ (2.0 MMBTU)/HR HOT WATER BOILERS

TABLE 5-IX

REPLACEMENT ANALYSIS FOR 2.0 MMBTU/hr HOT WATER BOILERS

REPLACEMENT OPTION	PAYBACK PERIOD (IN YEARS)	REPLACEMENT TIME (IN YEARS) r=0.20 p=0.03
• Diesel System		
- Low Voltage Resistant Boilers Using		
T-4 Electricity	1.1	0
T-10 Electricity	0.2	0
- Heat Pumps Using		
T-4 Electricity	1.3	0
T-10 Electricity	1.1	0
• Bunker C System Replaced By:		
- Low Voltage Boilers Using		
T-4 Electricity	*	28
T-10 Electricity	*	7
- Heat Pumps Using		
T-4 Electricity	11.8	9
T-10 Electricity	5.4	1

r = discount rate
p = petroleum price escalation rate
* = the savings from the replacement option are negative

oven systems include conveyors, heat tunnels or chambers and other integrated components to automate the operation. Similar electric microwave systems are commercially available (Lord, 1977). The main advantage of microwave systems include energy efficiency, increased rates of production, improved product characteristics and uniform heat (for more details see pp 66-68 and pp 114-146, Lord, 1977).

This case study compares a conventional petroleum food oven system against an equivalent microwave system. The cost and operating data obtained for both the petroleum and microwave systems is preliminary. Actual costs are closely associated with specific operating conditions and are difficult to define under generic conditions. The data provided by vendors is, therefore, general and the estimated cost derived from this data is subject to a wide variation.

Cash flow data for kerosene, diesel and electric microwave food oven systems are presented in Table 5-X. The capital investment estimated for the petroleum and microwave systems are equivalent though quite large. The equipment estimates for these systems are based on U.S. industrial requirements which require a greater degree of sophistication in controls and automation than is generally required in Costa Rica. Base year annual fuel costs for the electric microwave system are from one-third to one-sixth the annual fuel costs for the diesel or kerosene systems.

The LCC analysis for the petroleum and microwave food oven system is presented in Figure 5-8. The microwave system under both T-4

TABLE 5-X

CASE E: BASE YEAR CASH FLOW FOR 2.11GJ (2.0 MMBTU/hr) FOOD OVEN SYSTEMS

Cost Components ($\$x10^3$)	Fuel System Alternatives			
	Oil-Fired Drier System		Microwave Drier System	
	Kerosene	Diesel	T-4 Electricity	T-10 Electricity
• Total Capital Investment	1,401.4	1,399.0	1,285.3	1,282.7
Fixed Capital Investment	1,373.6	1,373.6	1,267.5	1,267.5
Working Capital	27.8	25.4	17.5	15.2
• Total Annual Non-Fuel O&M Costs	144.6	144.6	129.4	129.4
Maintenance	137.4	137.4	126.8	126.8
Manpower	2.6	2.6	2.6	2.6
Auxiliary Power	4.6	4.6	0.0	0.0
• Total Annual Fuel Costs	133.5	109.2	45.6	22.8

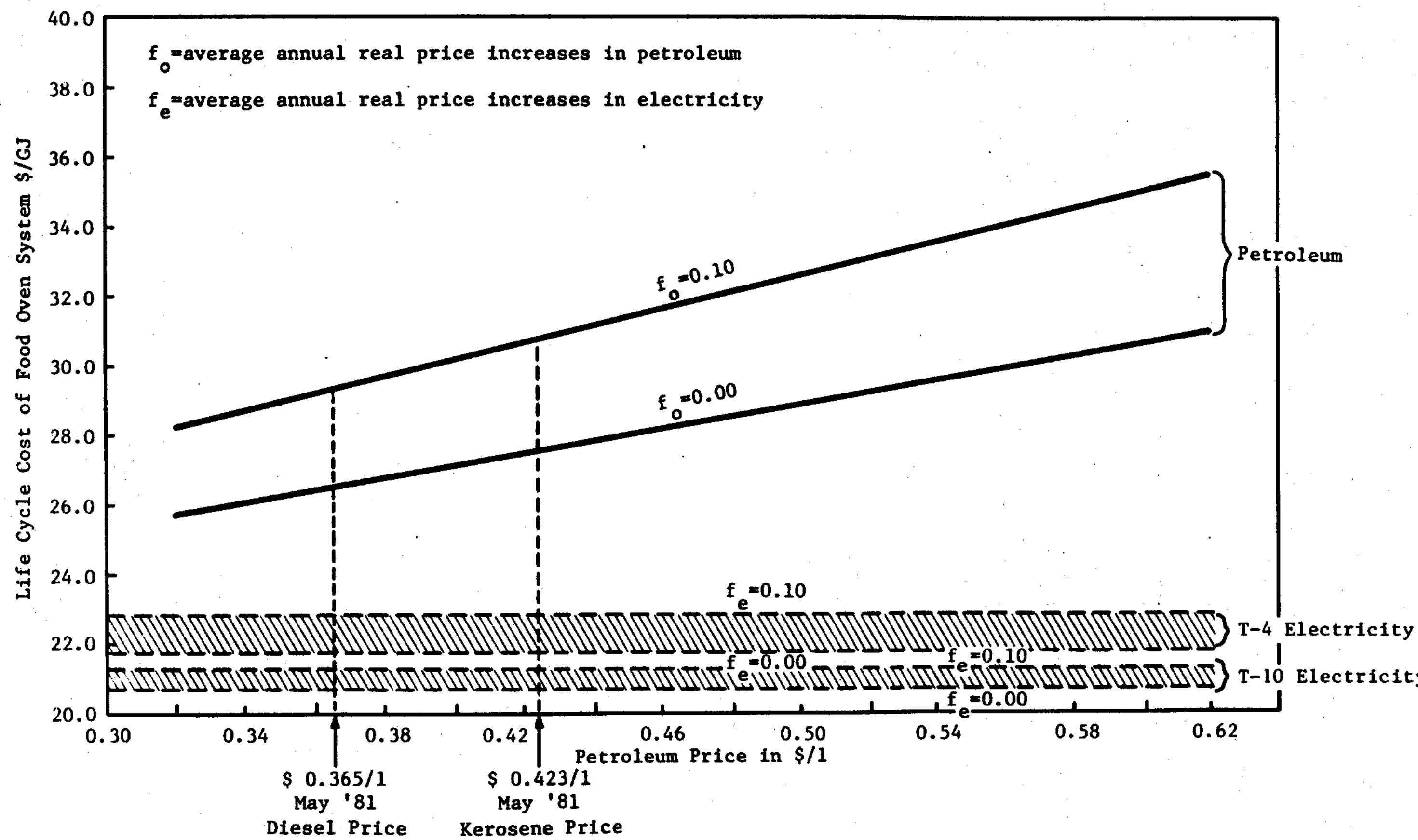

FIGURE 5-8
CASE E: LIFE CYCLE COST OF FOOD OVEN SYSTEM VERSUS FUEL COSTS—2.11 GJ (2.0 MMBTU)/HR OVEN

and T-10 electricity tariffs has a 25 to 30 percent lower LCC per GJ of heat output than does the diesel or kerosene system. Thus, the microwave system will remain competitive even if the relative difference between the estimated capital costs of the microwave and petroleum systems is increased by approximately $600,000 to $800,000.

Existing petroleum systems cannot be retrofited with microwave systems but would need to be completely replaced. The replacement analysis presented in Table 5-XI indicates that it is uneconomic to replace any existing food oven system with an electric system over the next 10 years.

<u>Case F</u>: 1MW diesel electric generator versus purchased grid electricity.

Diesel electric generators are used extensively by remotely located industries in Costa Rica. In 1979, industrial diesel generated electricity accounted for approximately 39 GWh (SNE, 1979). Many of these industries do not presently have access to the national grid. However, some industries in Costa Rica have recently indicated a willingness to share in the cost and financing of transmission lines to bring the electricity grid to their facilities. This case study evaluates the life cycle costs of diesel generated electricity and compares it to the cost of purchased grid electricity. The differential costs between the two options provides a measure of the economic benefits for industry to participate in extending the grid system to their facilities. With the present policy of uniform pump prices for diesel throughout the country, transportation costs for

TABLE 5-XI

REPLACEMENT ANALYSIS FOR 2.0 MMBTU/hr
FOOD OVEN SYSTEMS

REPLACEMENT OPTION	PAYBACK PERIOD (IN YEARS)	REPLACEMENT TIME (IN YEARS) r=0.20 p=0.03
Diesel System		
Replaced By:		
T-4 Electricity	12.2	14.0
T-10 Electricity	10.0	12.0
Kerosene System		
Replaced By:		
T-4 Electricity	16.0	17.0
T-10 Electricity	12.4	15.0

r = discount rate
p = petroleum price escalation rate
BC = May 1981 Bunker C Gulf Spot price
* = the savings from the replacement option are negative

diesel to remote areas is essentially subsidized. Similarly, uniform electricity prices to remote areas also constitutes a subsidy.

Cash flow estimates for a 1MW diesel electric generator operating at a 0.5 load factor and for an equivalent quantity of purchased grid electrcity are shown in Table 5-XII. An estimated $25,000 hook-up charge and 10 percent of the annual fuel cost is assessed as the total capital investment in the case of the purchasing of grid electricity. Base year annual costs for purchased electricity is about one-third the annual cost of fuel for the diesel generator. This alone provides an indication of large cost differential between the two options.

The LCC analysis for the diesel and grid electricity options is presented in Figure 5-9. At current diesel prices, the LCC of diesel generated electricity ranges between 5.3 ¢/kWh with no expected real price inflation over the next decade and 7.7 ¢/kWh with 10 percent average annual real price increases. The LCC of purchased grid electricity at the T-4 industrial tariff ranges between 1.6 ¢ to 2.3 ¢/kWh depending on the assumed average annual real price increase of electricity.*

The difference between the discounted present worth of expenditures (PW) for each alternative yields a rough measure of the economic benefit to industry of purchasing grid electricity. A plot

*The LCC of a unit of grid electricity is lower than the present average unit price of T-4 electricity (3.5 ¢ /kWh) because the LCC discounts future costs at the rate of 20 percent per year.

TABLE 5-XII

CASE F: BASE YEAR CASH FLOW FOR 1MW
DIESEL ELECTRIC GENERATION AND PURCHASED GRID ELECTRICITY

Cost Components ($x10^3)	Fuel System Alternatives	
	Electric Generator Diesel	Electricity Grid T-4 Electricity
• Total Capital Investment	247.7	40.6
Fixed Capital Investment	197.7	25.0
Working Capital Investment	50.4	15.6
• Total Annual Non-Fuel O&M Costs	21.0	0.0
Maintenance	19.7	0.0
Manpower	1.3	0.0
Auxiliary Power	0.0	0.0
• Total Annual Fuel Costs	479.4	155.57

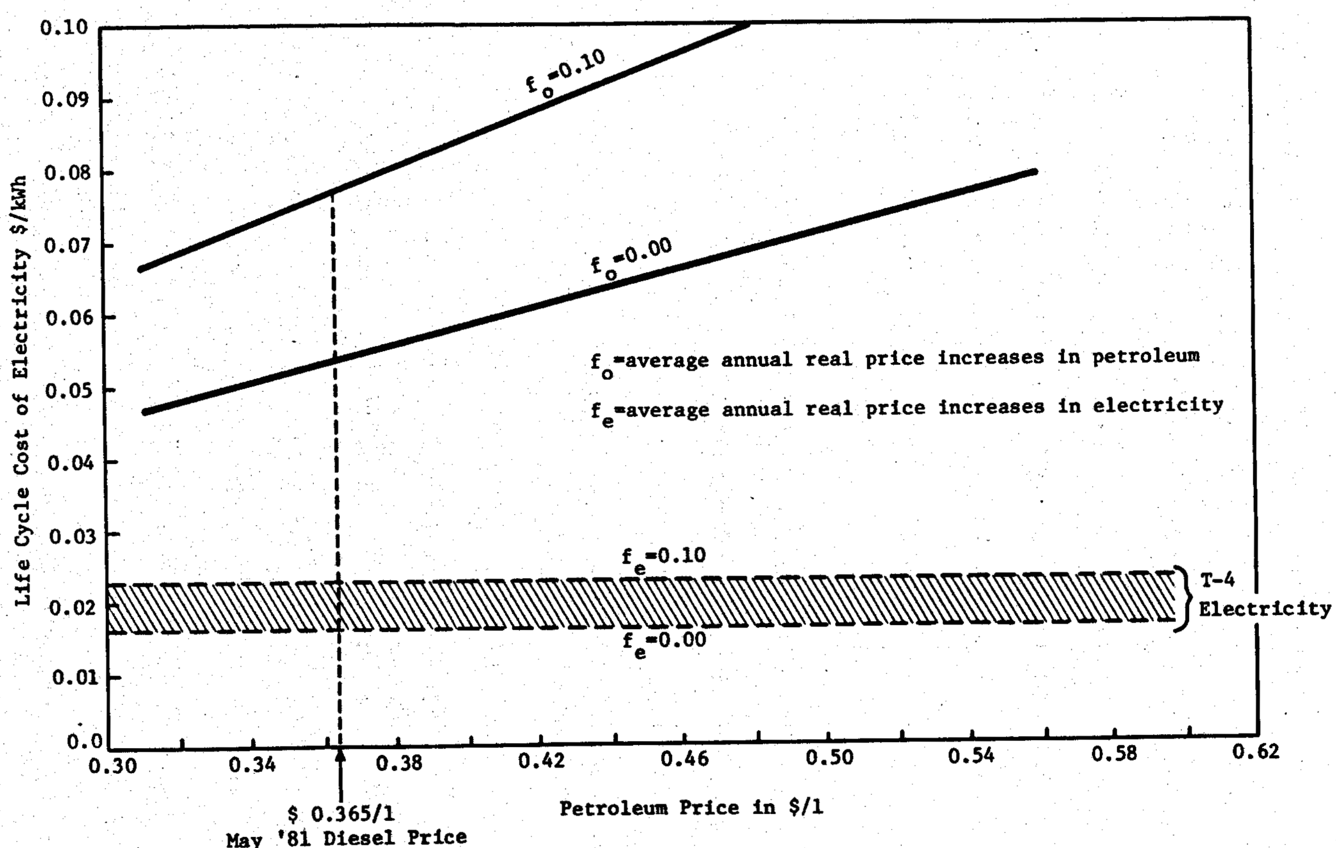

FIGURE 5-9
CASE F: LIFE CYCLE COSTS OF DIESEL GENERATED ELECTRICITY VERSUS FUEL COSTS—1 MW GENERATOR

of the present worth of all expenditures over a 10 year period discounted at an annual rate of 20 percent is presented in Figure 5-10. At current diesel prices, the differences between the PW of the diesel and grid options, or the net present worth of expenditures (NPW) is $\$1.7 \times 10^6$ to $\$2.4 \times 10^6$ for a 1MW industrial consumer. In theory, a 1MW industrial consumer presently using a diesel generator should be willing to spend up to the NPW in order to purchase the lower priced grid electricity. This analysis does not account for reliability, safety and environmental externalities associated with each system.

The replacement analysis conducted in this case indicates that immediate replacement of diesel generators is economic if grid electricity is available to the user.

Case G: 250 HP oil-fired boilers versus retrofit biomass gasification systems.

Costa Rica has a considerable biomass resource base. An active lumber industry generates a significant quantity of wood waste products such as sawdust, shavings, off-cuts, bark, veneer cores, pulpwood fines and condemned timber. As such, wood as a potential fuel for industry is available in most regions of the country.

Industrial use of wood in the past has been primarily by direct combustion. Wood handling and low conversion efficiencies (below 60 percent) were the major drawback which led industry to a shift away from wood and toward petroleum. However, as petroleum prices

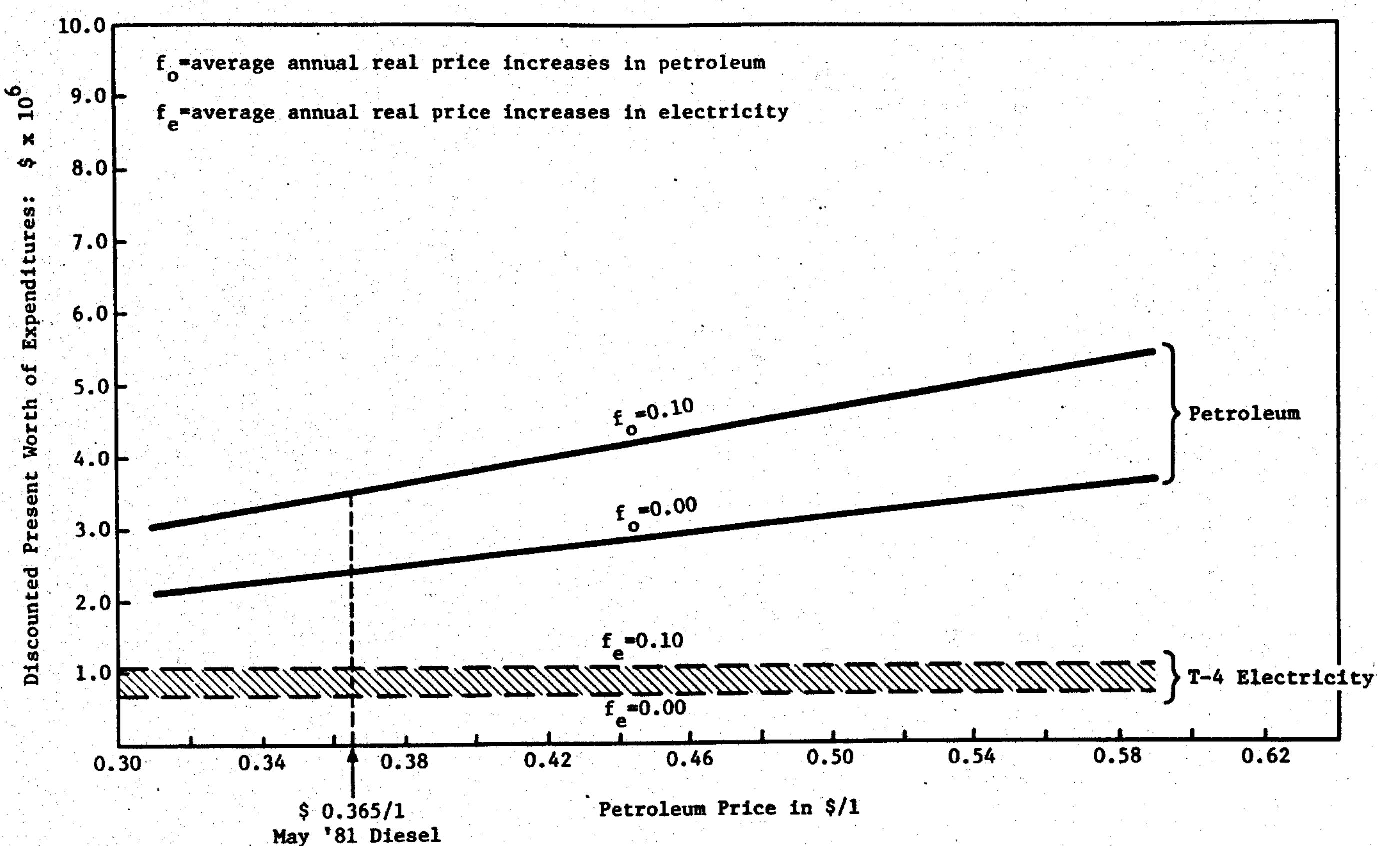

FIGURE 5-10
CASE F: DISCOUNTED PRESENT WORTH OF EXPENDITURES FOR DIESEL GENERATOR SYSTEM VERSUS FUEL COSTS— 1 MW GENERATOR

continue to rise rapidly, the economics of wood use is becoming increasingly attractive.

In the past two years, small retrofit wood gasification systems in the 60 HP to 400 HP boiler size range, have become commercially available from vendors in the United States. The potential application of these wood gasification technologies to easily replace existing petroleum combustion systems has been recently recognized. This last case study evaluates the economics of refurbishing an existing oil-fired combustion system on a 250 HP boiler against replacing the oil combustion system with a retrofit wood gasification system. Technical details on potential wood gasification systems and supporting wood handling systems were compiled on a more detailed case study performed by MITRE for the government of Papua New Guinea (Mendis, 1981).

The BIOTHERM gasification system was shown to have the greatest technical and economic potential as a result of that study. The BIOTHERM is capable of gasifing wood chips, hogged wood, sawdust, shavings and densified wood pellets. Other biomass feedstocks are are currently being tested.

Cash flow estimates for refurbishing an existing diesel or Bunker C boiler versus retrofitting a wood gasification system are shown in Table 5-XIII. The FCI of the wood gasification is approximately $235,000 or over 15 times greater than refurbishing the existing system. However, $125,000 of the total FCI is required for the

TABLE 5-XIII

CASE G: BASE YEAR CASH FLOW 250HP REFURBISHED OIL-FIRED BOILERS VERSUS RETROFIT BIOMASS GASIFICATION SYSTEM

Cost Components ($\$x10^3$)	Fuel System Alternative		
	Existing Oil-Fired Boiler		Retrofit Wood Gasifier
	Diesel	Bunker C	
• Total Capital Investment	42.0	25.9	242.9
Fixed Capital Investment	13.5	15.0	235.0
Working Capital Investment	28.5	10.9	7.9
• Total Annual Non-Fuel O&M Costs	10.7	11.1	32.5
Maintenance	6.8	7.5	23.5
Manpower	3.0	3.0	6.0
Auxiliary Power	0.9	0.6	3.0
• Total Annual Fuel Costs	274.1	98.2	46.1

wood fuel handling and storage system. Base year annual fuel costs for the wood system is half that of the Bunker C system and about one-sixth that of the diesel system. The annual fuel costs are very sensitive to fuel prices and boiler utilization. The wood fuel costs are based on an price of $20 per tonne. In addition, the utilization of the boiler systems is assumed at only 30 percent of total annual capacity. If wood waste such as sawdust is available at $10 per tonne and the boiler utilization is 0.6, then fuel cost for the wood gasification system would be only one-fourth that the Bunker C system and one-twelfth that of the diesel system.

The LCC analysis of steam generated by a refurbished oil-fired combustion system versus a retrofit wood gasification system is presented in Figure 5-11. LCC of 10^3 kgS for wood of $10, $20 and $40 per tonne increasing at between zero and ten percent per annum is shown. Wood gasification systems are very competitive with diesel systems even at $40/tonne. Wood gasification with $10 to $20/tonne wood is competitive with Bunker C. With any base year increase in Bunker C prices or a greater than zero average annual real price increase, the economic attractiveness of the wood gasification system will rapidly increase.

The replacement analysis for the 250 HP retrofit biomass gasification system is presented in Table 5-XIV. The analysis assumes wood fuel priced at $20/tonne. The results indicate that existing diesel systems can be replaced immediately while existing Bunker C systems can be replaced in four years.

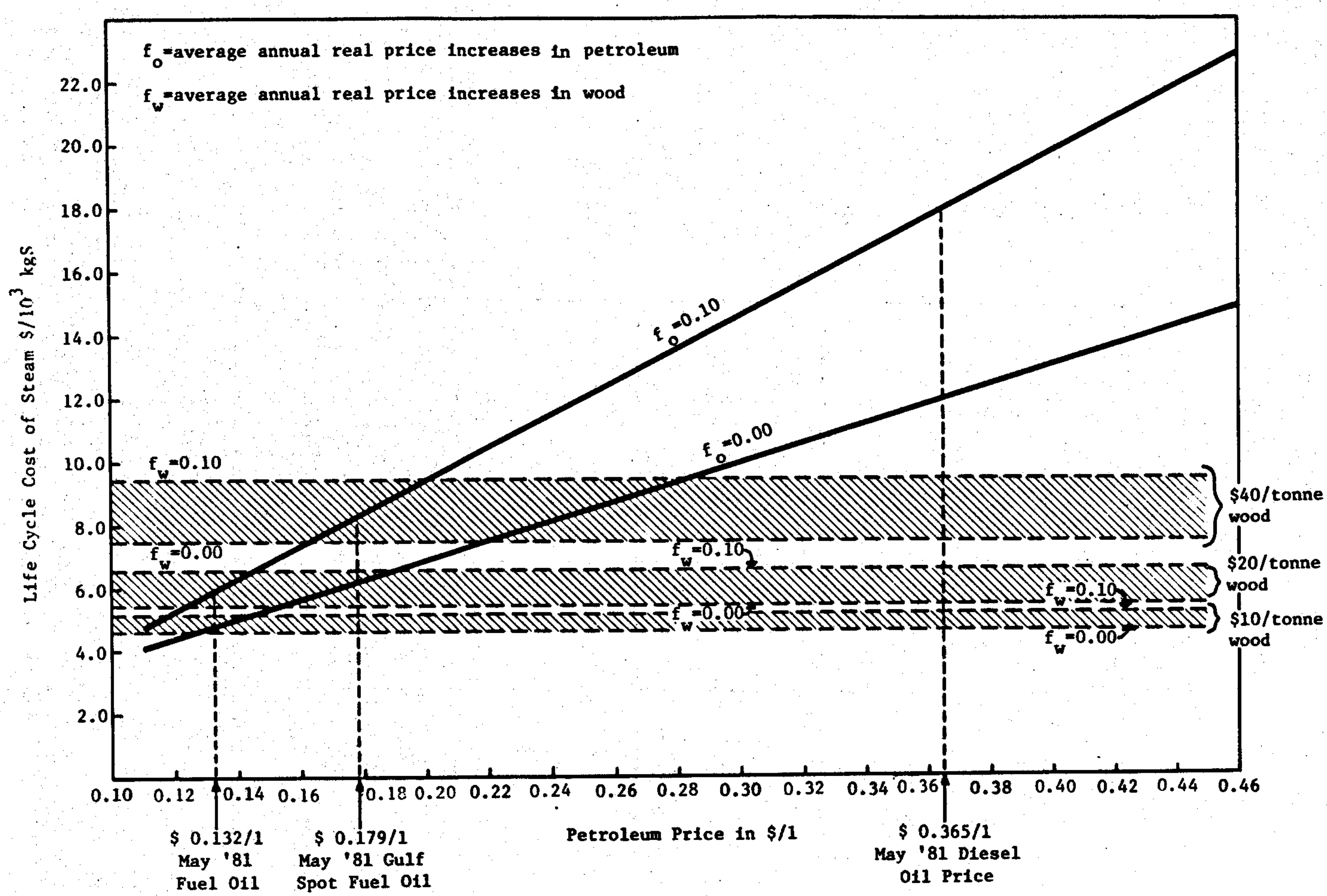

FIGURE 5-11
CASE G: LIFE CYCLE COST OF STEAM VERSUS FUEL COSTS— 250 HP OIL-FIRED BOILERS VERSUS RETROFIT BIOMASS GASIFICATION SYSTEMS

TABLE 5-XIV

REPLACEMENT ANALYSIS FOR 250 HP RETROFIT

BIOMASS GASIFICATION SYSTEM

REPLACEMENT OPTION	PAYBACK PERIOD (IN YEARS)	REPLACEMENT TIME (IN YEARS)
		r=0.20 p=0.03
Diesel System Replaced By: $20/tonne wood	1.0	0.0
Bunker C System Replaced By: $20/tonne wood	7.6	4.0

r = discount rate
p = petroleum price escalation rate
* = the savings from the replacement option are negative

6.0 POTENTIAL FOR ELECTRIC SUBSTITUTION

The potential for electric substitution of industrial and agro-industrial petroleum consumption is estimated based on the technical analysis in Section 3 and the economic analysis presented in Section 5. Comparisons are made for the two electricity tariffs, T-4 and T-10, domestic and Caribbean spot market petroleum prices and for relative petroleum price escalation rates of from zero to ten percent per year. A range of five cases was defined for the analysis. These are summarized in Table 6-I. The substitution potential in each case is determined for two possible options. In the first option, only conversions of petroleum to electricity are permitted (i.e., conversions to other petroleum fuels are not permitted). The second option considers the possibility of conversions from the more expensive diesel and kerosene fuels to the less expensive Bunker C fuel. The results of this analysis are presented in Table S-IV of the Summary.

The methodology for arriving at the substitution potential estimates presented in Table S-IV is summarized below.

- Determine from the technical analysis those petroleum technologies that can be substituted for by electric technologies. (Tables 3-IV and 3-V).
- Determine from the economic analysis the minimum criteria to:
  - substitute electric technologies in energy capacity expansions historically fueled by petroleum (Figures 5-4 through 5-10); and

TABLE 6-I

DEFINITION OF SUBSTITUTION POTENTIAL CASE STUDIES

Cases	VARIABLES			
	Electric Tariff	Annual Electricity Real Price Escalation Rate	Petroleum Price Base	Annual Petroleum Real Price Escalation Rate
1	T-4	0	Domestic	0
2	T-10	0	Domestic	0
3	T-10	0	Domestic	3%
4	T-10	0	Domestic	10%
5	T-10	0	Caribbean Spot	3%

- replace existing petroleum capacity with electric technologies. (Tables 5-III, V, VII, IX, and XI).

- Determine for each of the range of five cases the maximum substitution potential that can be achieved over a planning horizon of 10 years.*

The analysis in section 3 indicated that substitution of electric for petroleum technologies was feasible for:

- Steam boilers
- Hot water boilers
- Low temperature process heaters
- High temperature process heaters**
- Diesel electric generators.

The maximum technically substitutable potential was estimated at 52 percent of the total 1980 industrial and agro-industrial petroleum consumption.

A summary of the estimated minimum criteria to substitute technically feasible electric technologies for existing petroleum energy systems is presented in Table 6-II. Data are presented for both capacity expansion and capacity replacements. The minimum criteria presented in Table 6-II also may be used to determine the

*A planning horizon of 10 years was selected to provide sufficient time to account for the full economic substitution potential that may result from replacement of existing petroleum systems with a remaining useful life (see Section 5.0 for details on the replacement analysis).

**High temperature process heaters for the cement and glass industries are excluded from this category.

TABLE 6-II

MINIMUM CRITERIA TO INSTITUTE ELECTRIC TECHNOLOGY SUBSTITUTIONS*

Energy Product	FUEL					
	Bunker C		Diesel		Kerosene	
	Exp.(1)	Rep.(2)	Exp.	Rep.	Exp.	Rep.
Steam	T-10 fo = 8%	T-10/C.S. 5 yr	T-4 fo = 0%	T-4 0 yr	T-4 fo = 0%	T-4 0 yr
Hot Water	T-10 fo = 6%	T-10/C.S. 5 yr	T-4 fo = 0%	T-4 0 yr	T-4 fo = 0%	T-4 0 yr
Low Temperature	T-10 fo = 8%	T-10/C.S. 5 yr	T-4 fo = 0%	T-4 1 yr	T-4 fo = 0%	T-4 1 yr
High Temperature	T-10 fo = 8%	N/A	T-4 fo = 0%	T-4 1 yr	T-4 fo = 0%	T-4 1 yr
Electricity Generation	N/A	N/A	T-4 fo = 0%	T-4 0 yr	T-4 fo = 0%	T-4 0 yr

1) Exp. = expansions

2) Rep. = replacements

T-10/T-4 = electricity tariffs
C.S. = Caribbean spot price
fo = annual escalation rate of petroleum products
yr = optimum replacement year for existing petroleum systems

*Estimates are based on domestic petroleum prices, discount rate of 20% and fo = 3% unless otherwise indicated.

substitution potential that is economically achievable.* The substitution potentials for the range of the five fuel price cases defined in Table 6-I are presented in Table S-IV.

As can be seen in Table 6-II, a T-10 tariff and an annual petroleum price escalation of from 6 to 8 percent are the minimum criteria required to justify displacing Bunker C systems with equivalent electricity systems in the future capacity expansions. Alternately, if the current price for Bunker C were to rise to the Caribbean spot market price, then an annual price escalation rate of only 3 percent is necessary to justify the displacement of Bunker C systems. Replacement of existing Bunker C systems becomes economic in about 5 years if T-10 electricity tariffs and Caribbean spot market prices are assumed to rise at 3 percent per year. In the case of diesel and kerosene systems, capacity expansions are economic with T-4 tariffs and petroleum price escalation rates of 3 percent. Replacements are economic within one year.

*For example, under the tariff and price conditions outlined in Case 1, all capacity expansions of diesel and kerosene systems meet the minimum economic criteria for conversion while existing systems can be economically replaced in one year or less. Therefore, all technically feasible diesel and kerosene systems are assumed to convert to electricity under Case 1 conditions. The minimum economic criteria required for conversion of Bunker C systems to electricity is not met by Case 1 tariff and price conditions and therefore no Bunker C conversions are assumed for this case. A similar analysis was conducted for the remaining four cases and results presented in Table S-IV.

7.0 COST/BENEFIT ANALYSIS AT THE NATIONAL LEVEL

The national costs and benefits of an industrial electricity conversion program are estimated in this section. The national costs of the program can be subdivided into:

- the costs of providing the additional electricity demanded; and
- the cost of converting the potential industrial energy systems to electricity.

The benefits of the program are essentially the reduction in petroleum demand and therefore petroleum imports. Secondary benefits may result in part due to improvements in the balance of trade and higher gross national products.* Additionally, environmental improvement and increased security of energy supply are indirect benefits of an electricity conversion program. However, this analysis does not quantitatively address the secondary impacts of an industrial electricity conversion program.

The cost/benefit analysis is based on the electricity conversion potential defined in Case 5 of the conversion scenarios (outlined in Section 6.0). This implies a T-10 industrial electricity pricing structure, a 1981 Bunker C price of $0.179 per liter and a relative increase in petroleum prices of 3 percent per year. The industrial petroleum conversion potential in this case is estimated at 52 percent of projected industrial petroleum consumption.

*Balance of trade and GNP gains must be evaluated against external capital requirements of the electrification program.

The 52 percent petroleum to electricity conversion potential represented in Case 5 is the result of the relative pricing structure represented by the T-10 electricity tariff and the Gulf equilibrium Bunker C price. The important point of this case is that a 52 percent conversion potential can be achieved under similar electric and petroleum pricing structures. Thus, while the cost/benefit analysis is based on a T-10 tariff and Gulf spot price, it is not an endorsement of these price structures but rather an indication of the potential results achieved under a pricing scheme with similar relative relationships.

The internal rate of return (IRR) for the industrial electricity conversion program is approximately 13 percent. Figure 7-1 presents a graph of the net present value (in 1981) of the annual stream of costs and benefits over a range of discount rates. The net present value of the cost/benefits is zero at approximately 13 percent.

Details of the electricity and petroleum demand projections are presented in Section 7.1. Projected costs of the additional hydro and geothermal electricity generating capacity and conversions to electricity of industrial energy systems are presented in Section 7.2. The projected benefits of reduction in industrial petroleum consumption are outlined in Section 7.3. Finally a comparison of the stream of benefits and costs and an estimate of the IRR of the electricity conversion project are detailed in Section 7.4.

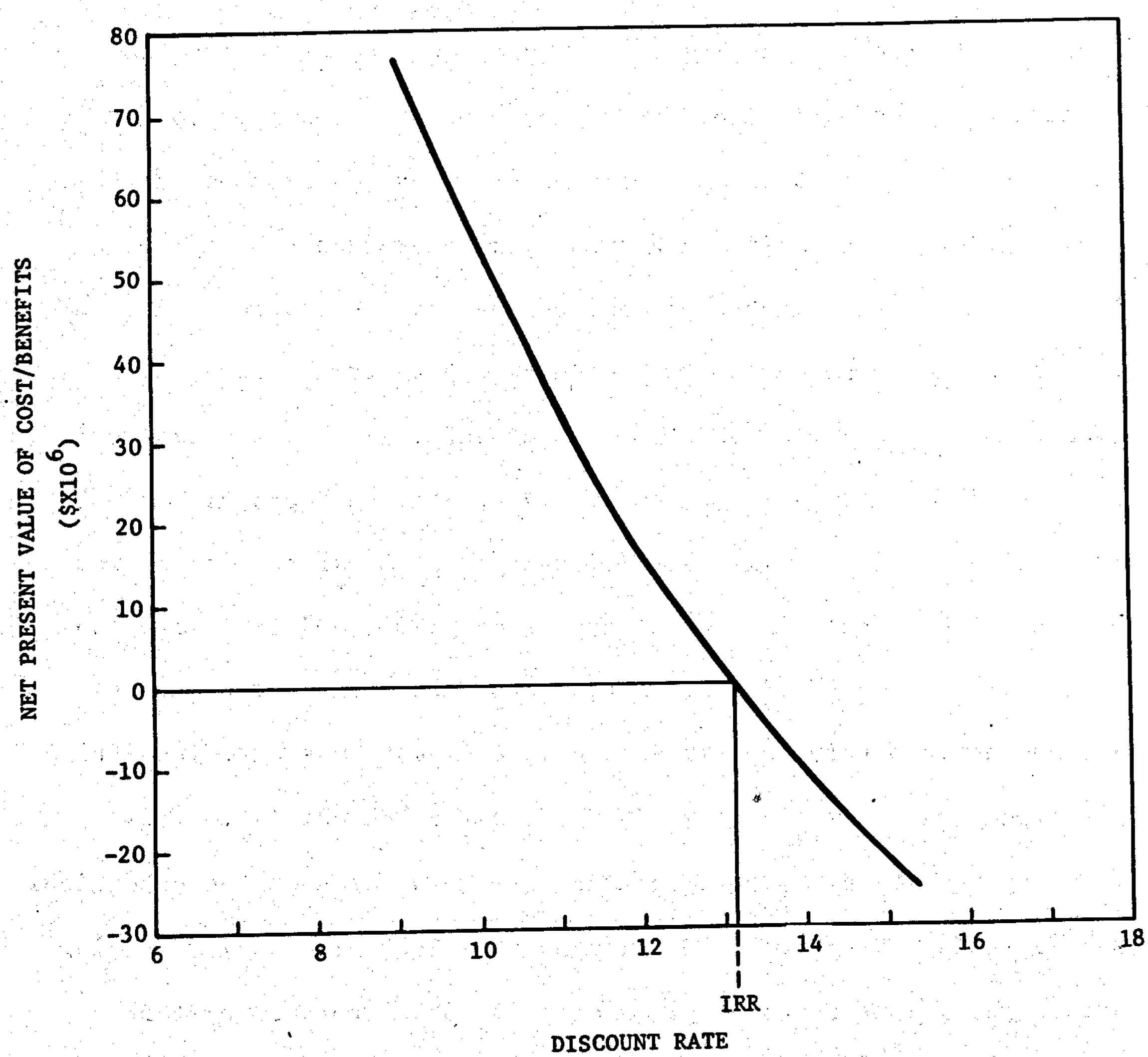

FIGURE 7-1
NET PRESENT VALUE OF COST/BENEFITS

7.1 Petroleum and Electricity Demand Projections

Two data sources (BID, 1980 and Republica de Costa Rica, 1981) were used to provide the baseline projections against which the impacts of an industrial electrification program could be compared. Both documents provide similar economic and energy projections where they overlap. Both assume a gross domestic product (GDP) growth in the range of 6.1 to 6.6 percent per year and electricity demand growth in the range of 8.6 to 8.8 percent per year. Projections of industrial petroleum consumption of kerosene, diesel, and fuel oil provided in the Costa Rica document (Republica de Costa Rica, 1981), are estimated at approximately 9.1 percent per year for the period 1985 to 2000. These projections for 1985, 1990, and 1995 were combined with the MITRE 1980 tabulation for industrial petroleum use and geometrically interpolated to give the base case agro-industrial petroleum use estimates given in the first column of Table 7-I.

The industrial electrification option is based on the conditions stated in Case 5 of the Summary, namely, a T-10 electricity pricing structure, a 1981 Bunker C price of $.179 per liter, a constant dollar escalation of petroleum prices at 3 percent per year while electricity prices remain fixed.*

The option is applied in two forms: the replacement of existing petroleum systems with electricity systems and the addition of new electric systems to meet the growing industrial demand. As discussed

*Electricity prices vary directly with the U.S. dollar inflation rate.

TABLE 7-I

COMPARISON OF PETROLEUM AND ELECTRICITY CONSUMPTION FOR BASE CASE AND INDUSTRIAL ELECTRIFICATION OPTION

Year	1 Base Case[1] Agro-Ind. Petroleum Use (TJ)	2 Petroleum Saved-Conversions (TJ)	3 Petroleum Saved-New Equipment (TJ)	4 Petroleum Savings (TJ)	5 Electricity[2] Equivalent (GWH)	6 Base-Case[3] Electricity Consumption (GWH)	7 Industrial Electrification Electricity Consumption (GWH)
1981	8185	- -	-	-	-	2148	2148
1982	8783	- -	-	-	-	2339	2339
1983	9425	175 (2%)	334	510	116	2546	2662
1984	10114	527 (6%)	692	1219	276	2770	3046
1985	10853	1230 (14%)	1076	2306	523	3008	3531
1986	11850	2635 (30%)	1595	4230	959	3269	4228
1987	12939	4567 (52%)	2161	6728	1526	3552	5078
1988	14128	4567 (52%)	2779	7347	1666	3849	5515
1989	15426	4567 (52%)	3455	8022	1819	4169	5988
1990	16844	4567 (52%)	4192	8759	1986	4517	6503
1991	18372	4567 (52%)	4986	9553	2166	4881	7047
1992	20038	4567 (52%)	5853	10420	2363	5275	7638
1993	21855	4567 (52%)	6798	11365	2577	5701	8278
1994	23837	4567 (52%)	7828	12395	2811	6161	8972
1995	25998	4567 (52%)	8952	13519	3066	6658	9724

(1) Republica de Costa Rica - 1981 and Table 2-X.

(2) (Petroleum Savings/3.6 TJ/GWH) x (.8/.98).

(3) BID-1980, p 27 and 28.

Note: 1 TJ = 173 BBL (crude oil).

in Section 6.0, the retirement analysis shows that based on Case 5 assumptions, replacement of any petroleum system by electrical equipment is cost effective within five years. For the purposes of this example and to match electrical supply capacity limitations, conversions are assumed to follow an exponential doubling pattern starting in 1983 at 2 percent of the total agro-industrial petroleum use in 1982 and ending at the maximum conversion potential of 52 percent in 1987. The petroleum savings provided by this conversion are given in the second column of Table 7-I.

In addition, for the industrial electrification option, 52 percent of the base case new petroleum demand is met by electricity. The petroleum savings for this new equipment demand is given in the third column.

Annual totals for petroleum savings are given in the fourth column. By year 1987, with all replacements completed, the annual total petroleum savings is henceforth exactly 52 percent of the base case agro-industrial petroleum use.

The electricity required to replace the saved petroleum is given in the fifth column. These calculations assume an average end-use efficiency of 80 percent for petroleum and 98 percent for electricity.

The last two columns show the national electricity demands for the base case and industrial electrification option. The base case demand is extrapolated from information taken from (BID, 1980).

It is interesting to note, that by 1992 the additional industrial electricity demand will exceed the current 1982 total estimated electricity demand for the country.

Table 7-II provides two hydro and geothermal electric capacity expansion plans to meet the electricity demands for the base case and the industrial electrification option.

The first column is the estimated maximum load to match the base case electricity requirements. This information was taken directly from (BID, 1980) and extrapolated to 1995 as shown in the footnotes. The maximum load applies only to the Costa Rican national interconnected system (SNI) and includes transmission, distribution, and other losses downstream of the generation facilities.

The second column provides the similar information for the industrial electrification option and duplicates the logic used to arrive at the base case maximum load estimates. Although reserve margins are based on more detailed requirements, for this effort, MITRE assumes a 10 percent reserve margin requirement which is added to the totals in the third column.

The next block of data provides the 1980 electric capacity expansion plans for Costa Rica as taken from (BID, 1980). To meet the increased electricity requirements for the industrial electrification option, MITRE simply accelerated the existing expansion plan to match closely the new demand requirement. In both cases the names of the facilities are given along with their design MW capacities. The last

TABLE 7-II

COMPARISON OF ELECTRIC CAPACITY NEEDS
FOR BASE CASE AND INDUSTRIAL ELECTRIFICATION OPTION

	1	2	3	4	5	6	7	8
Year	Base Case(1) SNI-Max. Load (MW)	Industrial Electrification SNI-Max. Load (MW)	Industrial Electrification SNI-Max. Load Plus 10 Percent Reserve Margin (MW)	Base Case(2) Capacity Additions	Base Case(2) Hydro/ Geothermal Capacity (MW)	Industrial(3) Electrification Capacity Additions	Industrial Electrificacion Hydro/Geothermal Capacity (MW)	Excess(+) or(4) Shortfall(-) in Capacity (MW)
1981	454	454	499	- - -	445	- - -	445	- 54
1982	490	490	539	Corobici(174)	619	Corobici(174)	619	+ 80
1983	530	555	611	- - -	619	- - -	619	+ 8
1984	573	630	693	Ventanas-Garita(80)	699	Ventanas-Garita(80)	699	- 3
1985	619	728	801	Miravalles-I(40)	739	Miravalles-I(40)	779	- 22
1986	669	867	954	Palomo(40) Miravalles-II(40)	819	Palomo(40) Miravalles-II(40) Angostura(180)	999	+ 45
1987	723	1037	1141	Angostura(180)	999	Guayabo(213)	1212	+ 71
1988	780	1121	1233	- - -	999	- - -	1212	- 21
1989	841	1212	1333	Guayabo(213)	1212	Siquirres(300)	1512	+179
1990	908	1312	1443	- - -	1512	- - -	1512	+ 69
1991	982	1423	1565	Siquirres(300)	1512	Boruca(760)	2272	+707
1992	1062	1543	1697	- - -	2272	- - -	2272	+575
1993	1149	1673	1840	- - -	2272	- - -	2272	+432
1994	1242	1814	1995	Boruca(760)	2272	- - -	2272	+277
1995	1343	1967	2164	- - -	2272	- - -	2272	+108

(1)(BID-1980, p 28); assumes 10 MW constant isolated generation capacity, system loss of .128, and system load factor of .644 for 1991-1995. SNI - national interconnected system.

(2)(BID-1980, p 38, p 75).

(3)Acceleration plan based on MITRE judgment.

(4)Compares third column and seventh column.

column of Table 7-II shows the excess or shortfall in capacity in meeting the demand of the industrial electification program.

It should be noted that the 117 MW of petroleum fired thermal electric generation capacity in existence in the SNI system in 1981 is retired according to plans and is accounted for accordingly in the generation expansion plans shown in Table 7-II.

7.2 Projected Costs

7.2.1 Electricity Supply Costs

The costs to provide the additional electric energy to meet the increased demands in the industrial sector are the costs of accelerating the hydroelectric expansion program. Table 7-III compares the schedules of the hydroelectric projects that are accelerated for the industrial electrification option. The left side of the table shows the base case schedule; the right side, the accelerated schedule. The projected capital and O&M costs as extracted and escalated from (BID, 1980) are shown adjacent to each hydroelectric project name.

The estimated total costs to accelerate the hydroelectric development program is the diffence of the discounted costs of these two programs. Annual operating costs of a hydro facility are included in the costs of the accelerated program for each year of operation before the plant would normally have been on-line in the base case.

TABLE 7-III

COMPARISON OF ELECTRIC CAPITAL AND O&M COSTS
FOR BASE CASE AND INDUSTRIAL ELECTRIFICATION OPTION

Year	Base Case Capacity Additions Changed in Electrification Case	Capital Cost[1] ($x10^6)	Annual O/M Cost[1] ($x10^6)	Industrial Electrification Changed Capacity Additions	Capital Cost[1] ($x10^6)	Annual O/M Cost[1] ($x10^6)
1981	- -	- -	- -	- -	- -	- -
1982	- -	- -	- -	- -	- -	- -
1983	- -	- -	- -	- -	- -	- -
1984	- -	- -	- -	- -	- -	- -
1985	- -	- -	- -	Palomo	35.9	.66
1986	Palomo	35.9	.66	Angostura	242.3	3.37
1987	Angostura	242.3	3.37	Guayabo	334.5	4.31
1988	- -	- -	- -	- -	- -	- -
1989	Guayabo	334.5	4.31	Siquirres	366.4	4.23
1990	- -	- -	- -	- -	- -	- -
1991	Siquirres	366.4	4.23	Boruca	1127.5	12.18
1992	- -	- -	- -	- -	- -	- -
1993	- -	- -	- -	- -	- -	- -
1994	Boruca	1127.5	12.18	- -	- -	- -

[1] BID-1980, p75 x (1.14 = $\frac{191.06}{167.47}$) to adjust to May 1981 dollars.

7.2.2 Industrial Energy System Conversion Costs

The net costs of industrial energy system conversions from petroleum to electricity were estimated to determine the national net benefits or costs of an industrial electrification program. Conversions of industrial energy systems to electricity were separated into existing petroleum systems (i.e., replacements) and new installations (i.e., expansions). The estimated petroleum saved from replacements and expansions is shown in the second and fourth column of Table 7-IV.

Estimates of the annual net capital and O&M costs* of industrial energy system replacements and expansions as a result of the electrification program are presented in the third, fifth, seventh and eight columns. The capital costs of replacements, in the third column, represent the estimated costs of converting existing petroleum based energy systems to electric systems. The level of conversions each year were based on the replacement analysis in Section 5.0 and is discussed in Section 7.1. The net capital costs of electricity replacements are set equal to the capital costs of the electricity system.** The net capital costs of electricity expansions shown in the fifth column, are set equal to the difference between the capital costs of electricity systems and that for equivalent petroleum

*Net costs are defined to be the cost of the electricity system less the cost of the equivalent petroleum system.

**This implies that the capital costs of an existing petroleum system is zero. This assumption will generally overestimate the net capiital costs of the electricity systems because it does not account for the possible salvage value of the existing petroleum systems.

TABLE 7-IV

INDUSTRIAL ENERGY SYSTEM CAPITAL AND O&M CONVERSION COSTS

Year	1 Base Case Petroleum Consumption (TJ)	2 Petroleum Saved From Replacements (TJ)	3 Net Capital Costs of Replacements ($x10^3)	4 Petroleum Saved From Expansions (TJ)	5 Net Capital Costs of Expansions ($x10^3)	6 Total Petroleum Saved (TJ)	7 Net O&M Costs of Conversions ($x10^3)	8 Total Costs of Conversions ($x10^3)
1981	8185	—	—	—	—	—	—	—
1982	8783	—	—	—	—	—	—	—
1983	9425	176	929	334	585	510	- 15	1499
1984	10114	527	1864	692	627	1219	- 37	2454
1985	10853	1230	3733	1076	672	2306	- 69	4336
1986	11850	2635	7460	1595	908	4230	- 127	8241
1987	12939	4567	10259	2161	991	6728	- 202	11048
1988	14128	—	—	2779	1082	7347	- 220	862
1989	15426	—	—	3455	1183	8022	- 241	942
1990	16844	—	—	4192	1290	8759	- 263	1027
1991	18372	—	—	4986	1390	9553	- 287	1103
1992	20038	—	—	5853	1517	10420	- 313	1204
1993	21855	—	—	6798	1654	11365	- 341	1213
1994	23837	—	—	7828	1803	12395	- 372	1431
1995	25998	—	—	8952	1967	13519	- 406	1561

Note: 1 TJ = 173 BBL (crude oil).

systems. The net O&M costs of industrial electric systems are shown in the seventh column. This represents the difference between the resulting O&M costs of the electricity systems from that of the equivalent petroleum systems.

Net capital and O&M costs were derived from estimated capital and O&M cost coefficients for both industrial electric and petroleum energy systems. Cost coefficients for energy systems in $/GJ/yr were obtained from the cost data in Section 5.0 for both electric and petroleum energy systems. The coefficients were derived for each technology by fuel type and energy product. This set of coefficients were then weighted according to their overall contribution to the electrification conversion potential presented in Case 5. The resulting coefficients for the aggregate electric conversion systems and equivalent petroleum systems are shown in Table 7-V.

7.3 Projected Benefits

The primary benefits that will accrue from an industrial electrification option in Costa Rica are the savings from reduced petroleum imports. Table 7-VI shows the estimated annual monetary savings that would result from the scenario of petroleum savings developed initially in Table 7-I. The 1981 cost of petroleum of $5570/TJ is based on a weighted average of 1981 Caribbean market prices for Bunker C and diesel fuel. Subsequent year petroleum cost is based on a 3 percent annual price escalation for each year to 1995.

TABLE 7-V

ENERGY SYSTEM CAPITAL AND O&M COST COEFFICIENTS

Energy System	Capital Costs ($/GJ/yr)	O&M Costs ($/GJ/yr)
Petroleum	3.56	0.66
Electricity	5.31	0.63
Net Costs of Substituting Electricity for Petroleum Systems	1.75	-0.03

TABLE 7-VI

PETROLEUM SAVINGS FROM INDUSTRIAL ELECTRIFICATION

Year	Petroleum[1] Savings (TJ)	Cost/TJ[2] of Petroleum ($/TJ)	Monetary Savings ($x10^6)
1981	--	5570	--
1982	--	5737	--
1983	510	5909	3.0
1984	1219	6086	7.4
1985	2306	6269	14.5
1986	4230	6457	27.3
1987	6728	6651	44.7
1988	7347	6850	50.3
1989	8022	7056	56.6
1990	8759	7256	63.7
1991	9553	7486	71.5
1992	10420	7710	80.3
1993	11365	7941	90.2
1994	12395	8180	101.4
1995	13519	8425	113.9

(1) From Table 7.1

(2) Based on mix of Bunker C and diesel as shown in Table 4-II adjusted for energy differences; assumes .57 x 459 $/GJ (Bunker C) + .43 x 6.88 $/GJ (Diesel) = 5570 $/TJ; and 3 percent annual cost escalation from 1981 until 1995.

As seen from the last column in the table, the large increases in monetary savings occur with the replacement of existing industrial equipment between 1983 and 1988. By 1995 the constant 1981 dollar annual savings for the program are estimated at $114 million per year.

7.4 Internal Rate of Return

The internal rate of return (IRR) for the industrial electrification conversion project is estimated to be 13 percent. The IRR for the project was derived by determining the discount rate that resulted in a zero net present value to the stream of monetary benefit and costs. Table 7-VII presents the cash flow stream of benefits and costs derived for the project under the assumptions outlined in Case 5.

The net present value (NPV) in 1981 of the cash flow for the project was determined for a 15 year period and for discount rates of 9, 12, 13 and 15 percent. The NPV was defined as the sum of the discounted value of the difference between the annual net benefits and the net costs of the program. Table 7-VIII presents these results. A continuous plot of the NPV over a range of discount rates was presented previously in Figure 7-1.

Several secondary and non quantifiable benefits and costs will also result from an industrial electricity conversion program. For example, the reduction in the total petroleum import bill should improve the country's trade balance and therefore the country's currency exchange rates. A lower priced, stable, domestic energy

TABLE 7-VII

CASH FLOW OF NET BENEFITS AND COSTS FOR INDUSTRIAL ELECTRICITY CONVERSION PROGRAM

Year	Net Cost of Electricity Generation Capacity		Net Cost of Industrial Energy System Conversion		Net Benefits From Reduction of Petroleum Imports	
	Capital Costs $\$x10^6$	O&M Costs $\$x10^6$	Capital Costs $\$x10^6$	O&M Costs $\$x10^6$	Petroleum in 10^3 BOE	Savings in $\$x10^6$
1981	--	--	--	--	--	--
1982	--	--	--	--	--	--
1983	--	--	0.57	- 0.02	88.2	3.0
1984	--	--	0.63	- 0.04	210.9	7.4
1985	35.9	0.66	0.67	- 0.07	399.0	14.5
1986	206.4	3.37	0.91	- 0.13	731.8	27.3
1987	92.2	4.31	0.99	- 0.20	1,164.0	44.7
1988	--	4.31	1.08	- 0.22	1,271.1	50.3
1989	31.9	4.23	1.18	- 0.24	1,387.9	56.6
1990	--	4.23	1.29	- 0.26	1,515.4	63.7
1991	761.1	12.18	1.39	- 0.29	1,652.8	71.5
1992	--	12.18	1.52	- 0.31	1,802.8	80.3
1993	--	12.18	1.65	- 0.34	1,966.3	90.2
1994	- 1127.5	--	1.80	- 0.37	2,144.5	101.4
1995	--	--	1.97	- 0.41	2,338.9	113.9

TABLE 7-VIII

DISCOUNTED BENEFITS/COSTS OF PROGRAM

Benefit Cost Components	Discount Rate			
	9% $\$ \times 10^6$	12% $\$ \times 10^6$	13% $\$ \times 10^6$	15% $\$ \times 10^6$
Petroleum Benefits	308.7	239.4	220.6	188.2
Electricity Costs	210.1	206.4	202.4	194.3
Industrial Costs	21.9	18.8	17.9	16.3
Net Benefits Minus Costs	76.7	14.2	0.3	-22.4

resource will induce additional industrial growth in Costa Rica. In addition, the production of a domestic resource will stimulate employment and production in the supporting sectors. The substitution of electricity for petroleum will have positive environmental benefits from a reduction in air pollutant emissions. The electricity systems are generally less complex and require less maintenance than the petroleum systems. Many of the existing petroleum systems observed in Costa Rica were operating at below optimum efficiencies due to a lack of maintenance. The low efficiencies also imply incomplete combustion and therefore higher than normal pollutant emissions. Electricity systems are also generally safer to operate. Petroleum spills or vapor build-ups can be extremely dangerous and present a fire hazard. Finally, most industrial petroleum systems presently operating, with the exception of the engine generators, require some grid electricity to operate pumps, fans and motors. Thus, questions of electricity reliability affect equally the downtime of both petroleum and electricity systems.

APPENDICES

APPENDIX A

MISSION ITINERARY

8/13/81

8:00 AM	Banco Interamericano de Desarrollo • Laureano Rodrigo Especialista Sectorial en Cooperación Técnica y Preinversión
9:00 AM	• Luis Cosenza Jiménez Especialista Sectorial • Efraín Jiménez V. Ingeniero Civil
11:30 AM	Despacho del Ministro de Energía y Minas • Rogelio Sotela Muñoz Director: Secretaría de Energía
1:30 PM	• Roberto Gomelsky Energía - Experto Principal • Oscar E. Solera Castro Ingeniero Químico
3:30 PM	Ministerio de Economía, Industria y Comercio • Eladio Bolaños S. Director General de Industrias
4:30 PM	• Eulogio Domínguez V. Director Ejecutivo Secretaría Ejecutiva de Planificación

8/14/81

10:00 AM	Servicio Nacional de Electricidad • Adrián F. Flores Rodríguez Sub-director y Jefe del Departamento Técnico
2:00 PM	Instituto Costarricense de Electricidad • Eugenio Odio G. Jefe Dirección Planificación Electrica

8/17/81

8:30 AM Despacho del Ministro de Energía y Minas
- Roberto Gomelsky
  Energía Experto Principal

2:30 PM Subproductos de Café, S.A. (Afiliada a CODESA)
- Kenneth Rivera R.
  Gerente General

8/18/81

10:00 AM Derivados de Maíz Alimenticio, S.A. (De Masa)
- Enrique González
  Gerente General
- José Luis Garza Garza
  Gerente de Producción (Molina)

3:00 PM Cámara de Industrias de Costa Rica
- Rodolfo Alvarado Moreno
  Director Ejecutivo

8/19/81

9:00 AM Cooperativa de Leche (Dos Pinos)
- Edgar Villalobos
  General Services

11:00 AM CODESA
- Marco A. Madríz M.
  Gerente

1:30 AM United Brands Co. (Comp. Bananera de Costa Rica)
- Alvaro Madrigal
  Director de Relaciones Públicas

3:00 PM Oficina de Planificación Nacional y Política Económica
- William Corrales Harley
  Jefe Sección Planificación Industrial
  División de Planificación y Coordinación Sectorial

- César Augusto Díaz Poveda
  Sectorialista de Energía

8/20/81

8:15 AM Cooperativa de Café
- José J. Salas
  Gerente Interino

11:00 AM Cooperativa Matadero Nacional de Montecillos, R.L.
- Víctor R. Vargas B.
  Gerente de Producción

2:00 PM Textiles Industriales de Centro America, S.A. (Tica Tex)
- Toshiaki Mikawa
  Vice-Presidente Ejecutivo
- Daisaburo Kabayashi
  Jefe de Instalaciones
- Hiroshi Okamo
  Jefe de Fábrica

4:00 PM Standard Fruit Company
- Senen C. Bacani
  Gerente General

8/21/81

8:00 AM Costa Rica Centro de Promoción de Exportaciones
- Miguel Ruíz H.
  Director Ejecutivo

10:30 AM Fertilizantes de Centro America (Costa Rica), S.A. - FERTICA
- José A. Castro Beeche
  Gerente General

2:00 PM Compañia Numar
- Saberio Altamura
  Superintendente de Mantenimiento

4:00 PM Beef Products Co., Ltd.
- Carlos A. Urcuyo B.
  Presidente
- Antonio P. Urcuyo Peña
  Gerente

8/24/81

8:00 AM	Consejo Nacional de Producción • José Pablo Rodríguez A. Director División Administrativa • Luis A. Alvarado Ariaz
11:00 AM	Industria Nacional de Cemento • Oscar Navarro Jefe Administrativo • Manuel González Jefe de Producción
2:00 PM	Zeledón y Cía • Carlos R. Aubert Zeledón Gerente

APPENDIX B

CUESTIONARIO DE FABRICA

1.0 GENERAL

1.1 Nombre:

Dirección:

Contacto: Título:

Teléfono:

1.2 Sector Industrial (SIC)[1]

1.3 Producción Total (ventas por año)

1.4 Número de Empleados

1.5 Tipo de Compañía:

Propiedad Familiar
Sociedad Responsabilidad Limitada
Otro (indicar)

1.6 Tipo de Productos (producción anual de cada uno)

a.
b.
c.
d.

1.7 Contribución a la producción nacional de este sector industrial:

1.8 Planes de Ampliación (1981-1985)
(1985-1990)

Incremento (estimado) de energía debido a ampliaciones.

1.9 Interes/Colaboración/Problemas en reemplazar petróleo reacondicionando o reemplazando con equipo nuevo:

[1] SIC = Número en el System Industrial Classification

2.0 DETALLE DE PLANTA

2.1 Uso de Energía

	Por Mes	Costo Unitario
Petróleo (tipo)		
Gas		
Electricidad		
Otro (indicar)		

2.2 Operación

a. Turno por Día
b. Días por Semana
c. Paros por Vacaciones

2.3 Máquinas/Equipos Principales (identificar con un diagrama de proceso)

Para cada una indicar tipo de operación, fabricante, requerimiento energético (tipo), edad

Número 1

2

3

4

5

6

2.4 Calderas/Hornos

Para cada unidad indicar lo siguiente:

Unidad Número				
Fabricante Edad Eficiencia				
Usos del Vapor				
Características del Vapor: temperatura presión capacidad				
Uso del Vapor durante el fin de semana				
Tipo de Combustible				
Precio (Vapor) basado en Combustible solo				
Precio (Vapor) incluyendo también capital y operación				

2.5 Información Eléctrica

Suministro Primario ________ voltios ________ fase ________ frecuencia.

Capacidad Total Conectada ________ KW

Describa los usos (%) de la Capacidad Conectada

<u>Usos</u>	<u>%</u>
• Iluminación	
• Refrigeración	
• Bombas	
•	
•	

Consumo Típico ________ Kwhr (indicar período)

APPENDIX C

INDUSTRIAL ELECTPICITY TARIFFS

Tariff T-4 (T-4)

a) Application: For monthly consumption greater than 20,000 kWh except for the Cooperative of Rural Electrification.

When the monthly consumption is less than 20,000 kWh for more than 6 times during the last 12 consecutive months, or if the characteristics of the service are changed then the user most be reclassified to a corresponding tariff either upon request by the user of officially by the ICE. The characteristics of the service will be considered to determine if the reclassification corresponds - such reclassification will not affect invoices previous to the reclassification date.

b) Service: Service will be supplied only in lhigh voltage

Triphase - 2,400/4,160; 7,620/13,200; 14,400/24,900 or 19,000/33,000 vlts or higher according to grid availability.

c) Monthly Prices:

Demand Charge

For the first 27 kW of demand invoicing or less	C 2,030.40
For the following 40 kW of demand invoicing	75.20/kW
For each kW of additional demand invoicing	115.35/kW

Energy Charge

For the first 20,000 kWh or less	C 9,795.90
Each additional KWh	0.3586/kWh

Tariff T-10 (T-10)

a) Application: For special contracts with customers with more than 20,000 kWh monthly consumption. When monthly consumption is less than 20,000 kWh in more than 6 times during the last 12 consecutive months, or if the characteristics of the service are changed then the user most be reclassified to a corresponding tariff either upon request by the user of officially by the ICE. The characteristics of the service will be considered to determine if the reclassification corresponds - such reclassification will not affect invoices previous to the reclassification date.

b) Monthly Prices

Demand Charge - The maximum demand to be invoiced will be the highest average load in kW for any 15 minutes interval during the month registered between 10:00 and 12:30 hours or between 16:30 and 20:00 hours. In the period from May 21 to January 20 of each year the demand registered on saturdays, sundays and oficial holidays will not be considered for invoice purposes, this is if in each monthly period the highest demand of the Interconnected System on Saturdays, Sundays, and official holidays is not greater than the 85 percent of the maximum demand of the rest of the week days. The maximum demand so established will be invoiced in accordance with the demand charges established by Tariff (T-4) of the Instituto Costarricense de Electricidad.

Energy Charge

For the period between 21 May one year and 20 January of the following year and between the 20:00 and 10:00 hours of the following day, the energy consumed in excess of the average consumption at those hours during the period between 21 January and 20 May of the previous period, will be invoiced at ¢0.16/kWh.

For the period between 21 May of one year and 20 January of the following year and between the hours 10:00 to 20:00, the energy consumed in excess of the average consumption for those same hours of the previous period between 21 January and 20 May, will be invoiced at ¢ 0.1938/kWh.

All the energy balance will be invoiced in accordance with the requirements of Tariff 4 of the Instituto Costarricense de Electricidad.

APPENDIX D

LIST OF EQUIPMENT SUPPLIERS CONTACTED

COMPANY/ADDRESS	EQUIPMENT
AlResearch Manufacturing Company 2525 West 190th Street Torrance, CA 90509 2B/512-4519	Heat Pumps
CAM Industries, Inc. 18250-68th Avenue, South Kent, WA 98031 206/226-6012	Electric Boilers
Chromalox Industrial Heating Products 4 Allegheny Center Pittsburgh, PA 15212 412/323-3800	Resistance Heating
General Electric 166 Boulder Drive Fitchburg, MA 01420 617/343-6441	Heat Pumps
Hauck Manufacturing Company P.O. Box 1084 Lebanon, PA 17042 717/272-3051	Combustors
Hydro Steam Industries, Inc. 7661 Fullerton Road Springfield, VA 22153 703/455-3600	Electric Boilers
Microdry Corporation 3111 Fostoria Way San Ramon, CA 94583 415/837-9106	Microwave Systems

APPENDIX D (Concluded)

COMPANY/ADDRESS	EQUIPMENT
Raytheon Co. 141 Spring Lexington, MA 02173 617/862-6600	Microwave Systems
Tate Engineering 601 West Street Baltimore, MD 21230 301/539-0787	Boilers Water Feed Systems
Va-Power Products 6420 West Howard Street Chicago, IL 60648 312/631-9200	Oil-Fired Boilers
WABASH Power Equipment Co. 444 Carpenter Avenue Wheeling, IL 60090 312/541-5600	Diesel Generators Oil-Fired Boilers
Westinghouse Air Conditioning International P.O. Box 2510 Staunton, VA 24401 603/248-0711	Heat Pumps

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Department Approval: ______________________

MITRE Project Approval: ______________________