To the Graduate Council:

I am submitting herewith a dissertation written by Jawaharlall Baguant entitled "Energy and Economic Development Strategies System Studies for LDCs." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Chemical Engineering.

Carl O. Thomas, Major Professor

We have read this dissertation
and recommend its acceptance:

Accepted for the Council:

Vice Chancellor
Graduate Studies and Research

A

ENERGY AND ECONOMIC DEVELOPMENT STRATEGIES

SYSTEM STUDIES FOR LDCs

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Jawaharlall Baguant

June 1980

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DEDICATION

Dedicated to my father

Moteelall Baguant

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ABSTRACT

At present approximately 30% of the world's population is within the industrialized nations, and approximately 70% within the less developed countries (LDCs), although there obviously is considerable diversity within each of these two generalized groups.

The present average per capita income within the LDC group is roughly one-tenth that within the industrialized nation group. If there is a collective desire to close that very large economic gap, this would mean accelerated economic development within the LDCs. Consequently this would have an impact upon energy demand and supply questions in the LDCs, as well as the world at large.

This dissertation addresses the above problem in two general ways. The first involves the development of a long range energy demand model through the year 2010 for the LDCs, based upon aggregate analysis of population dynamics, labor force, labor productivity, and the efficiency of energy utilization for economic development. The second part of the dissertation focuses upon the potential of biomass, and biomass derived fuels and chemicals, to become a significant domestic renewable energy resource in the context of LDC economic development.

The rate of economic growth which may be accomplished in the LDCs, as well as their future energy consumption patterns, also will have related impacts upon the industrialized nations and the world's energy problem as a whole.

Three LDCs, Brazil, Mauritius, and Nicaragua, have been chosen for study, in part because of their diversity. The U. S. and West

Germany have been used as comparative examples from the industrialized nation group. The biomass work focuses upon sugar cane as the source, with lesser emphasis upon corn. The end products examined are ethyl alcohol, ammonia, and electricity, with secondary emphasis upon methyl alcohol and ethylene.

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INTRODUCTION

The first portion of this dissertation deals with the question of future trends in energy demand within the LDCs (less developed countries) as a function of future patterns of economic development.

The LDC group of nations, containing about 70% of the world's total population, now has an average per capita income only about one-tenth that prevailing in the industrialized nation group. The desire to close this large economic gap would cause a faster increase in the growth rate of energy demand by the LDCs compared to the industrialized nations because energy can be viewed as one of the raw materials of economic development. Within individual countries historical data for the past three decades or more show reasonably smooth trends in the ratio of energy consumed to real (constant dollar) GNP or GDP (gross national product or gross domestic product). The absolute values of that ratio vary considerably from one nation to another, however.

The U. S. and West Germany serve to bracket the characteristics of the industrialized nations. The U. S. now has the largest per capita consumption of energy of any nation in the world, and also has the highest consumption of energy per unit of real economic output. By contrast those two values in West Germany are roughly half the U. S. values, although the per capita economic status of people in Germany is very similar to that in the U. S.

At present economic growth and the growth of energy demand in the individual LDCs appear to be moving toward the average characteristics of the industrialized nations. If a pattern of simply copying the industrialized nations prevails, and if this pattern is successful in

closing the economic gap while world population continues to grow toward a stable level of perhaps 8-12 billion people, world energy demand will eventually reach an enormous level, an order of magnitude or greater than present world consumption. Such levels of energy consumption would be self-defeating from an economic development standpoint, and may be difficult or impossible from the viewpoint of available supply, economics, and ecology.

In order to provide analytical tools for more effective long range planning related to energy supply and demand, the technique of systems analysis and modeling has been applied increasingly to these problems within the industrialized nations. Such modeling in the industrialized nations has been oriented toward analysis by consuming sectors, with summing to provide an analysis of aggregate demand. The IEA (Institute for Energy Analysis) model has been discussed in this dissertation as one comparative model.

In the LDCs sectoral data generally are unreliable or unavailable. Because of this an Aggregate Energy Demand Model, through the year 2010, has been developed based upon population dynamics, labor force, labor productivity, and the efficiency of energy utilization for economic productivity. This Aggregate Energy Demand Model has been tested against other U. S. models, and used in this dissertation for analyses related to Brazil, Mauritius, and Nicaragua.

Such system models are not predictive, but rather are used to help gain better understandings of relationships amongst the parameters that are involved in economic growth and in creating energy demand. To the extent that they are reliable or credible, they may be useful tools for long range planning purposes.

It is clear that the rate of energy consumption in the LDCs must increase in relation to future growth in their populations and their economies. The purpose of this type of model is to provide help and understanding that will assist in accomplishing economic growth at a minimum growth rate in energy demand, rather than simply drifting into the patterns of the various industrialized nations.

The world energy supply and price situation already is such that any nation, industrialized or LDC, that is heavily dependent upon imported oil has serious economic growth handicaps. The economic constraints imposed by dependency upon imported energy are likely to worsen with time. This suggests the importance of energy strategies which may use domestic and renewable energy sources, of which biomass is one category of increasing interest.

The second portion of this dissertation focuses upon the potential for biomass and biomass derived fuels and chemicals as an energy option for the LDCs, with Brazil, Mauritius, and Nicaragua chosen as examples.

One can make a kind of analogy here to the terminology of banking and finance. Fossil fuels, which originated from biomass, are analogous to economic capital, and we are now living off that capital. By contrast current production of biomass is analogous to current economic income.

The three countries from the LDC group were chosen for several reasons as follows:

(i) They represent diversity in size and population.

(ii) All have a strong domestic production capability for sugar cane and sugar, which is one of the more attractive biomass materials.

(iii) Brazil in particular already is far along on a national biomass strategy, e.g., all gasoline now sold in Brazil contains at least 10% alcohol manufactured from domestic sugar cane.

(iv) All three countries are in the category of low GNP per capita as compared with the average for the industrialized nations.

The combination of system analysis to provide a better understanding of the relationship between long range economic development and associated energy demand, and the potential for domestic biomass to provide the requisite energy on a renewable basis in the LDCs is the dual thrust of this dissertation.

CHAPTER I

POPULATION DYNAMICS

A. General Discussion

One of the most important factors associated with economic development and the consumption of energy, food, and other natural resources is population dynamics. This is why increasing effort is being made by organizations such as the United Nations (U. N.), the U. S. Bureau of the Census, and several other organizations in studying population dynamics. Since this relates to the present investigation of potential future trends in economic development and energy demand and supply through the year 2010, this chapter is devoted to population dynamics.

A recent study of the world population trends carried out and published by the U. N.[1] is summarized and included in the text. Because of the complexity of population growth, such projections always are uncertain and they must be used with considerable care and understanding. Fertility and mortality, immigration and emigration, natural catastrophe, standard of living and education are major factors that influence the overall population growth rate of a country. If all of these factors are considered quantitatively while studying future population trends, the analysis becomes very complex in terms of mathematical computations. In order to take these factors into account in this dissertation certain assumptions have to be made to simplify the computations, based either upon historical trends or future technological developments, or a combination of both. It is quite obvious that the validity of such work will be a function of how good the assumptions are.

For the purpose of this study the U. N. population model has been modified and simplified as described in Section C. This modified model has been used for the estimation of population trends up to the year 2010. In addition to the five selected nations, i.e., the U. S., West Germany, Brazil, Mauritius, and Nicaragua, considered in this study, the modified model is used for the estimation of the population of the less developed countries [LDCs] and the developed nations as a whole. The results are compared with those of the U. N. in Section D.

B. Brief Description of the U. N. Population Projections

In the recent U. N. population study mentioned earlier, use was made of the Cohort Component Method[2]. The basic steps and the assumptions on fertility, mortality, and migration associated with the method have been described briefly in Subsections 1 through 4.

1. Basic Steps of the Cohort Component Method.

The Cohort Component Method involves the following four basic steps:

(i) Available data on sex-age structure of the population and on levels and trends of fertility, mortality, and migration are compiled, evaluated, and adjusted in order to arrive at acceptable measures of fertility and mortality.

(ii) An assumed schedule of sex-age specific probabilities of survival based on national life or model life tables is applied to give the number of survivors at the end of each five-year period.

(iii) The number of births is arrived at using an assumed schedule of age-specific birth rates and applying it to the

corresponding numbers of females in the reproductive age groups. These births are usually described using the ratio 105/100 (male/female), and survivors at birth are again estimated using survival probabilities. The assumed schedule usually is based upon statistical analysis of interviews with women of child bearing age.

(iv) Migration is also accounted for wherever possible.

It must be noted that in all U. N. population studies decreases in population caused by national catastrophies are not considered.

2. Working Model for Fertility.

The following assumptions and factors were considered in the development of a working model for fertility.

(i) The theory of demographic transition, that is, fertility declines with socio-economic development, was taken into account in developing fertility projections. Moreover, U. N. demographers assumed fertility would eventually decline to the stage that the reproduction level would become 1.0, i.e., replacement level.

(ii) Family planning policies and birth control, etc., would continue to receive governmental and various organizational support as in the past. This would have a direct bearing on fertility decline, signs of which have already been seen in many LDCs.

(iii) From past experience it has been observed that fertility decline is slow at first, then gains momentum and slows down again.[3] This S-shaped trend in fertility decline

was assumed to apply in the future for other nations which still have high net population growth rates.

(iv) Culture and religious background, which have an effect on fertility (this varies from country to country), were considered for individual countries and assumptions modified accordingly.

(v) The fact that small countries, especially small islands, have shown differences in fertility decline patterns (mostly downward trends) during the past decase,[4] was taken into account when dealing with the future trends of these small countries.

Using the above assumptions and factors, a model of fertility decline represented by the gross reproduction rate*, which is also a measure of fertility, was developed as illustrated in Figure I-1. From the model it can be seen that the gross reproduction rate will decline from the neighborhood of 3.0 to a replacement level, i.e., 1.0 in some 30 to 70 years, if the model is reliable.

3. Working Model for Mortality.

Mortality assumptions were based on the following:

(i) Life expectancy at birth.

(ii) Sex-age patterns of probabilities of survival corresponding to different levels of life expectancy at birth.

---

*Gross reproduction rate is the average number of daughters that would be born per woman in a group of women if all women survived to the end of their reproductive years and bore daughters at each age in accordance with the age-specific fertility schedule for women of various ages in a specified area and period.

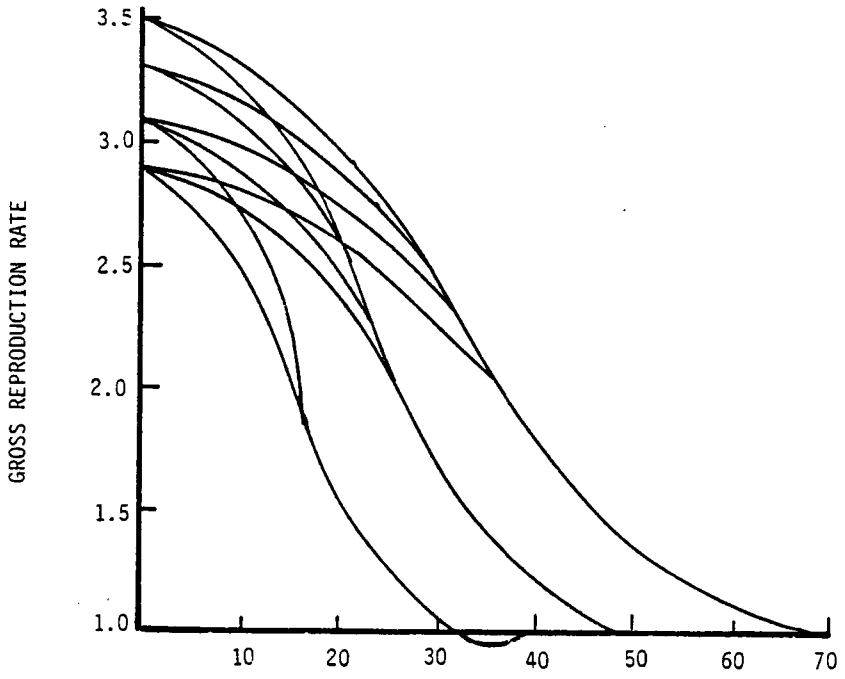


FIGURE I-1. GROSS REPRODUCTION RATE AS A MEASURE OF FERTILITY

[a]Working model of fertility decline, initial gross reproduction levels of 3.5, 3.3, 3.1, and 2.9.

Source: U. N., Department of Economic and Social Affairs, "World Population as Assessed in 1973, Population Studies No. 60," U. N., New York, 1977.

Mortality rates of the 1960's compared to those of the 1950's have not shown the decline that was expected. Moreover, the fact that mortality rates tend to approach asymptotic limits suggests an assumption of very moderate or even no further decline in mortality in the future in certain countries. Thus, the U. N. assumed that the gain in life expectancy at birth would be 2.5 years for every fifteen year period until a life expectancy of 70 years is reached. After this level has been attained the gain in life expectancy at birth would be much less than 2.5 years. Furthermore, the upper limit of the life expectancy of 72.6 years for males and 77.5 years for females was assumed.

4. Migration Assumptions.

Migration is a function of the socio-economic and political nature of a country. Since the future development of a country is itself so uncertain and data on migration generally is lacking, migration becomes a very difficult factor to be considered for population projection. In the U. N. population study migration effects were arbitrarily taken care of by analogies among selected countries.

Using the above assumptions on fertility, mortality, and migration (for countries where data are available), the population of all the countries of the world was estimated by the U. N. up to the year 2000.[5] In order to account for the degree of uncertainty associated with work of this nature, three variants of projections, the low, medium and high, were calculated by matching various levels of fertility and mortality. According to the U. N. the medium variant of projection gives the most probable future population trend, whereas, the low and

high represent the limits of the range of possibilities. A summary of results is given in Section D for comparison purposes.

C. Modified Version of the U. N. Population Model Used

In order to estimate the population trends beyond the year 2000, and at the same time to simplify computer simulation of population growth, the U. N. population model illustrated in the previous section has been modified for use in this dissertation. The various ways in which the modifications have been carried out and the use of the modified model to estimate the population trends of the countries considered in this study are described in this section. Some of the potentials and the limitations of this model have also been included.

1. Basic Concept Associated With the Modified Model.

In the absence of migration, the population growth rate of any nation can be measured using the crude birth and death rates as shown in the equation below.

$$\begin{matrix}\text{Annual} \\ \text{Population Growth} \\ \text{Rate (\%)}\end{matrix} = \frac{1}{10}\left[\begin{matrix}\text{Annual Crude} \\ \text{Birth Rate} \\ \text{Per 1000}\end{matrix} - \begin{matrix}\text{Annual Crude} \\ \text{Death Rate} \\ \text{Per 1000}\end{matrix}\right]$$

Data on migration generally are lacking or very unreliable for many countries, thereby making measurement of its influence on population growth rates difficult. Also, stronger restrictions on immigration by developed nations as well as LDCs would decrease the influence of migration on population growth in the future. Therefore, the above equation which ignores migration has been used for the estimation of future population trends. In order to use the equation, data on birth and death rates are required. Thus, working models as illustrated below have been developed.

2. Working Model for Crude Birth and Death Rates.

Before the industrial revolution of the eighteenth century, world population was growing at approximately 0.1% annually.[6] The gradual development of technology (including improvements in public health) and the availability of natural resources following the industrial revolution caused the net growth rate of world population to rise to a high of 2.0% per year in the early 1960's, for the first time in the entire history of mankind. It is believed that the high growth rate is only transitory and may approach the 0.1% level again sometime during the next century. Such future decline will have to be the result of reductions in birth rates since the social structure mandates keeping the mortality rate as low as possible. The annual population growth rate of below 0.1% in the developed nations, as well as the signs of decrease in some LDCs such as Mauritius, Taiwan, and even India and China during recent years do justify the above speculation.[7]

Using the above argument it has been assumed that the crude birth rate would decline from the neighborhood of 50 per 1000 (approximately corresponding to a reproduction rate of 3.0) to the death rate level in the next 40 to 100 years (corresponding to reproduction rate declining to replacement level in 30 to 70 years). It must be noted that a 70-year cycle is the most typical one observed from historical data of many developed nations, whereas the 40 and 100 year cycles give the probable lower and upper limits. It has also been assumed that decline would be slow at first, then gain momentum and would slow down again. This is similar to the U. N. assumption of an S-shaped trend already discussed. The S-shaped trend pattern already has been demonstrated in a number of developed or transitional countries. Based on these assumptions, a crude birth rate model as illustrated on Figure I-2 has been developed.

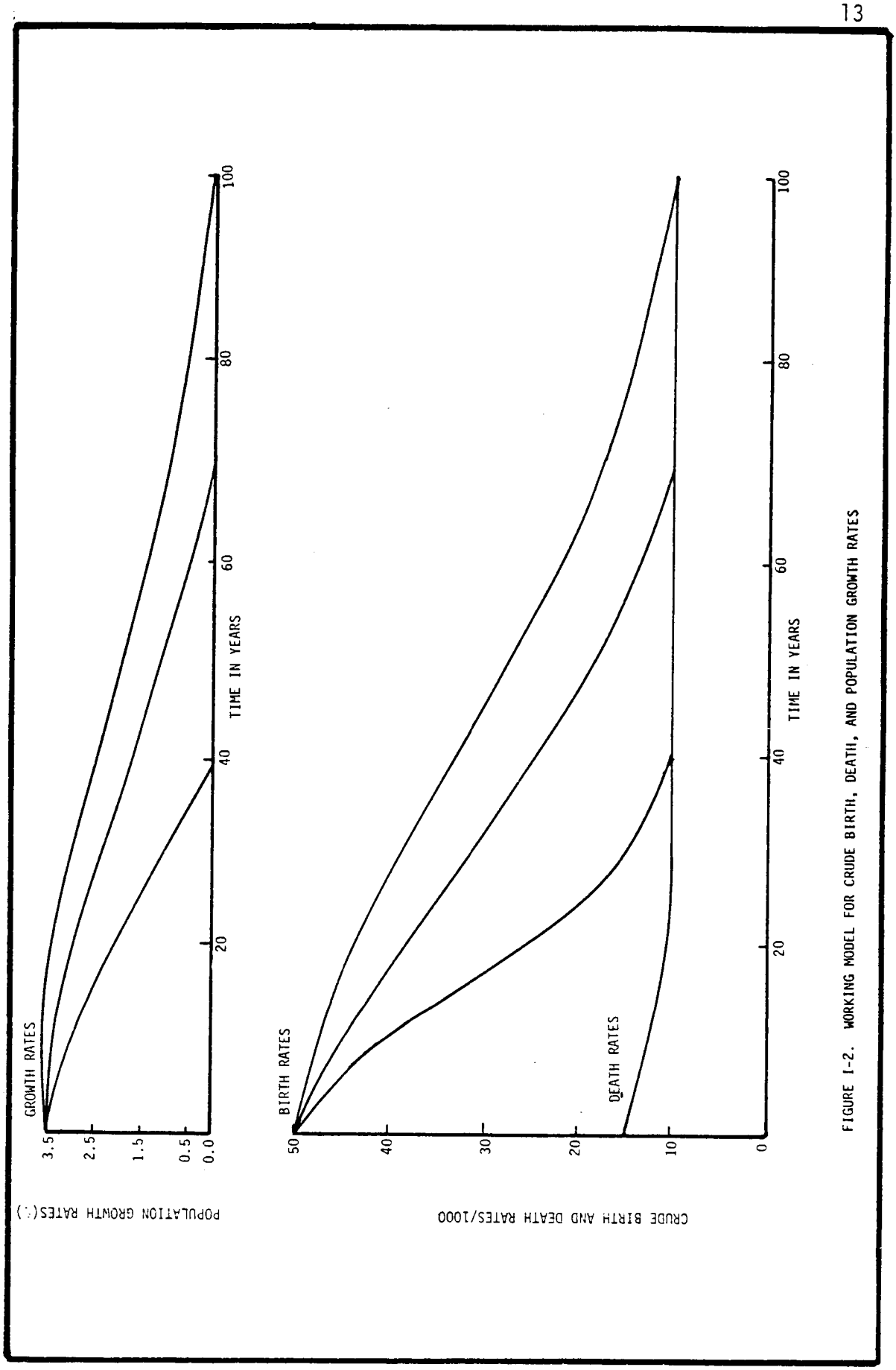


FIGURE I-2. WORKING MODEL FOR CRUDE BIRTH, DEATH, AND POPULATION GROWTH RATES

The working model for crude death rate represented by the curve in Figure I-2 has been developed based on the following arguments:

(i) For countries where annual death rates are greater than 10 per 1000, it has been assumed that continuous decline would be experienced until the rates drop to the 10 per 1000 level in the next 20 to 30 year period.

(ii) For other countries where death rates have already dropped below 10 per 1000, it has been assumed that not much can be done for further improvement. Thus, the rates would remain more or less stable in the region of 7 to 10 per 1000 in the future.

By the combination of crude birth and death rate models three levels of population growth rate curves (high, medium, and low) have been generated as illustrated in Figure I-2. It is clear from the figure that the median level of population growth rate corresponds to the 70-year declining cycle of the birth rate which is considered to be the most typical one observed from long term historical data. Thus, the population trends generated from the median level population growth rate have been referred to as the most probable future trend.* Finally, the population trends for the countries considered in this study have been estimated based on the above models.

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*Note that the 70-year median transition also corresponds to the "time constant" between fertility and mortality occurence at the average life expectancy level of 70 years.

3. Potential Advantages and Limitations of the Modified Population Model.

One of the most important advantages of this modified population model is that it can be handled by either a simple computer program or a desk calculator. The latter is an important characteristic, especially in the LDCs where computer facilities are not always available. Even with all the modifications the percentage variation between the results of the modified model and those of the U. N. model is less than 7% which is comparable to the variation (±6%) within the U. N. results themselves.

On the other hand, the major limitation of the modified model is that it does not give any idea of the age distribution of the population, which is an important factor for the determination of the labor force. Nevertheless, the modified model has been used for the estimation of the population of the selected countries in the interest of computational simplicity.

D. Results and Comments

The simplified model described in the previous section has been used to estimate the population trends of Brazil, Mauritius, Nicaragua, United States, and West Germany from 1975 to 2010. In order to be consistent with the U. N. population study and at the same time to give an idea of the uncertainty involved, three population trends, high, medium,

and low, have been estimated by using the three possible declines in population growth rates shown in Figure I-2. The results of the median population estimation, which gives the most probable trend, for the reason described in the previous section, are summarized in Table I-1 and Figure I-3, and the more detailed results are given in Appendix A. Similarly, results from the U. N. medium variant population projection are summarized in Table I-2. Finally future world population has been estimated by first estimating the population of the LDCs as a group and that of the developed nations as a second group, and then calculating the sum. The results have been represented diagramatically in Figure I-4.

1. Comparison of Results of the Two Models.

The highest percentage variation between the results of the two models, the modified model discussed in the previous section and the U. N. population projection model, is roughly 7% and this occurs in the case of Brazil where tremendous uncertainties in the future population trends exist. On the whole, the average variation between the results is in the range of 4 to 5%, which is less than ±6% variation within the U. N. results themselves. Thus, it can be concluded that the results of the modified model are comparable to those of the U. N. population projection model. As far as the advantages and the disadvantages of the models are concerned, the modified model allows much simpler computer programming with little sacrifice of quantitative precision. On the other hand, the U. N. model is advantageous in that it can be used to give the population age structure which, for example, is useful in estimating characteristics of the labor force. On balance, the modified

TABLE I-1

MEDIUM POPULATION ESTIMATES USING MODEL DEVELOPED 1975-2010

Year	Brazil		Mauritius		Nicaragua		United States		West Germany	
	Population 10^6	Average Annual Percentage Growth Rates	Population 10^6	Average Annual Percentage Growth Rates	Population 10^6	Average Annual Percentage Growth Rates	Population 10^6	Average Annual Percentage Growth Rates	Population 10^6	Average Annual Percentage Growth Rates
1975	109.73		0.899		2.23		213.93		61.68	
1975-1980		2.78		1.71		3.58		0.96		0.15
1980	125.86		0.978		2.66		224.38		62.14	
1980-1990		2.54		1.45		3.44		0.85		0.10
1990	161.68		1.141		3.73		244.24		62.79	
1990-2000		2.38		1.21		2.77		0.63		0.0
2000	197.42		1.287		4.90		259.95		62.79	
2000-2010		1.42		0.83		2.00		0.40		0.0
2010	227.39		1.396		5.97		270.40		62.79	

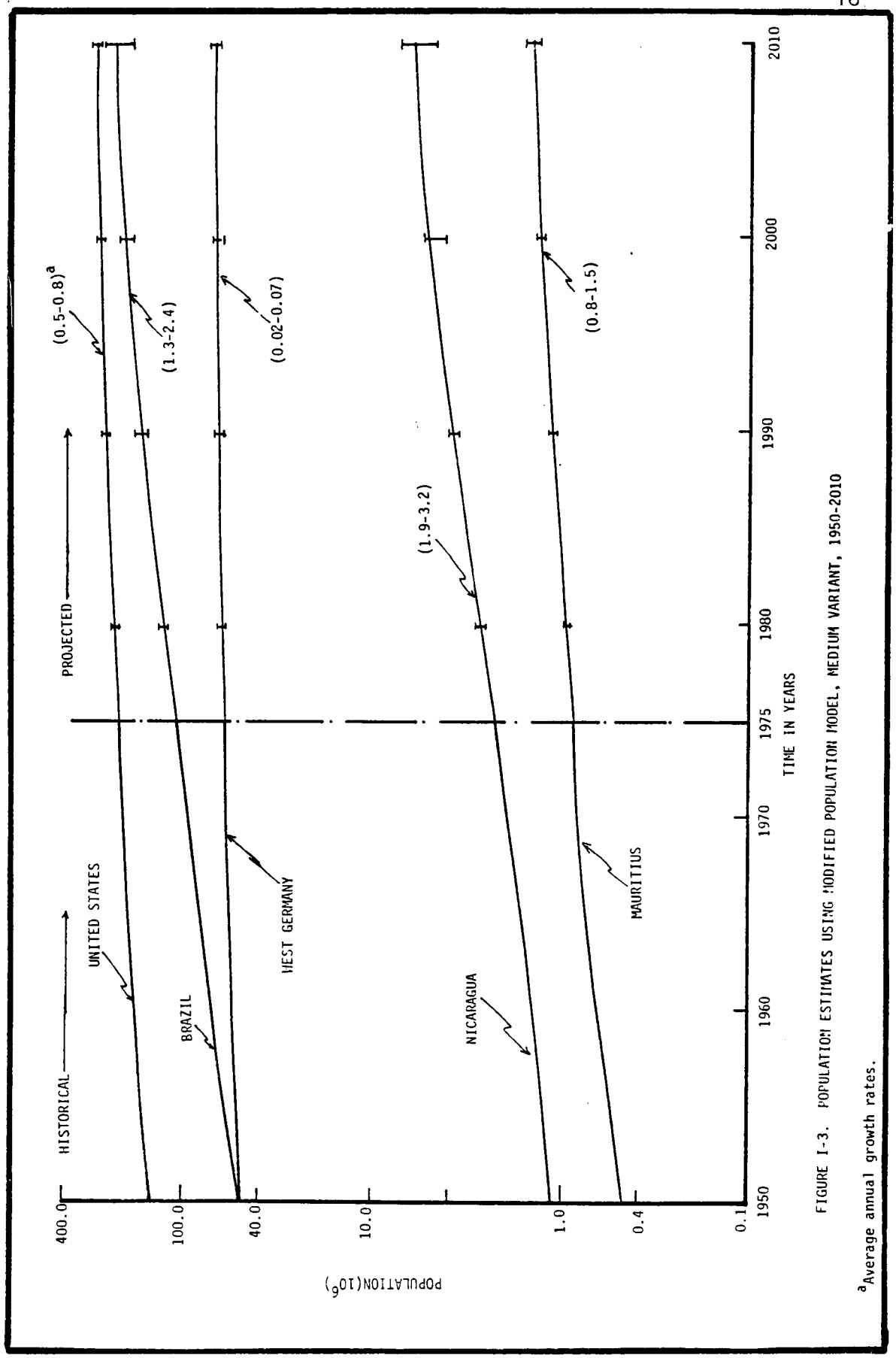


FIGURE I-3. POPULATION ESTIMATES USING MODIFIED POPULATION MODEL, MEDIUM VARIANT, 1950-2010

[a]Average annual growth rates.

TABLE I-2

MEDIUM POPULATION ESTIMATES USING UNITED NATIONS MODEL 1975-2010

	Brazil		Mauritius		Nicaragua		United States		West Germany	
Year	Population 10^6	Average Annual Percentage Growth Rates	Population 10^6	Average Annual Percentage Growth Rates	Population 10^6	Average Annual Percentage Growth Rates	Population 10^6	Average Annual Percentage Growth Rates	Population 10^6	Average Annual Percentage Growth Rates
1975	109.73		0.899		2.32		213.93		61.68	
1975-1980		2.87		1.51		3.27		0.94		0.11
1980	126.39		0.964		2.73		224.13		62.02	
1980-1990		2.74		1.40		3.31		0.96		0.34
1990	165.76		1.113		3.78		246.64		64.19	
1990-2000		2.66		1.22		3.14		0.70		0.31
2000	215.51		1.257		5.15		264.43		66.24	

Source: U. N., Department of Economic and Social Affairs, "World Population Prospects as Assessed in 1973, Population Studies No. 60," U. N., New York, 1977.

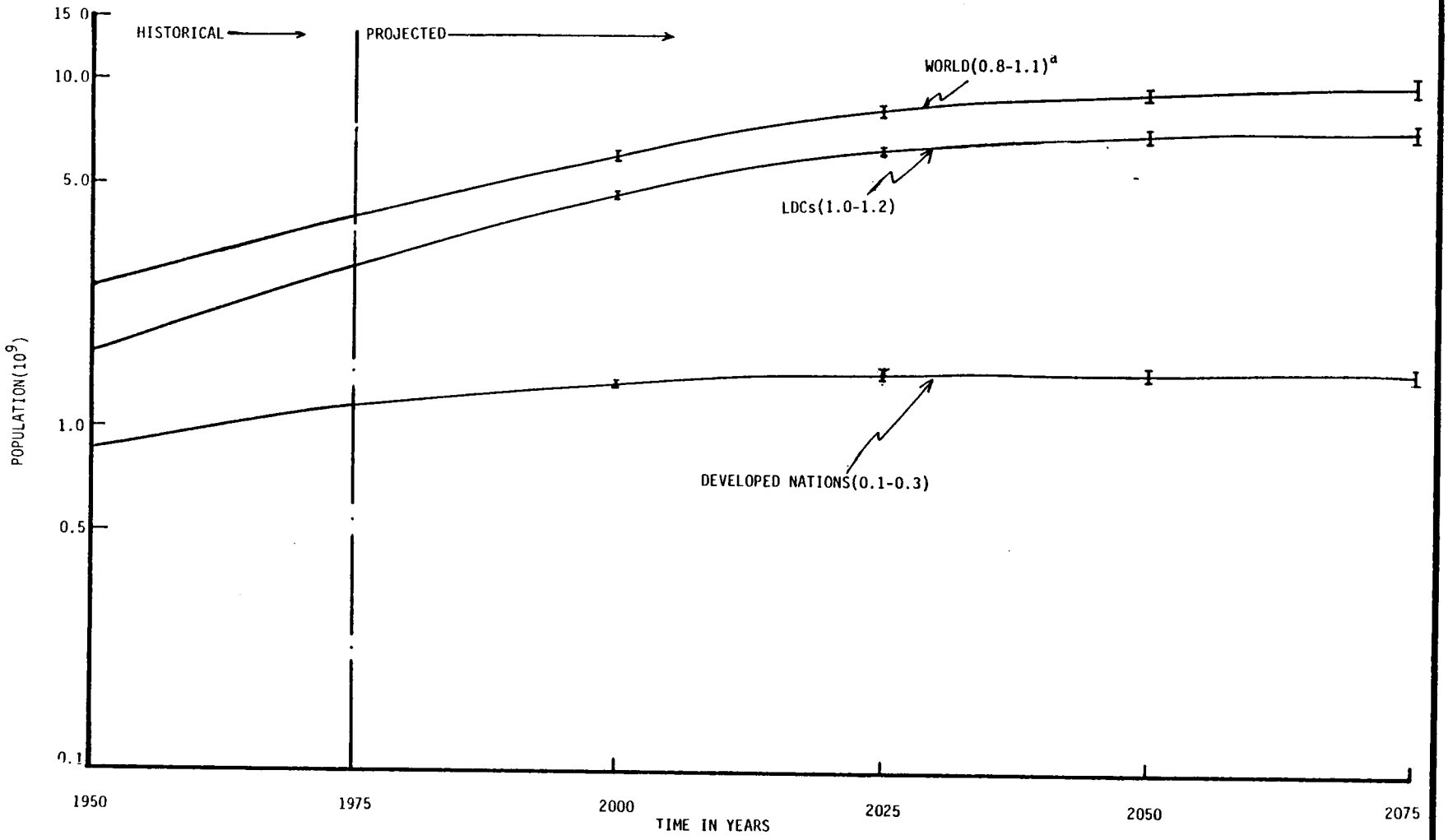


FIGURE I-4. POPULATION ESTIMATES OF THE WORLD(LDCs + DEVELOPED NATIONS) USING MODIFIED POPULATION MODEL, MEDIUM VARIANT, 1950-2010

[a]Average annual growth rates.

model which is believed to be within acceptable limits of accuracy for the purpose of this study, has been selected for use in the chapters that follow.

2. Additional Comments on Population Results of Selected Countries

a. Brazil

The results show that the annual population growth rate of above 2.0% in Brazil probably will be sustained for at least the next 20 years. This is the result of the high birth rate of 47/1000 experienced in the early 1950's which decreased to only 37/1000 in 1975. The rate will most likely decline very slowly for the next 20 years. It is only at the turn of the century that a birth rate of approximately 24/1000 together with a death rate of approximately 9/1000 will likely result in an annual population growth rate of below 2.0%. From there on, it is believed that the decrease in population growth rate will be much faster. It must be pointed out that such a characteristic is fairly common in most of the Latin American countries and will likely be so in the future.

b. Mauritius

In the case of Mauritius, the results show that the decrease in population growth rate from 3.5% to 1.7% experienced during the third quarter of this century will likely be continued during the last quarter also. This will result in a population growth rate of slightly below 1.0% and an absolute population of approximately 1.4 million by 2010. If the decreasing trend is maintained, it is very likely that a zero-growth rate can be attained sometime in the middle of the next century. The most logical explanation for the above decrease

in growth rate is that birth control programs undertaken by various organizations since the early 1960's have been very effective and indications are that such programs will be maintained in the future.

c. Nicaragua

Because Nicaragua is one of the Latin American countries similar arguments to those given for Brazil apply also. The results show that a population growth rate of above 2.0% will likely be sustained during the rest of this century which will result in an absolute population of approximately 6 million by 2010.

d. United States

From the results of the modified model, it can be seen that the low population growth rate[8] already attained (0.9% in 1975) will most likely continue to decline during the rest of the century. This will result in a population growth rate of 0.6% and an absolute population of approximately 270 million by 2010. On the basis of the above result which does agree with the U. N. results, it seems unlikely that U. S. population will stabilize at 260 million by the middle of the next century as predicted by the F-Series population projection of the U. S. Bureau of the Census.[9]

e. West Germany

Since West Germany is one of the developed nations, similar arguments to those used in the case of U. S. apply also. From the modified model it can be seen that the low population growth rate in West Germany of approximately 0.3% in 1975 will continue to decline during the remainder of the century. This will most probably result in a population growth rate of 0.1% and an absolute population of 66 million by 2010. It can be speculated that after 2010 West Germany will not be far from reaching a stable population of 70 million.

3. World Population

Figure I-4 summarizes the population trends of the LDCs, developed nations, and that of the world as estimated by the simplified model described in this chapter. It can be seen from the figure that the model has been stretched to 2050 in order to provide some additional idea of when and where the world population might stabilize. As a result it can be speculated that, according to this simplified model, the world population might stabilize in the range of 8 to 12 billion sometime towards the end of the next century. Furthermore, it must be noticed that the percentage of the world population living in the LDCs will likely be increasing constantly from 70% in 1975 to roughly 85% towards the middle of the next century.

CHAPTER II

ECONOMIC DEVELOPMENT

A. General Discussion

Though the world economy has been growing, the growth rate has varied considerably from one country to another. This has given rise to two rather general categories of nations, the developed nations, the United States, Canada, Western Europe, and Japan, and the less developed countries (LDCs) which include the rest of the world. For example, in the United States the annual real economic growth has been 2.5% or higher, whereas, in certain regions of Africa it has been as low as 0.5%. There are, of course, substantial variations within each of these two groups.

The gross national product (GNP) or the gross domestic product (GDP) per capita is one means for classifying nations with respect to their economies. Though both of them fail to give any idea of the welfare distribution within the nation, both do indicate the general economic status of the nation. As an example, the GNP per capita in 1975 of the developed nation group was about $3000 compared to about $300 for the LDCs.[10] Though there continues to be disparity of income among the inhabitants of the LDCs, this comparison of average GNP per capita does show that very substantial differences in per capita output exist between the developed nations and the LDCs. It is this very obvious economic gap between the developed and the less developed nations and the long range energy supply/demand implications of closing that gap that provide the underlying theme of the present dissertation.

The interrelationships of the factors contributing to real economic growth in any nation are varied and complex. These interrelationships have been analyzed by Denison (1974)[11] for the U. S. economy for the post World War II period. In general terms economic growth is influenced by factors such as the availability of capital, diversity within the economy which creates opportunities for economic multiplication and further employment, the education and training level of the labor force, the ability to generate and implement long range planning, the extent of long range political stability, and other such factors. The problem of formulating all or even part of the factors and parameters associated with economic development is very complex, and a large volume of historical data is required. Such data are available in the U. S. and have been used by Denison in his study; whereas, studies of that nature are difficult in most of the LDCs because of the scarcity and unreliability of data.

It is not the purpose of this dissertation to carry out a detailed analysis of the economy of any particular country or to attempt to generate an economic development plan for any country. Rather the purpose is to attempt to develop some improved understandings of the relationships between economic development and the consequences for energy supply and demand. Better understandings of these relationships will be helpful in trying to find ways to sustain future economic growth with a less rapidly growing demand for energy. In developing such understandings some ideas of the future economic trends are essential.

Analyses are carried out in Section B of this chapter to help estimate the range of economic growth rates that would have to be sustained

in the LDCs, during a period in which the developed nations' economies also continue to grow, if the economic gap between these groups is to be closed. Though the economic gap might possibly be closed towards the end of the next century, the analyses have been limited to the time frame of 35 years, i.e., up to 2010, since the uncertainties increase rapidly with time. In addition, there are other rational reasons for using a 35 year time frame. It approximates the population doubling time at present world population growth rates. It also approximates the time required for the introduction of new technologies and capital facilities and the requirements for amortization of those facilities.

B. Closing the Economic Gap Between Developed Nations and LDCs

Table II-1 shows the average GNP per capita for all the developed nations and for all the LDCs for 1970 and 1975. The most important observation relative to this dissertation is the tremendous economic gap that exists between the two groups of nations. Similar ratios in the vicinity of 12:1 in 1970 and 10:1 in 1975 are observed when the average GNP per capita of the two selected developed nations, U. S. and West Germany, is compared to that of the average GNP per capita of the three selected LDCs, Brazil, Mauritius, and Nicaragua. Though historical data do indicate some improvement during the 1970-1975 period, the process of narrowing the gap is still extremely slow.

According to the U. N. study[12] on the future of the world economy, the decreasing trend of the ratio from 12:1 in 1970 and 10:1 in 1975 is likely to continue and reach roughly 7:1 by the end of the century if the following assumptions prove to be correct.

TABLE II-1

COMPARISON OF GNP PER CAPITA IN CONSTANT 1970 U. S. DOLLARS

	Average GNP Per Capita	
	1970	1975
World		
I - Developed Nations	$[a] 2700	$ 3000
II - LDCs	$ 230	$ 300
Ratio: [I/II]	∿[b] 12:1	∿ 10:1
Selected Countries		
I - U. S. and West Germany	$ 3910	$ 4914
II - Brazil, Mauritius, and Nicaragua	$ 336	$ 457
Ratio: [I/II]	∿ 11.6 : 1	∿ 10.7 : 1

[a]Constant 1970 U. S. dollars

[b]Approximately

Source: Leontief, W., Carter, Ann P., and Petri, Peter A., "The Future of the World Economy, A United Nations Study." New York: Oxford University Press, 1977.

(i) Slow real growth of the economy of the developed nations during the last quarter of this century.

(ii) Less dependency of the LDCs upon developed nations as far as food and energy are concerned.

(iii) Larger capital flow from the developed nations into the LDCs in the form of aids and investments.

(iv) Greater technological assistance to the LDCs from developed nations.

(v) Increases in the price of raw materials supplied by LDCs to developed nations.

Based upon the above discussion, Figure II-1 and Table II-2 illustrate two extreme situations that might be experienced by both categories of nations in the process of trying to close the economic gap during the next 100 years. In the first situation an average real annual GNP per capita growth rate of 2% in the developed nations is assumed, and similarly an average real annual GNP per capita growth of the order of 4 to 5% per year is assumed for the LDCs. In the second situation, even if the developed nations were to completely stop economic growth, a sustained real economic growth of 2 to 2.5% would still be required in the LDCs in order to close the gap. Both the above situations represent a real dilemma for the LDCs.

In addition to the above arguments, the method and assumptions described in the next section have been used for the estimation of economic development trends of the selected countries.

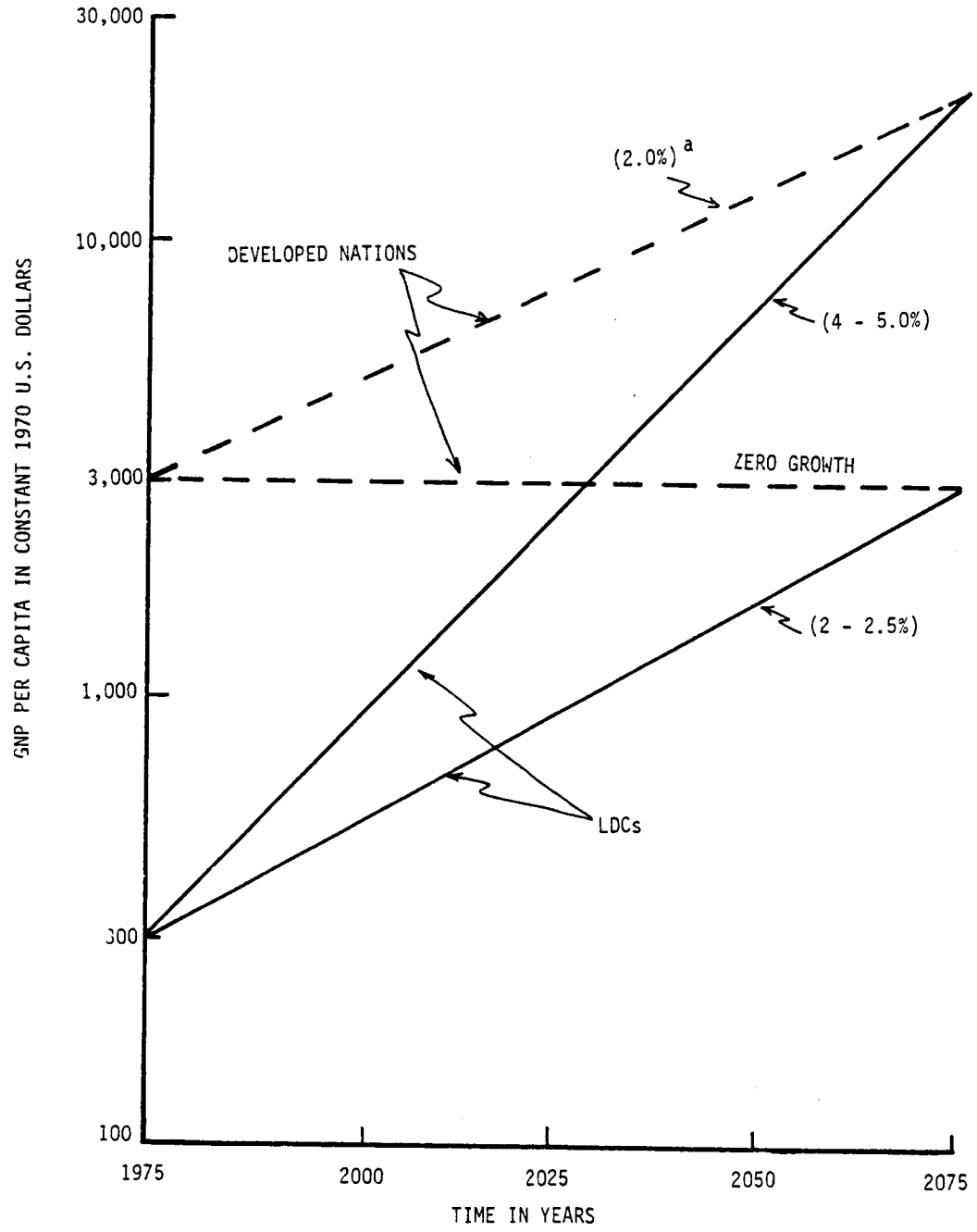


FIGURE II-1. COMPETITIVE ECONOMIC DEVELOPMENT, DEVELOPED NATIONS AND LDCs

[a]Average annual growth rates.

TABLE II-2

COMPETITIVE ECONOMIC DEVELOPMENT 1975-2075
DEVELOPED NATIONS AND LDCs

Year	Ratio GNP/Capita Developed Nations/LDCs	First Senario - GNP Per Capita in Constant 1970 U. S. Dollars		Second Senario - GNP Per Capita in Constant 1970 U. S. Dollars	
		Developed Nations	LDCs	Developed Nations	LDCs
1975	10:1	3000	300	3000	300
2000	5.5:1	5560	890	3000	520
2025	3.2:1	8075	2500	3000	940
2050	1.8:1	13248	7500	3000	1675
2075	1:1	21734	21734	3000	3000
Average Annual Growth Rates		2.0%	4-5%	0%	2-2.5%

C. Method Used for Estimation of Economic Development Trends

1. Description of Method

The method used here is based on the following definition of GNP.

$$GNP = F[H, P, L]^*$$

where: GNP = Total Gross National Product

H = Number of hours worked/year/employee

P = Productivity in terms of dollars/year/employee

L = Total number of employees (men and women)

The number of working hours per week has decreased from 50-55 hours to 40 hours during the first two quarters of the century[13] in the world's industrialized countries. This figure of 40 hours per week, which is socially accepted over the world, has remained almost constant during the third quarter of the century. The number of working weeks per year has been assumed to be 50. However, it is recognized that in practice it is slightly less. Thus, for calculation purposes H is considered to remain constant during the last quarter of the century, which means the relationship can be further simplified to:

$$GNP = F[P, L]^*$$

The GNP then becomes simply a product of productivity and labor force.

$$GNP \left[\frac{\$}{Year}\right] = P \left[\frac{\$}{Year\ Employee}\right] X\ L\ [No.\ of\ Employees]$$

---

*It must be noted that GNP is a function of the quality and quantity of the factors of production (land, labor and capital). However, for the purpose of this study GNP has been linked to labor and its productivity only.

If the productivity and labor force can be estimated, the total GNP of a nation also can be estimated. The steps involved in the application of this equation are listed below:

(i) Population estimation and calculation of labor force based upon the percentage of population that goes into the labor market.

(ii) Calculation of productivity based on historical data or on assumptions discussed below.

(iii) Calculation of total GNP from L and P.

2. Comments on Labor Force and Productivity

a. Labor force

The supply of labor in a nation depends upon the population, its growth rate and its age distribution. The portion of the available labor force that can be absorbed depends upon capital investment, the nature of the nation's commerce and industry, i.e., whether it is agricultural or industrial, technological advancements, and many other factors such as level of education, health systems, and other social service policies. Thus, to estimate the future supply and demand of the labor force, each sector, e.g., industrial, agricultural, transportation, social services, and many others, must be analysed carefully. At the same time, the technological advancements must also be looked into. It means that this approach becomes very complex. Since this type of detailed analysis of labor supply and demand is beyond the scope of this dissertation a simple method has been used to estimate the labor force supply and utilization in the selected countries.

The method is based upon the following:

(i) As the net population growth rate, crude birth rate less crude death rate, is greater than zero, or the replacement level, the percent of the population in the age group of 15 through 64 years will slowly but steadily decline, i.e., the relationship is an inverse one. Conversely as the net population growth rate decreases the percent of population in the age group of 15 through 64 years increases. Only when the net growth rate is zero will the available labor force as a percentage of the total population remain constant. If the labor force as a percentage of the age group 15 through 64 years is assumed to be constant, it will change directly as the size of these age groups. This relationship is evident when the age distribution figures for the U. S., obtained from the U. N. population study,[14] are considered. It can be seen from Table II-3 that the percentage of population between the ages of 15 and 64 would remain more or less constant at around 66%. This means that the supply of labor would tend to remain almost a constant percentage of the whole population. On the other hand, for countries where the population growth rate is still fairly high, the age distribution keeps changing. This is obvious in the case of Nicaragua, as shown on Table II-4, which shows that from 1985 to 2000 there would be an increase in the proportion of population aged 15 to 64 from 50% to roughly 54%. Thus, the labor supply as a percentage of the population will also increase.

TABLE II-3

U. S. AGE DISTRIBUTION

Year	Population Growth Rate (%)	Proportion of Population Aged 0-4	5-14	15-64	65+
1970	1.45	8.4	19.9	61.9	9.8
1985	1.01	8.7	15.2	65.1	11.0
2000	0.65	7.2	15.3	66.5	10.8

Source: U. N., Department of Economic and Social Affairs, "World Population Prospects as Assessed in 1973, Population Studies No. 60," U. N., New York. 1977.

TABLE II-4

NICARAGUA AGE DISTRIBUTION

Year	Population Growth Rate (%)	Proportion of Population Aged 0-4	5-14	15-64	65+
1970	3.26	19.3	27.2	41.0	2.4
1985	3.27	18.6	29.0	50.0	2.4
2000	3.06	16.6	27.3	53.7	2.4

Source: U. N., Department of Economic and Social Affairs, "World Population Prospects as Assessed in 1973, Population Studies No. 60," U. N., New York. 1977.

(ii) Industrialization and expansion of agriculture and other sectors have their limitations, and it appears that countries such as the U. S. and West Germany are asymptotically approaching their limits. This means that there would be only a slight increase in labor demand in these countries in the future, only enough to absorb the low increase in the labor supply. This suggests that labor employed as a percentage of the population will tend to remain constant at about 40% as shown by historical data of the U. S. and West Germany. In the LDCs, if the goal for closing the economic gap as discussed in Section B is to be achieved, increase industrialization, agricultural development for food production and improvement of social services probably will be required. All these developments would imply an increase in the demand for labor force and this would translate into an increase in the percentage of population being employed. Though it is recognized that at present serious unemployment problems are being experienced in many LDCs, the increasing growth of labor demand, as a result of efforts toward economic growth, is used for GNP estimation as illustrated in Subsection C-3.

(iii) Historical data on the percentage of population employed during the last 25 years also is used as a basis for the labor force estimates. The estimating method and additional assumptions for the individual countries are discussed in Subsection C-3.

b. Productivity

There are several ways of measuring productivity of an employee.[15] For example, in the tea industry the productivity can be measured in terms of tea produced per employee per year. In the automobile industry it can be expressed as the number of cars produced per employee per year. Basically, it amounts to a measure of the ratio of material output to labor input. As far as the labor input is concerned this can be measured in terms of number of employee-hours used.

Since a 40-hour week has been assumed as pointed out earlier and the number of working-weeks per year has been considered constant, the labor input can be measured in terms of number of employees engaged during the whole year. The labor output is measured in terms of GNP (constant 1970 dollars) per year instead of material units as discussed above. Thus the productivity as discussed here is expressed as follows:

$$\text{Productivity} = \frac{\text{Total GNP (constant 1970 dollars)/year}}{\text{Total number of employees}}$$

Units of Productivity = dollars/year/employee

It would certainly be more accurate to consider number of hours, and number of working days per year for productivity calculations, but limitations of data have made it impossible. Productivity as discussed here should be differentiated from efficiency of an employee. Efficiency can be measured and be meaningful only when two exactly parallel situations are considered. For example, the employee efficiency of two refineries can be compared only when both have the same type of equipment and automation, treating the same type of crude oil, producing the same products and operating in the same kind of environmental and climatic conditions.

Productivity also is a function of several other factors such as capital formation, scale of production, climatic and soil condition in the agricultural sector, geographical size and location of the nation, technological advancement, and many others. Considering all these factors for productivity estimates increases the complexity of the method to a degree not considered necessary in this dissertation.

Thus, in addition to the historical trends, the concept of closing the economic gap between the LDCs and developed nations discussed in Section B is taken into account for the estimation of reasonable ranges of future productivity trends. Further assumptions for the selected countries are discussed below.

3. GNP Estimations for Selected Countries

a. U. S. and West Germany

Since the population annual growth rates of these two developed nations are likely to remain below one percent, as discussed in Chapter I, the age distribution will remain reasonably stable during the next 25-35 years. Moreover, the historical data for both nations show that the percentage of population fully employed has remained almost constant[16] at 40%. Thus by using this constant percentage of population employed and the three levels of population projections of the previous chapter, three possible sizes of labor force that would be available during the next 35 years have been estimated.

As for the productivity shown on Figure II-2 and in Table II-5 two levels of growth have been assumed. For the first level of growth, it has been assumed that the historical annual real growth of 1.7% for the U. S. during the period of 1950 to 1975 would be sustained until

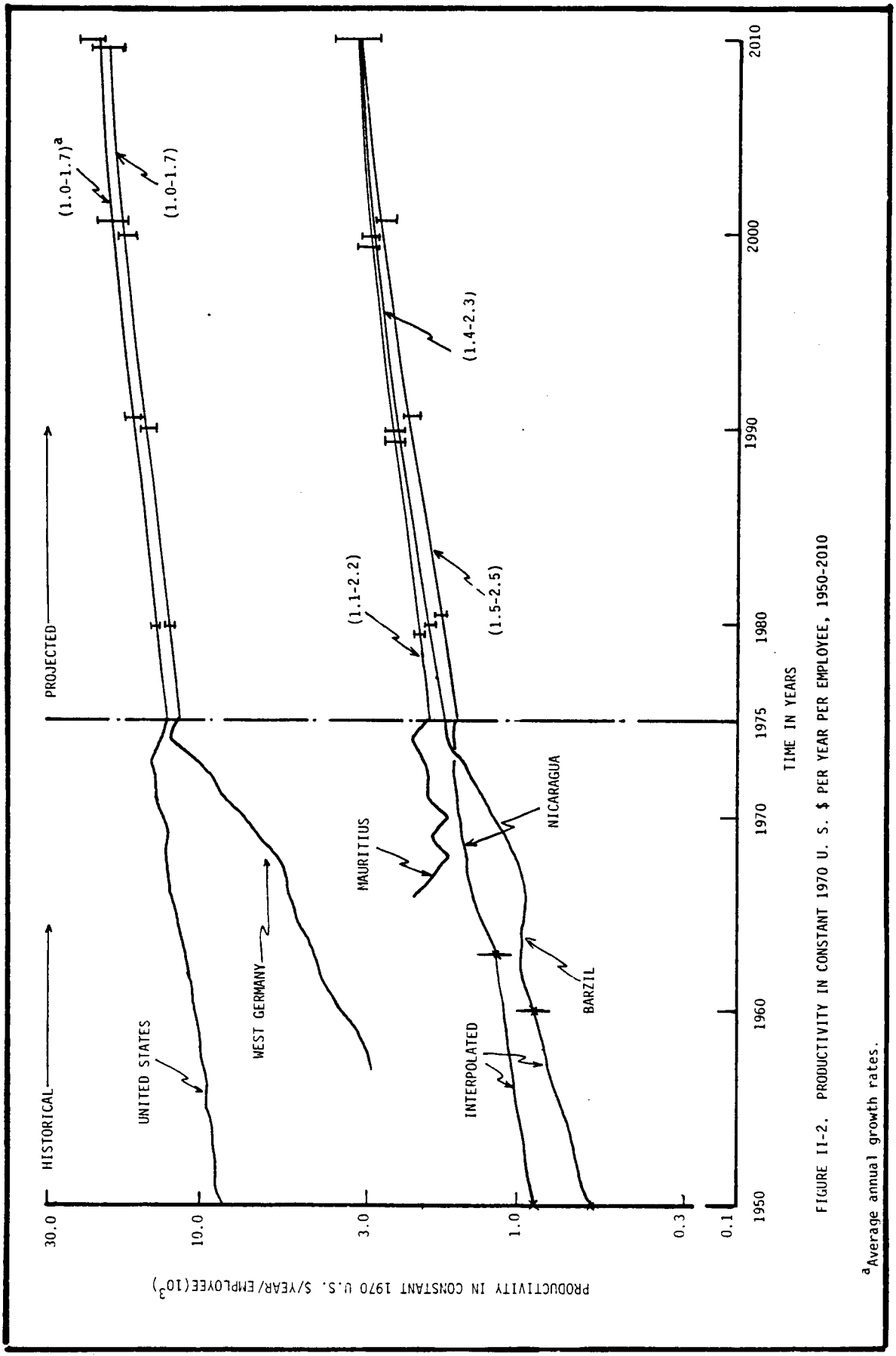


FIGURE II-2. PRODUCTIVITY IN CONSTANT 1970 U. S. $ PER YEAR PER EMPLOYEE, 1950-2010

[a]Average annual growth rates.

TABLE II-5

PRODUCTIVITY IN 1970 U. S. DOLLARS PER YEAR PER EMPLOYEE 1950-2010

Year	U. S.		West Germany		Brazil		Mauritius		Nicaragua	
Historical										
1950	8310		-		580		-		800	
1960	10030		3530		850		-		-	
1970	12390		7110		1170		1680		1490	
1975	12870		11830		1680		1890		1610	
Assumed	High	Low	High	Low	High	Low	High	Low	High	Low
1980	14000	13530	12870	12430	1884	1803	2084	1994	1817	1738
1990	16570	14940	15230	13730	2370	2075	2535	2220	2313	2025
2000	19620	16500	18030	15170	2981	2389	3083	2471	2945	2360
2010	23220	18230	21340	16760	3750	2750	3750	2750	3750	2750

the end of the century, which means that the productivity would go from 12,870 constant 1970 dollars/employee/year in 1975 to 23,220 constant 1970 dollars/employee/year in 2010. The second level of growth has been based on arguments that high inflation rates, energy supply limitations, energy conservation strategies, and other factors might reduce the historical productivity growth rate. This second assumption leads to a lower level of productivity growth of roughly 1% per year which means a moderate increase from 12,870 constant 1970 dollars/employee/year in 1975 to 18,230 constant 1970 dollars/employee/year in 2010. For West Germany it has been assumed that similar trends are likely to occur.

b. Brazil, Mauritius and Nicaragua

Table II-6 shows that the labor force represented as a percentage of population has been in the region of 30% for Brazil[17] and Nicaragua during the last 25 years. In Mauritius[18] it has been increasing gradually from 14% in 1968 to 20% in 1978. Using these historical data and the comments made on labor markets in the LDCs as well as in the industrialized nations, it has been assumed that the above percentages, 30% for Brazil and Nicaragua and[19] 20% for Mauritius, would gradually increase to 40%, which is the percentage used for the developed nations. This 40% is used as a limit for the same reason given in Subsection C-2.

The range of productivity of approximately $1,600-1,900 constant 1970 dollars per employee per year for Brazil, Mauritius, and Nicaragua is very low relative to the figures for the U. S. and West Germany. During the remainder of this century that low productivity would have to be increased considerably if the concept of closing the economic gap between the developed nations and the LDCs is to be realized.

TABLE II-6

LABOR FORCE AS A PERCENTAGE OF POPULATION 1950-2010

Year	U. S.	West Germany	Brazil	Mauritius	Nicaragua
Historical					
1950	38.0	-	32.4	-	29.8
1960	36.4	46.8	31.7	- (13.5)[a]	-
1970	38.4	43.1	31.0	13.6	27.8
1975	39.6	40.2	29.5	17.2 (19.6)[b]	28.2
Assumed					
1980	40.0	40.0	31.4	19.4	31.4
1990	40.0	40.0	34.2	26.3	34.2
2000	40.0	40.0	37.1	33.1	37.1
2010	40.0	40.0	40.0	40.0	40.0

[a]For the year 1966.

[b]For the year 1978.

The requisite range of productivity growth rates in the LDCs to accomplish complete closure within 100 years has been derived from the U. S. and German growth ranges by the following process. Extrapolation of the 1.7% and 1.0% annual growth figures for the industrialized countries to the year 2075 establishes the high and low "goals" for full closure. Constant annual growth rates from 1975, the most recent historical year used, to 2075 are then plotted as a straight line on semilog paper to connect with those high and low goal points.

The present dissertation is limited however to a consideration of the next 35 year time frame, through the year 2010. The figure obtained by the above method indicates closure of the economic gap to 5:1 to 7:1 by 2010 if all of the postulated growth rates, which are believed to be based upon reasonable assumptions exclusive of catastrophic events, are realized. The 2010 benchmark figure thus, is a figure derived from the 100 year closure assumption. Refer to Figure II-2 and Table II-5 for further illustration of these data.

The combination of the three possible sizes of labor force estimated and the two levels of productivity assumed result in six levels of total GNP estimates. The results are summarized and discussed in the next section.

D. Results and Discussion

Appendix A includes historical data on productivity, labor force, GNP and GNP per capita for the U. S., West Germany, Brazil, Mauritius, and Nicaragua covering the period 1950-1975, as well as the results of the extrapolation period of 1975-2010 obtained from the calculations carried out according to the various assumptions discussed in Sections B

and C of this chapter. For discussion purposes the results for GNP and GNP per capita are illustrated graphically in Figures II-3 and II-4.

The range of average annual growth rates of 1.5-2.5% of the GNP for the U. S. from 1975 through 2010 may seem low when compared to 3.3% for the historical period 1950-1975. According to Denison's (1974)[11] analysis of the U. S. economy, mentioned earlier, almost two-thirds of the growth rate in GNP of the U. S. was due to growth in the labor force and one third due to growth in productivity (it must be recognized that availability of capital was not limited as it is the case in the LDCs). Thus, taking into account that the growth rate of the labor force is likely to drop from 1.54% for 1950-1975 period to the neighborhood of 0.7% for the 1975-2010 period, because of slower growth in population, the above low growth rates in GNP, which would be due primarily to increase in productivity, are quite possible. Moreover, during the last quarter of the century, the U. S. will have to do with limited domestic natural resources as compared to the third quarter, i.e., 1950-1975, when domestic natural resources were more readily available. Because GNP per capita also is a measure of productivity, its growth rate would still be comparable to the historical growth rate, i.e., a range of average growth rates of 1.0-1.7% for the 1975-2010 period compared to 1.9% for the 1950-1975 period.

For West Germany similar assumptions suggest that the range of average annual growth rates in GNP from 1975 through 2010 is likely to be 1-2% which is lower than the historical growth rate of 10.3% for the 1950-1975 period. By analogy to the U. S. these growth rates seem reasonable. Moreover, the high growth rate of 10.3% during the

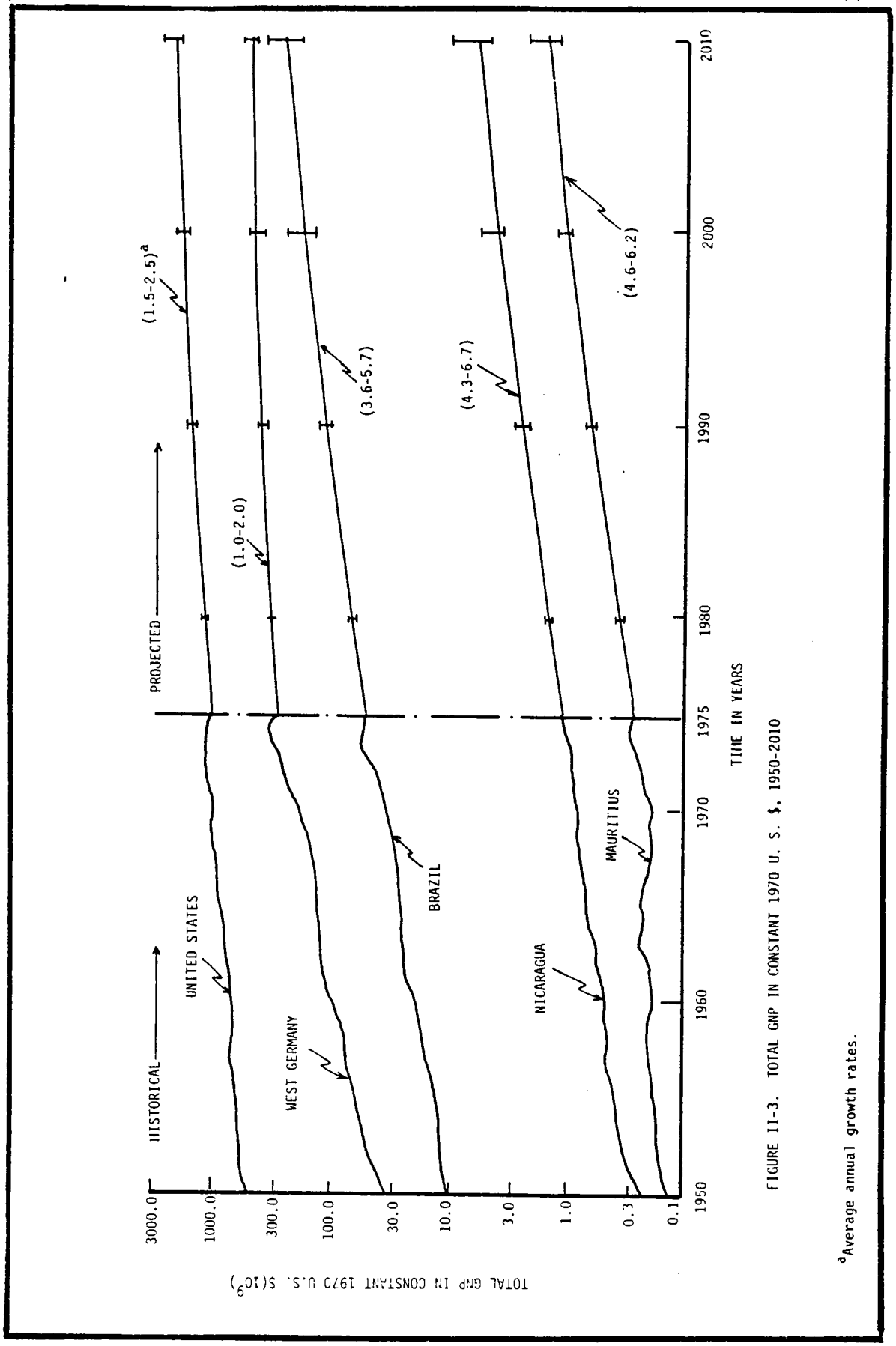


FIGURE II-3. TOTAL GNP IN CONSTANT 1970 U. S. $, 1950-2010

[a]Average annual growth rates.

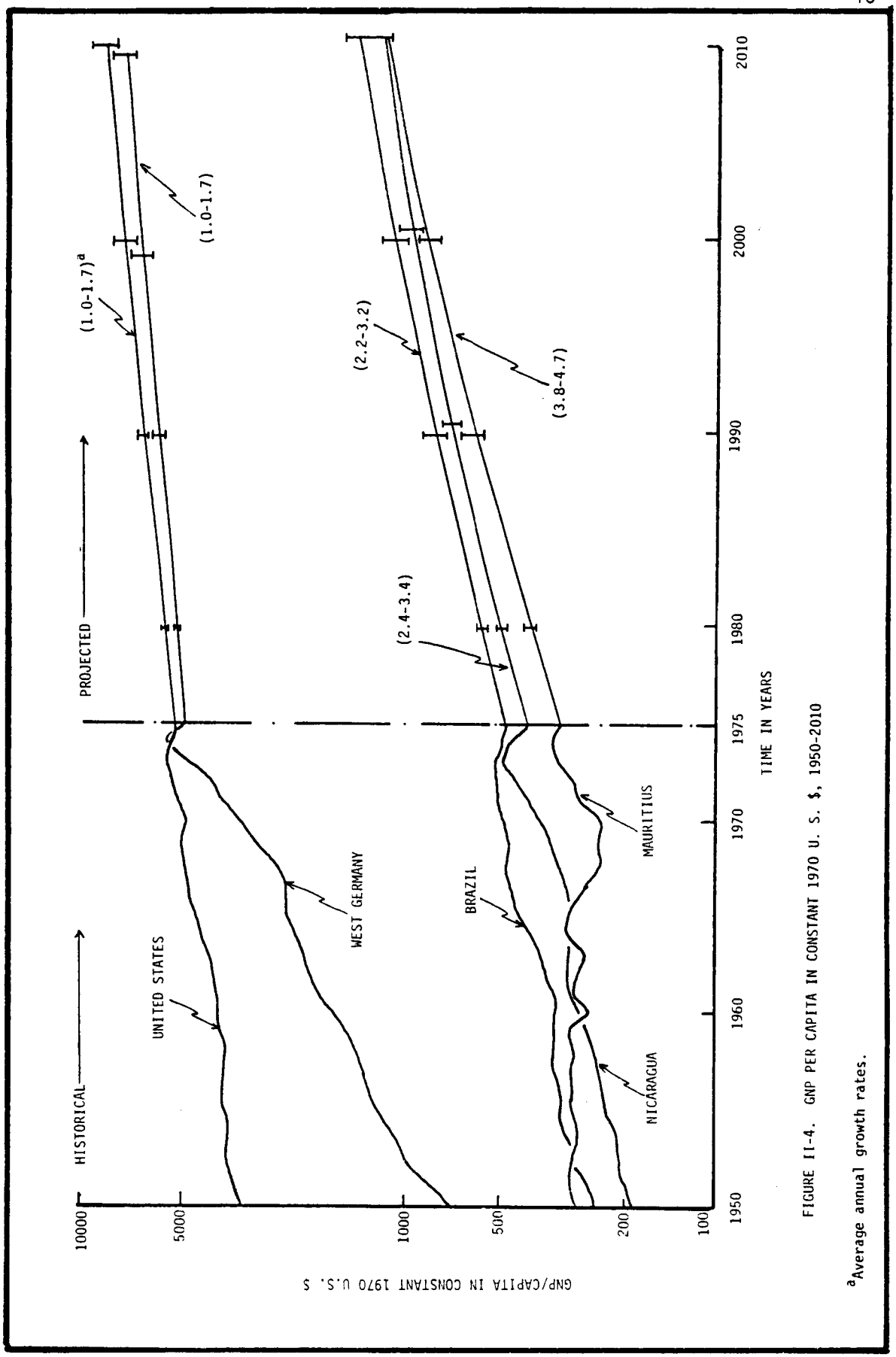


FIGURE II-4. GNP PER CAPITA IN CONSTANT 1970 U. S. $, 1950-2010

[a]Average annual growth rates.

1950-1975 period can be attributed to the fact that West Germany was being rebuilt following the Second World War and assistance from several parts of the world was provided for that process. The GNP per capita, a measure of productivity, also is likely to grow in the range of 1.0-2.0% annually for the period covering 1975-2010.

In the case of the LDCs, the calculations based on the labor force and productivity assumptions show average annual growth rates of GNP in the range of approximately 2.5-8.0% for the period 1975-2010. Though these growth rates in GNP do not seem high when compared to the historical growth rates of especially Brazil and Nicaragua, they are certainly much higher than those projected for the developed nations for the same period. As mentioned earlier these are the consequences of other assumptions related to population growth and the need to close the economic gap.

Table II-7 compares the GNP per capita figures of the developed nations, the U. S. and West Germany, with those of the LDCs, Brazil, Mauritius and Nicaragua for the period through 2010. Historical data[20] were shown in Table II-1, page 27. If the assumed growth rates in productivity and labor force are maintained, the ratio of GNP per capita of the developed nations to that of the LDCs would be in the region of 5:1 to 7:1 by 2010 compared to roughly 10:1 in 1975. For comparison purposes, Table II-7 also includes the U. N. ratios[21] of GNP per capita of the developed nations as a whole to that of all the LDCs of the world.

It is important to reemphasize that the GNP and GNP per capita trends estimated in this chapter do not represent economic development projections in the real sense. Rather, they represent the economic trends which need to be sustained by the LDCs if the economic gap

TABLE II-7

COMPARISON OF GNP PER CAPITA
[CONSTANT 1970 U. S. $]

	Average GNP/Capita 1975	Average GNP/Capita 2010	
		High	Low
From Assumptions Used in the Study			
I - Selected Developed Nations			
Average GNP/Capita-U. S. and West Germany	$[a] 4914	$8910	$7000
II - Selected LDCs			
Average GNP/Capita-Brazil, Mauritius and Nicaragua	$[b] 457	$1500	$1100
Ratio [I/II]	∿ 10.7:1	∿5.9:1	∿6.4:1
U. N. Estimates			
Ratio [All Developed Nations / All LDCs]	∿ 10:1	7:1[c]	

[a]Constant 1970-U. S. dollars.

[b]Approximately.

[c]Refers to the year 2000.

Source: Leontief, W., Carter, Ann P., and Petri, Peter A., "The Future of the World Economy , A United Nations Study." New York: Oxford University Press, 1977.

vis-a-vis the developed nations is to be closed at reasonably realistic rates. Moreover, in this study capital and land,[22] which are the major parameters associated with GNP projections, have not been considered. In Chapter III the economic trends derived in this chapter has been used to analyze the implications for long range energy supply and demand.

CHAPTER III

ENERGY DEMAND

A. General Discussion

An analysis of historical data for the past several decades shows a consistent correlation in individual countries over time between annual gross energy consumption and annual GNP (or GDP) in constant dollars. The correlation factor, E/GNP (also referred to as the energy-GNP ratio), as well as the upward or downward trend in the correlation factor with time, varies from one country to another. The many technical, economic, and social forces which determine the correlation factor in individual countries are only partially understood. Various energy demand models which have been developed during recent years in the U. S. and elsewhere include attempts to develop better understandings of this correlation in both a sectoral and an aggregate sense.

Basically there are two types of energy demand models, the Sectoral Energy Demand Model and the Aggregate Energy Demand Model. The major difference between the two models is that the first projects the energy that would be required by the primary consuming sectors, i.e., residential, commercial, agricultural, industrial, and transportation; whereas, the second model projects only the total energy that would be required by the nation as a whole. One of the potential advantages of the first model over the second is that its results can be used for the calculation of the types of energy carriers, i.e., solid, liquid, gas and electricity that would be required. This is much more difficult when dealing with the second model. The Sectoral Energy Demand Model

also allows one to examine energy/economic relationships in various sectors of the economy, and this is a more powerful tool in long range economic development planning of a country. The aggregate modeling approach is used, however, when the absence or unreliability of sectoral data preclude the use of the more disaggregated modeling method.

In the U. S., where adequate data on the economy, labor force, employment and total energy, as well as energy consumption by various primary consuming sectors are available, sectoral energy demand models have been developed by the Institute for Energy Analysis[23] (IEA) and other groups, for example, the United States Energy Model of Brookhaven National Laboratory,[24] the MIT Model of Poleske,[25] the University of Illinois Model of Hannon and Herendeen,[26] and the Texas State Model.[27] This method is described briefly in Section B using the IEA model as an example, and its results also are included for comparison purposes.

On the other hand in the case of the LDCs, because of lack of data, an Aggregate Energy Demand Model, which is described in Section C, has been developed. This model is used to estimate a range of energy demands that would be associated with the population and economic development trends estimated in the previous chapters for the selected LDCs. In order to check its validity, the Aggregate Energy Demand Model also is used to estimate the future energy demand range for the U. S. and the results are compared to those of the IEA Model. As mentioned in the previous chapters such models are not prophetic; rather they are oriented toward developing better insights into the relationships among the various factors which determine current and future energy demand.

B. Brief Description of the IEA Sectoral Energy Demand Model

The IEA Sectoral Energy Demand Model,[23] which is in reasonable agreement with other principal sectoral models, is described briefly in this section. The major steps involved the following:

(i) GNP was first projected based on the fact that GNP is generated as a result of the labor force and its productivity. First, the labor force was estimated from two levels of population projections which were carried out assuming a high level of fertility growth of 1.9 children per woman and a low level of fertility growth of 1.7 children per woman. Second, the productivity was assumed to grow at historical rates illustrated in Table III-1.

(ii) The energy demand was projected in two parts. The first part was directly related to GNP and included the industrial and transportation (of goods) sectors. The second part was directly related to population and included energy demand by households, commercial, and automobile sectors.

(iii) The growth rates of these consuming end sectors were projected and energy consumption calculated based on the magnitude of these sectors.

(iv) Total energy was then calculated by summing the energy demands of each of the consuming end sectors as shown in Table III-2.

From the results on total energy required by each of the four primary consuming sectors given in Table III-2, the various types of energy carriers that would be required were estimated by taking the following factors into consideration:

TABLE III-1

IEA-SECTORAL ENERGY DEMAND MODEL - UNITED STATES
POPULATION, LABOR FORCE AND GNP GROWTH

Year	Population 10^6		Labor Force 10^6		GNP 10^9 Constant 1975 Dollars		Percent Annual Growth	
	Low	High	Low	High	Low	High	Low	High
1975	213	213	95	95	1499	1499		
1975-1985							3.6	3.6
1985	228	231	110	110	2135	2135		
1985-2000							2.7	3.0
2000	245	254	123	124	3184	3326		
2000-2010							2.5	3.0
2010	250	264	128	132	4076	4470		

Source: Weinberg, A. M., et al., "U. S. Energy Demand and Economic Growth, 1975-2010," Institute for Energy Analysis, Oak Ridge Associated Universities, Oak Ridge, Tennessee, 1976.

TABLE III-2

IEA-SECTORAL ENERGY DEMAND MODEL - UNITED STATES
IN 10^{15} BTU

Year	Total		Household		Commercial		Transportation		Industrial	
	Low	High	Low	High	Low	High	Low	High	Low	High
1975	71.1	71.1	15.8	15.8	9.3	9.3	18.6	18.6	27.4	27.4
1985	82.1	88.0	17.2	19.3	10.2	11.8	19.2	21.4	35.5	35.5
2000	101.4	125.9	18.0	24.3	10.9	15.4	22.2	28.1	50.3	58.1
2010	118.3	158.8	17.7	26.8	10.8	17.9	25.3	33.9	64.5	80.2

Source: Weinberg, A. M., et al., "U. S. Energy Demand and Economic Growth, 1975-2010," Institute for Energy Analysis, Oak Ridge Associated Universities, Oak Ridge, Tennessee, 1976.

(i) The transportation sector would require liquid fuel only.

(ii) The commercial and household sectors would require a combination of natural gas and electricity produced primarily from coal, hydro and nuclear power.

(iii) The industrial sector would require energy from all the types of carriers, i.e., solid, liquid, gas, and electricity.

The results of these estimates are summarized in Table III-3.

It must be noted that the above estimates of the types of energy carriers required are useful in making decisions about various energy resources that would need the most attention in the future. This means that results from a sectoral energy demand model are more helpful to economists, engineers, and policy makers than results from the aggregate model which gives only the total energy required. Unfortunately, as mentioned earlier, it is not always possible to develop a sectoral model for LDCs due to unavailability or unreliability of data.

For example in the LDCs, the historical data on energy consumed by various consuming end sectors are almost non-existent. Thus, for the purpose of this study the Aggregate Energy Demand Model as discussed in the next section has been developed.

C. Aggregate Energy Demand Model

This section illustrates the aggregate modeling approach developed in this dissertation work and used to arrive at an acceptable Aggregate Energy Demand Model for better understanding of the relationship between future energy demand, economics, and population growth in the LDCs. The major steps associated with this modeling approach are listed below:

TABLE III-3

SUMMARY OF FUEL TYPES REQUIRED - UNITED STATES
IN 10^{15} BTU

Year	Coal		Oil		Gas		Electricity		Total	
	Low	High	Low	High	Low	High	Low	High	Low	High
1975	4.6	4.6	29.4	29.4	17.0	17.0	20.1	20.1	71.1	71.1
1985	6.2	6.2	25.8	27.5	18.7	19.6	30.8	34.1	82.1	88.0
2000	10.6	11.2	27.9	35.1	13.6	13.6	47.3	64.0	101.4	125.9
2010	14.2	14.2	31.2	41.9	9.2	9.2	55.5	82.4	115.1[a]	151.7[a]

[a]Add 4.0 X 10^{15} BTU which will be supplied by solar and geothermal.

Source: Weinberg, A. M., et al., "U. S. Energy Demand and Economic Growth, 1975-2010," Institute for Energy Analysis, Oak Ridge Associated Universities, Oak Ridge, Tennessee, 1976.

(i) Probable range of population growth rates has been estimated using a modified version of the U. N. population model (refer to Chapter I).

(ii) Labor force has been estimated as a percentage of the population based on historical data and other factors explained in Chapter II.

(iii) Labor productivity measured in terms of constant 1970 dollars of GNP per year per employee has been estimated based on historical trends. Moreover, the need to increase productivity in order to close the economic gap vis-a-vis the developed nations has been considered. High and low growth scenarios as discussed in Chapter II are used.

(iv) GNP and GNP per capita have been derived from the above assumed labor force and productivity increases, at the same time the historical trend has been taken into account. A desire to gradually decrease the gap in the ratio of GNP/capita between the developed nations and the LDCs from 10:1 in 1975 to approximately 5 or 7:1 by 2010 and probably reaching a 1:1 ratio by 2075 has been assumed.

(v) The E/GNP ratio has been extrapolated based upon a high range related to the U. S. pattern of economic development and energy management or a low range related to the West German pattern. Using the E/GNP ratio and the GNP the total energy required is calculated.

The first step has been discussed in detail in Chapter I, the second, third, and fourth steps in Chapter II, and the fifth step which

needs further elaboration is dealt with in this section. Some potential advantages and limitations of the Aggregate Energy Demand Model are also included.

1. Energy-GNP Ratio

The E/GNP ratio measures the total energy requirement for the creation of a constant dollar of GNP, or the energy utilization efficiency.[28] From Figure III-1 which shows the historical plots of this ratio for the five selected countries, i.e., the U. S., West Germany, Brazil, Mauritius, and Nicaragua, the decreasing trends for the U. S. and West Germany and the increasing trends for Brazil, Mauritius, and Nicaragua are obvious. The very slight but fairly steady decrease in the ratio of the U. S., i.e., from 71,000 in 1950 to 64,000 (BTU per constant 1970 dollar) in 1975 may be explained by improvements in the efficiency of energy use and recent conservation efforts. Moreover, due to shifts in the U. S. economic structure during the recent years, service sectors which are less energy intensive than the manufacturing sectors have become a larger part of the economy. The dramatic decrease, 103,000 in 1950 to 32,000 (BTU per constant 1970 dollar) in 1975 in the ratio for West Germany may be attributed in part to the more modern facilities which came after the Second World War when Germany was being rebuilt; to a smaller geographical area; to variations in residential and commercial heating and air conditioning practices; etc.

For the U. S. it has been assumed that if the strong measures for increasing efficiency of energy use and strong energy conservation policies suggested by President Carter are enforced and maintained, the slight declining trend of energy-GNP ratio would continue. This would

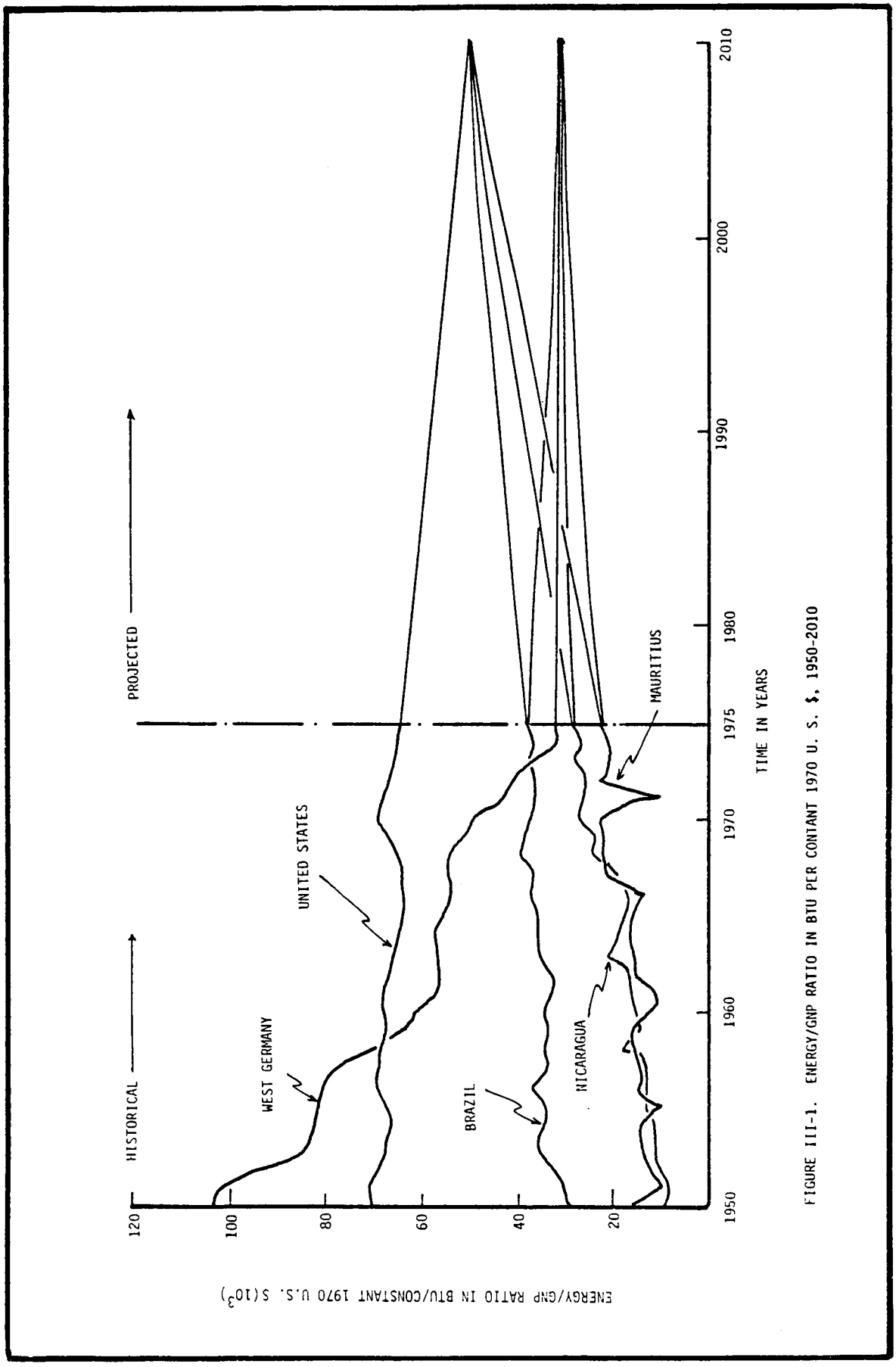


FIGURE III-1. ENERGY/GNP RATIO IN BTU PER CONTANT 1970 U. S. $, 1950-2010

result in a drop of the ratio from 64,000 in 1975 to 50,000(BTU per constant 1970-dollar) in 2010. For West Germany it has been assumed that, unless there is a dramatic change in present technology, which is very unlikely to happen in the next 30 years, the energy-GNP ratio which is already 32,000 (BTU per constant 1970 dollar) would asymptotically approach 30,000 by 2010, as illustrated in Figure III-1. The United States and West Germany have been chosen in this modeling approach because they represent two extreme cases among industrialized nations as far as energy demand per dollar is concerned, though their economic level is almost the same.

On the other hand, the increasing trends of the E/GNP ratio in the three LDCs can be explained in part by the fact that these countries are in the process of industrialization and mechanization of agriculture. It means that these countries are experiencing a shift from energy sources, i.e., man and animal power, which were not accounted for in the past, to fossil and other energy which is more easily measurable and accounted for in the nation's total energy consumption. At the same time, the shift from wood and other locally available materials, for purposes of cooking and heating, to fossil energy and electricity can be considered to contribute also. This increasing trend in the ratio which is also known as negative coupling is widespread in many LDCs and transitional countries.

In this Aggregate Energy Demand Model it has been assumed that the LDCs, in the process of closing the economic gap vis-a-vis the developed nations, would move toward the U. S. or the West German pattern of economic development and energy management. If the LDCs move toward the U. S. pattern, their ratio would approach asymptotically

that of the U. S.; whereas, if they move toward the West German pattern their ratio would approach asymptotically that of West Germany by the year 2010. The former represents a high level of energy demand and the latter a low level of energy demand. It is quite possible that the LDCs would develop a pattern of economic development and energy management of their own. In that case energy demand is most likely to be within the two extreme cases mentioned above. The process of extrapolation of the ratio has been illustrated in Figure III-1.

2. Calculation of Total Energy Demand Using the Aggregate Energy Demand Model

Using the GNP and the population results of the two previous chapters and the above E/GNP ratios, a range of total energy demands has been estimated for each of the three selected LDCs. The process is illustrated on the flow chart of Figure III-2. The units involved in the calculations are given below:

$$\text{Energy Demand } \left[\frac{\text{BTU}}{\text{Yr}}\right] = \text{GNP } \left[\frac{\text{Constant \$}}{\text{Yr}}\right] \text{ X Ratio } \left[\frac{\text{BTU}}{\text{Constant \$}}\right]^{*}$$

All the results have been included in Appendix A and summarized in the next section for discussion purposes. As pointed out earlier in this chapter, this Aggregate Energy Demand Model also has been used to estimate the aggregate energy demand for the U. S. and West Germany for comparison purposes.

D. Results and Discussion

Appendix A includes the base data[16,17,18,29] for the U.S., West Germany, Brazil, Mauritius, and Nicaragua covering the period 1950-1975 as well

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*It is recognized that the functional relationship between energy demand and GNP is more complex, however, the simplified approach has been used for the purpose of this dissertation.

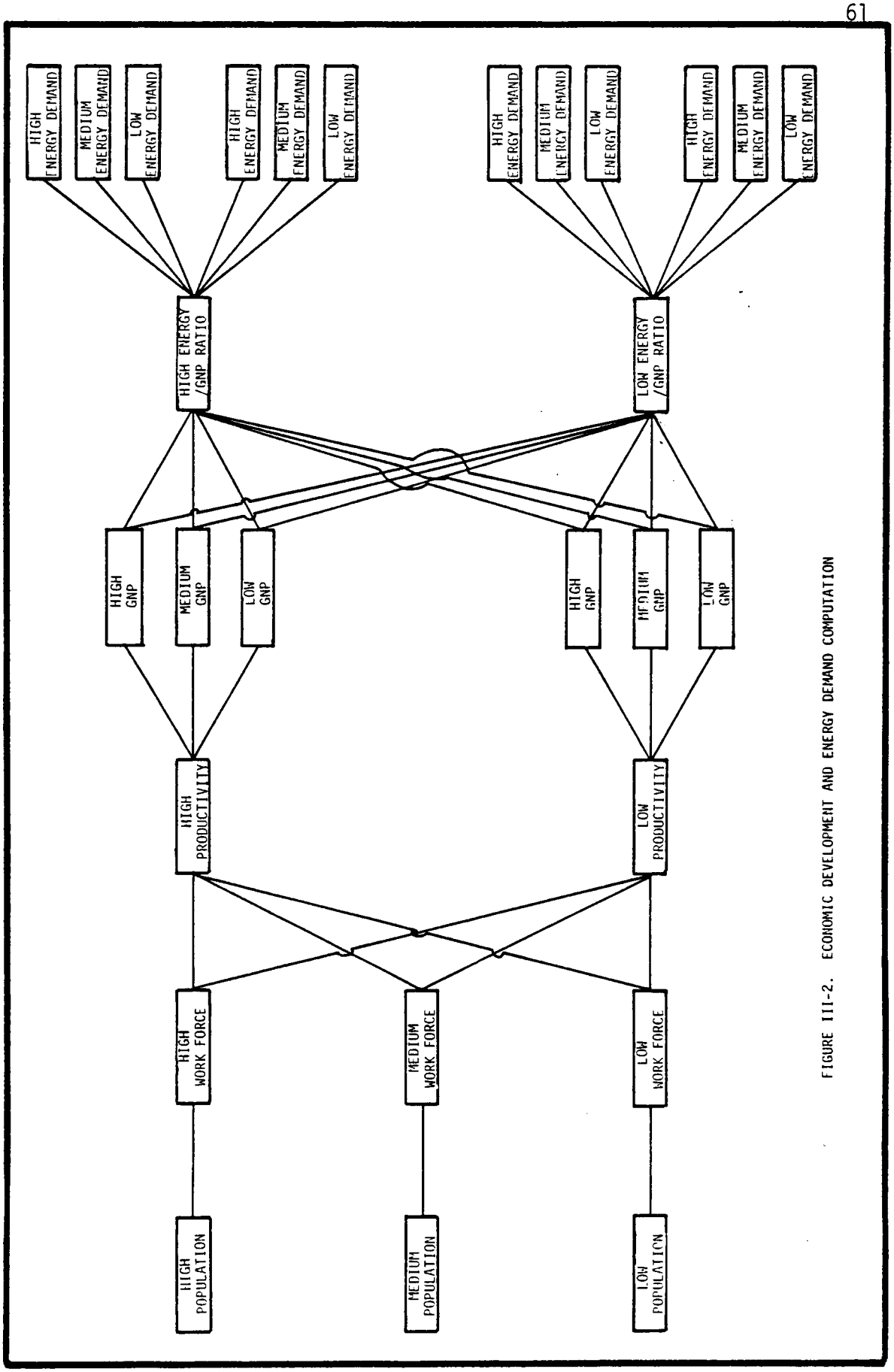


FIGURE III-2. ECONOMIC DEVELOPMENT AND ENERGY DEMAND COMPUTATION

as all of the results obtained by applying the Aggregate Energy Demand Model to these base data for the extrapolation period 1975-2010. For discussion purposes some of these results are illustrated graphically on Figures III-3 and III-4.

From Figure III-3, which illustrates the total energy demand for all the five selected countries obtained by using the Aggregate Energy Demand Model, it can be seen that the total energy demand for U. S. by 2010 would be in the range of 93 quads (1 quad = 10^{15} BTU) to 131 quads (average 112 quads) which translates into average annual growth rates of 0.8% to 1.8%. For the same period the IEA projection (see Table III-6) shows a range of 118 to 158 quads (average 138 quads) and average annual growth rates of 1.5 to 2.4%.

This means that there is a spread of ±12% in the average estimates of the total energy demand for the year 2010 between the two models, which is well within the ±17% internal variation of both the IEA and the present aggregate model. As for the average annual growth rates in energy demand, both models estimate lower than the historical (1950-1975) growth rate of 2.9 to 3.0%. This is probable if the strong conservation policies[30] and energy use efficiencies suggested for the future and discussed earlier in this chapter are taken into account. Considering the inherent uncertainty associated with such models, it is apparent that the results of the Aggregate Energy Demand Model are well within the ranges of other more detailed models. The simple nature of the model and its ability to be functional with minimum available data, which generally is the case in the LDCs, justifies its use for the estimation of energy demand for the LDCs. It is recognized, however, that the results from the sectoral models are not only more useful but at the same time they are more convincing.

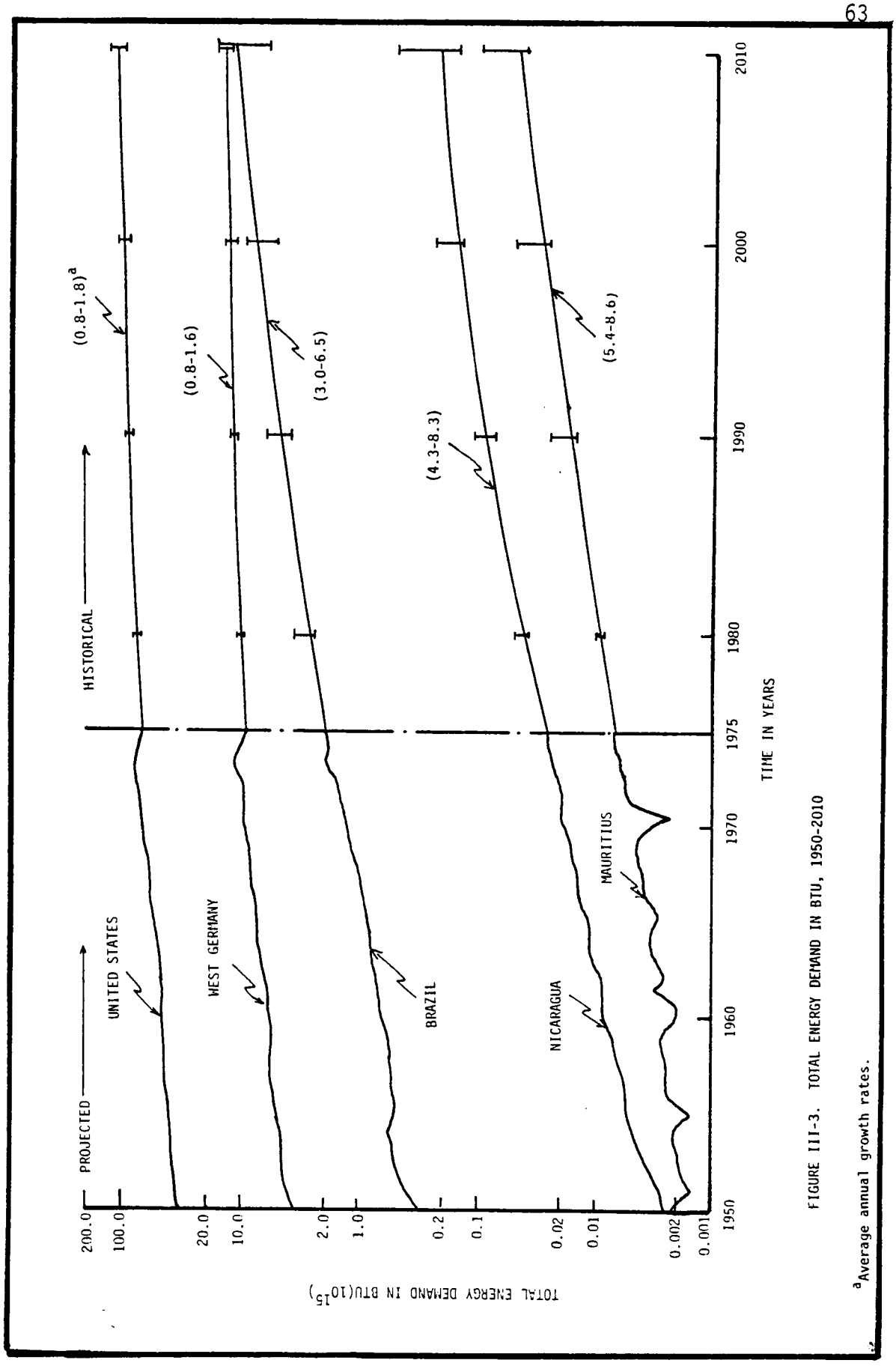


FIGURE III-3. TOTAL ENERGY DEMAND IN BTU, 1950-2010

[a]Average annual growth rates.

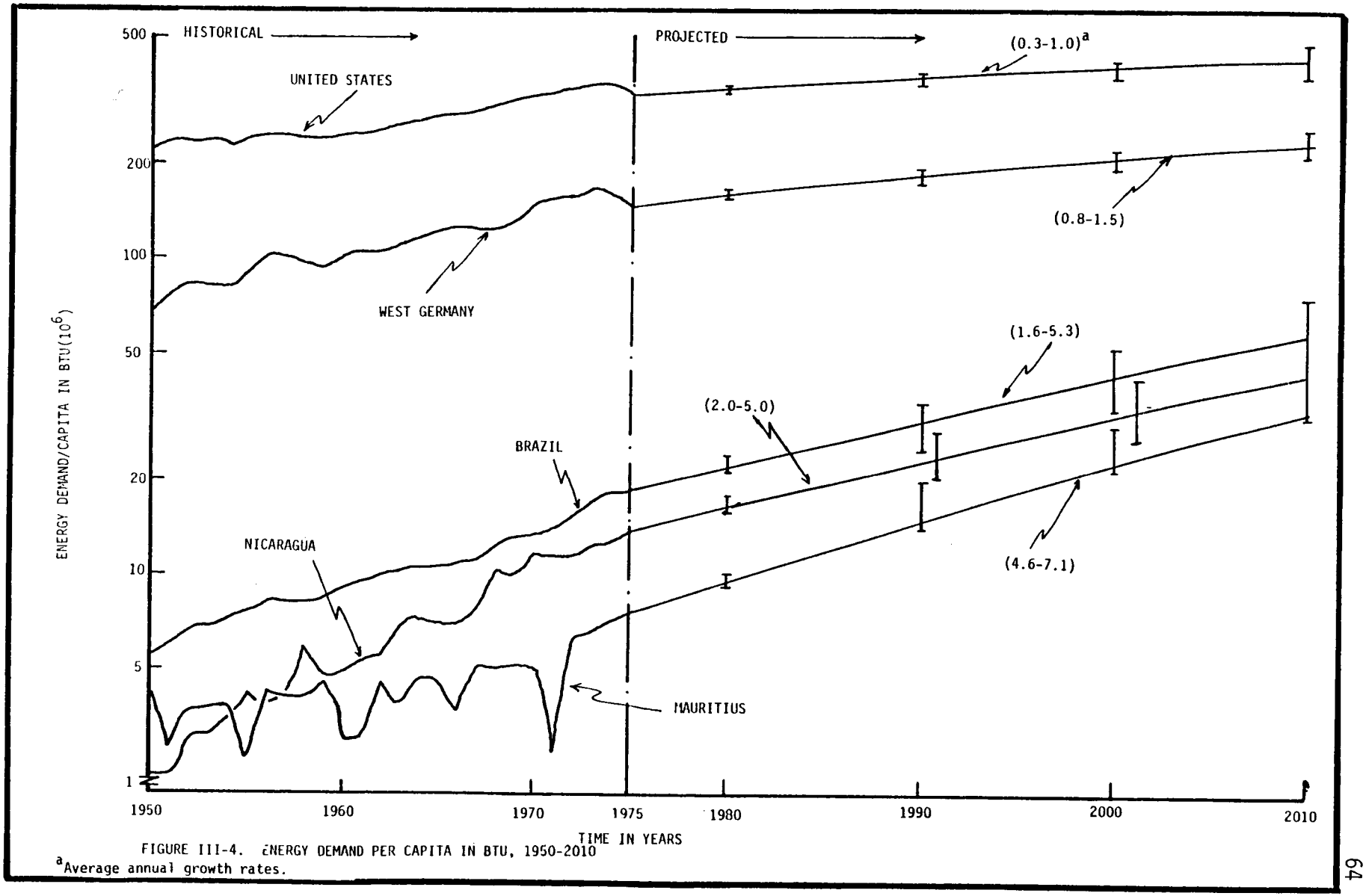


FIGURE III-4. ENERGY DEMAND PER CAPITA IN BTU, 1950-2010

[a]Average annual growth rates.

In the case of West Germany the Aggregate Energy Demand Model shows average annual growth rates in total energy demand in the range of 0.8 to 1.6% for the period of 1975-2010, compared to the average historical growth of 4.0% during 1950-1975. Unfortunately no sectoral energy projection for the same period was available for comparison purposes. It can be said, however, that a low growth in energy demand is expected for West Germany because of strong conservation efforts and low population growth.

For Brazil the model shows a range of average annual increase in energy demand of 3.0-6.5% for the period of 1975-2010 compared to a historical growth of roughly 8.0% during the period of 1950-1975. Though the growth appears comparable to the historical growth, it is quite high when compared to U. S. or West German growth rates. Nevertheless, it must be emphasized that a minimum of 3% in the annual growth rate appears to be necessary if the economic gap as discussed in Chapter II is to be closed. Similar arguments apply for Mauritius and Nicaragua where roughly a minimum of 5.5 and 4.5% in average annual growth rates in energy demand are likely during the 1975-2010 period.

As far as the per capita energy demand is concerned, the model shows average annual growth rates of 1.6 to 5.3% for Brazil, 4.6 to 7.1% for Mauritius, and 2.5 to 5.0% for Nicaragua for the period of 1975-2010. These average annual growth rates in energy demand per capita are higher than those of the two developed nations, i.e., 0.3 to 1.0% for U. S. and 0.8 to 1.5% for West Germany for the same period. Similarly, it can be argued as above, i.e., the 1.6% for Brazil, 4.6% for Mauritius, and 2.5% for Nicaragua are the minimum average annual growth rates in energy demand per capita necessary to cope with

the population and economic growth. Even with higher growth rates the per capita energy requirement in the three LDCs, compared to the energy demand per capita of the two developed nations in 2010, would still be lower as shown in Figure III-4.

If oil is to be used to meet the increasing energy demand of the U. S., West Germany, Brazil, Mauritius and Nicaragua, their dependency on countries producing the fossil fuel will increase. Especially for Brazil, Mauritius, and Nicaragua, which belong to the non-oil producing LDC group,[31] the increase in dependency on foreign fuel will be more rapid. Experience has shown on various occasions since 1973 that not only is the price of fossil fuel uncertain, increasing each time there is a meeting of the OPEC nations, but its supply also is unreliable, e.g., the Iranian case of March and November 1979. Thus, it is essential for the LDCs as well as for the developed nations to develop strategies for achieving what is commonly known in the U. S. as "Energy Independence."[32] It can be achieved only if all the locally available energy sources, more specifically renewable energy sources, are explored. There is a range of such sources, e.g., hydro, geothermal, direct or indirect solar energy sources and several other sources. It is recognized that not all the sources would be technologically or economically feasible in every case but a new look is essential. In this dissertation the use of biomass as an energy source in Brazil, Mauritius, and Nicaragua is investigated. Sugar cane and corn are used as illustrative examples.

E. Selected Scenarios for Brazil, Mauritius, and Nicaragua

From the flow chart of the Aggregate Energy Demand Model it is clear that twelve parametric values of energy demand and six parametric values of GNP for each of the selected LDCs, at intervals of five years for the period of 1975-2010 are projected. It is neither convenient to use all twelve energy demand levels and six GNP levels, nor appropriate to take an arbitrary average of all the levels. Thus, the most probable energy demand and GNP trends have been selected by analysing the possible scenarios more carefully in each of the three countries. This process is described below.

1. Brazil

Figure III-5 shows the most likely pattern to be followed by Brazil. The medium population trend which would result in a medium trend of labor supply has been chosen for the reasons already discussed in Chapter I. Because of the high annual inflation rate of 48% in the Brazilian economy,[33] it is assumed that the growth rate in GNP of Brazil would be in the lower half of the range, 3.6-5.7%, obtained from the model. Since Brazil is slightly smaller than the U. S. (compared in square miles) U. S. energy management and economic development patterns may be followed closely resulting in a high energy-GNP ratio. Furthermore, the historical trend of the ratio shows that it already has surpassed that of West Germany. This would result in an annual growth of energy demand of approximately 5% and a total energy demand of 12.5 quads by 2010.

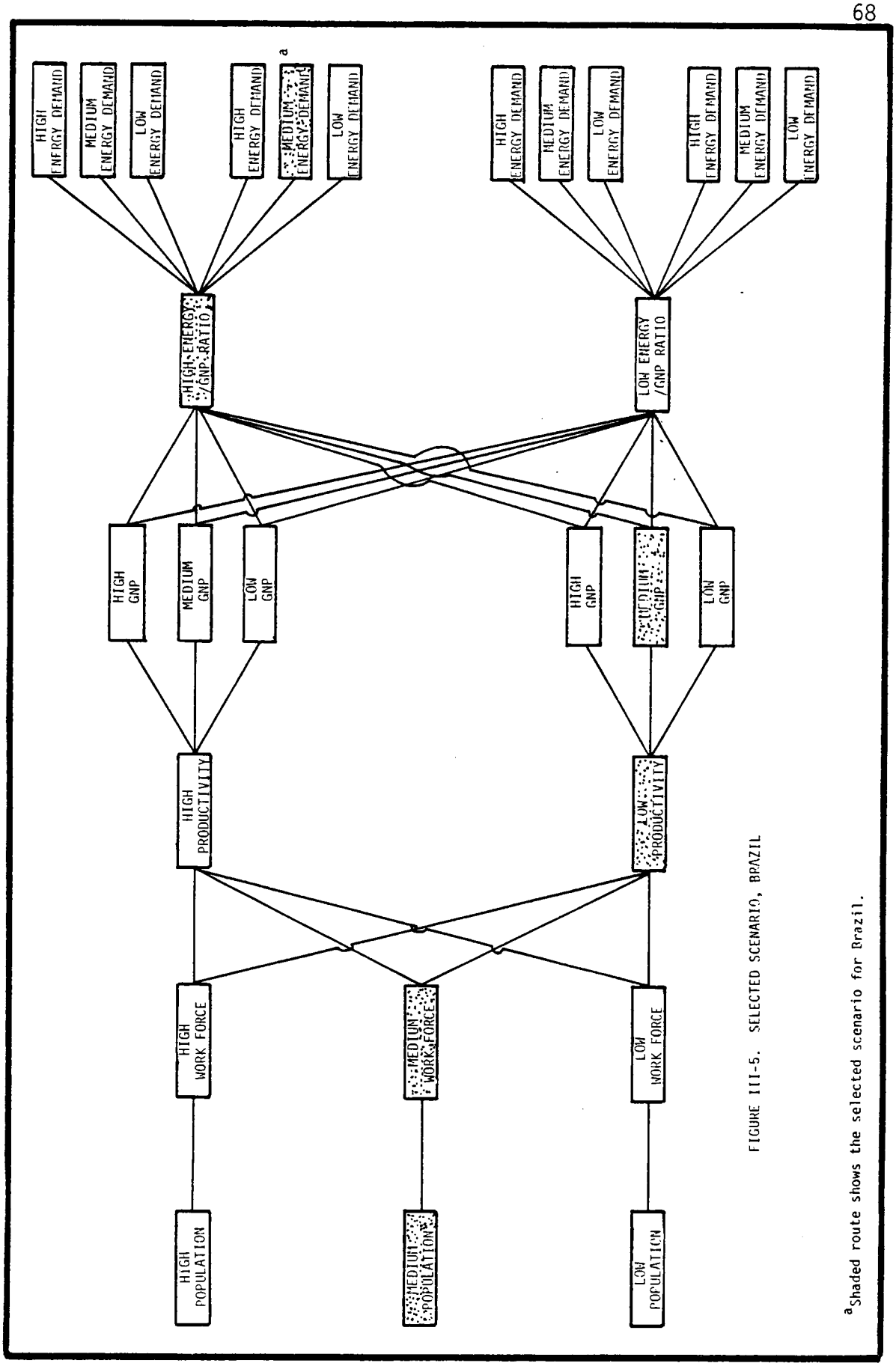


FIGURE III-5. SELECTED SCENARIO, BRAZIL

[a]Shaded route shows the selected scenario for Brazil.

2. Mauritius

Figure III-6 shows the most likely pattern for Mauritius. Medium population which yields a medium labor supply has been assumed for reasons already discussed in Chapters I and II. According to the model, the range of annual productivity growth rates that would be required is 1-2%. Since the historical productivity growth rate has been 0-2% during the last 10 years, the more conservative future growth rate in productivity, i.e., the low growth rate of 1%, is assumed.

As for the E/GNP ratio it is assumed that Mauritius is likely to approach the low ratio rather than the high. This assumption is justified by considering that, since Mauritius is small (720 square miles), the energy demand of its transportation sector would be low. At the same time because of its climatic conditions (average summer temperature of 92°F and winter of 68°F means that not much cooling and absolutely no heating is required), thus the energy consumption by its residential sector will continue to be low. This results in an average annual growth rate in energy demand of approximately 6% and a total energy demand of roughly 0.05 quads by 2010.

3. Nicaragua

Figure III-7 shows the most likely pattern to be followed by Nicaragua. Here again the medium population which yields a medium labor supply has been assumed. According to the model the range of annual productivity growth rates that would be required is 1.5-2.5%. Since the historical productivity has been approximately 1.6% during the last 10 years, it is likely that the future growth rate in productivity will be in the region of 1.5% (i.e. the low level) rather than in the 2.5% region (i.e. the high level).

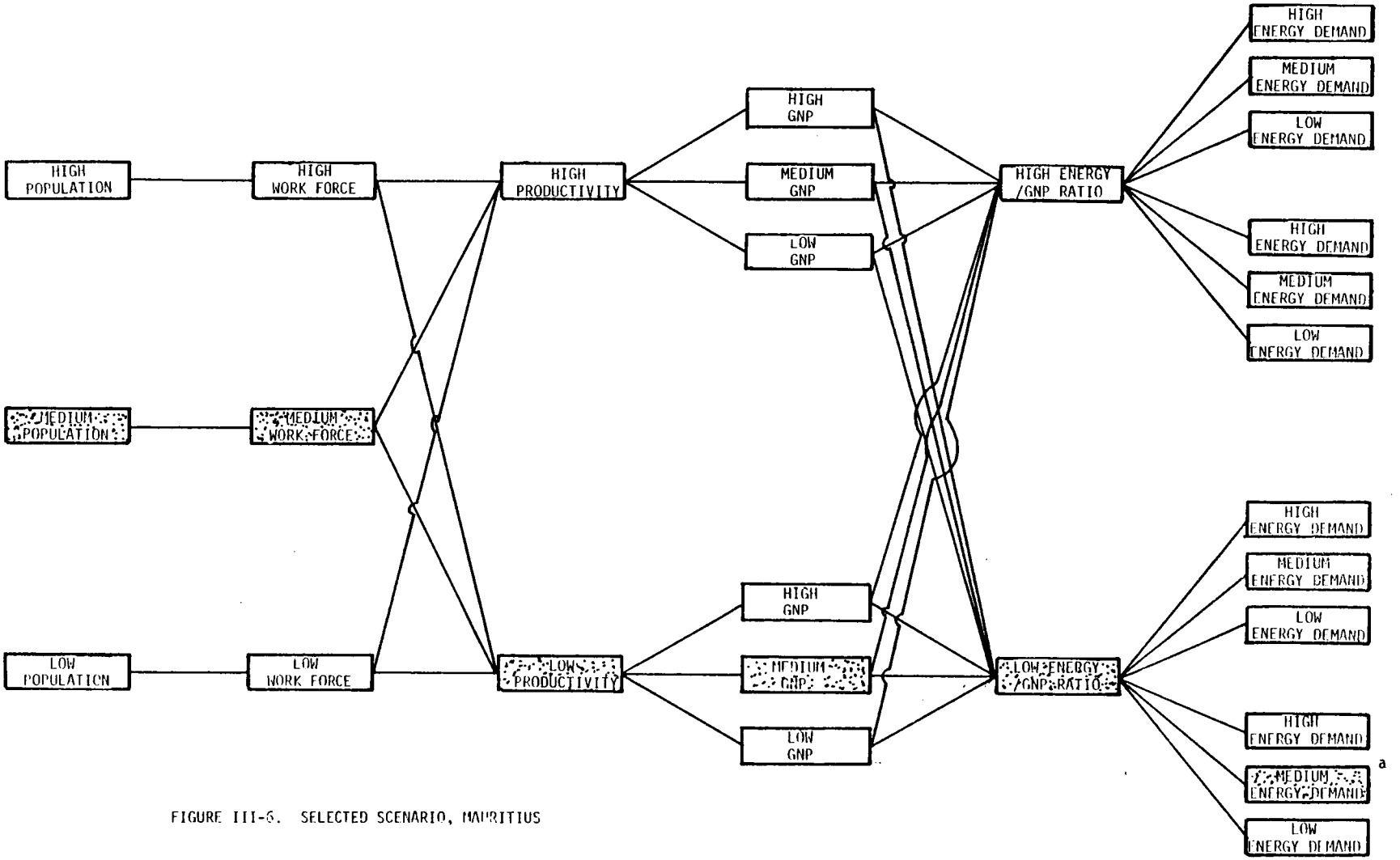


FIGURE III-6. SELECTED SCENARIO, MAURITIUS

[a]Shaded route shows the selected scenario for Mauritius.

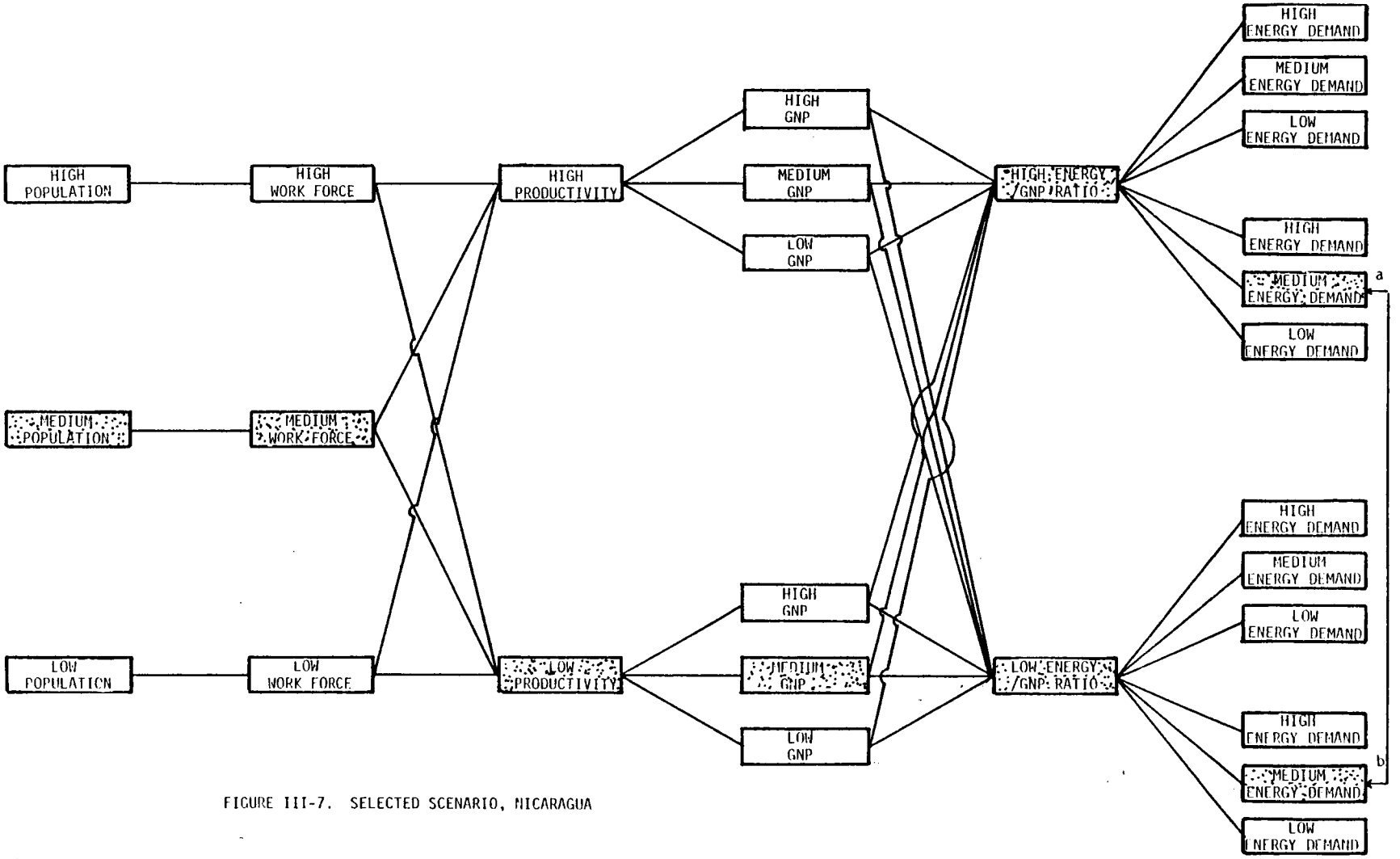


FIGURE III-7. SELECTED SCENARIO, NICARAGUA

[a]Shaded route shows selected scenario for Nicaragua.

[b]Note that in the case of Nicaragua a mean between high and low ratios has been used to estimate energy demand

This low level of growth in productivity can further be justified by considering the fact that Nicaragua went through a revolution during 1979 which almost completely destroyed the Nicaraguan economy. The low productivity coupled with the medium labor force supply result in an annual growth rate in GNP of 5.3% which is lower than the 5.7% historical growth. Even the 5.3% annual growth in GNP is very doubtful. Nevertheless, it has been used for the purpose of this study by taking into account that this growth is the minimum necessary in Nicaragua for gradual closing of the economic gap vis-a-vis the developed nations. Foreign assistance may help accomplish this. As for the E/GNP ratio it is assumed that by 2010 the ratio would be somewhere between the West German and the U. S. ratio. This can be justified by considering size, historical trends, and climatic conditions. The total energy demand through the year 2010 is obtained as explained in Figure III-7.

The most probable GNP and energy demand figures for the period of 1975-2010, to be used for future calculations associated with the three LDCs, Brazil, Mauritius, and Nicaragua, have been summarized in Table III-4.

F. Some Limitations of the Aggregate Energy Demand Model

In the process of using the model, its two major limitations became apparent. The first is due to the assumption used for extrapolating the GNP per capita of the LDCs. The 1975 GNP per capita ratio of approximately 10:1 of the two developed nations, U. S. and West Germany, to that of the LDCs, Brazil, Mauritius, and Nicaragua, was assumed to approach 1:1 by 2075 with 5-7:1 being the intermediate ratio achieved by 2010. Thus, for any LDC which in 1975 had reached a ratio

TABLE III-4

SELECTED SCENARIOS FOR BRAZIL, MAURITIUS AND NICARAGUA
ENERGY DEMAND (BTU) AND GNP
(CONSTANT 1970 U. S. DOLLARS)

	Brazil				Mauritius				Nicaragua			
	Energy		GNP		Energy		GNP		Energy		GNP	
Year	Total 10^{15}	Per Capita 10^{6}	Total 10^{9}	Per Capita	Total 10^{15}	Per Capita 10^{6}	Total 10^{9}	Per Capita	Total 10^{15}	Per Capita 10^{6}	Total 10^{9}	Per Capita
1975	2.10	19.2	55.3	504	0.0062	6.86	0.272	302	0.031	14.0	1.08	483
1980	2.81	22.4	71.3	567	0.0089	9.15	0.379	387	0.044	16.5	1.45	546
1990	4.91	30.4	115.0	711	0.0170	14.92	0.666	583	0.085	22.9	2.59	694
2000	8.10	41.0	175.2	887	0.0292	22.70	1.053	819	0.155	31.8	4.29	877
2010	12.51	55.0	250.1	1100	0.0461	33.00	1.536	1100	0.218	44.0	6.57	1100

of less than 5:1, or a GNP per capita of greater than 982 constant-1970 U. S. dollars, the model will show a negative growth rate in the GNP per capita through 2010. The second limitation is due to the extrapolation of E/GNP ratio with clear understanding that at no time any LDC is expected to have a ratio higher than that of the U. S. As illustrated in Figure III-8 Venezuela had an E/GNP ratio of 74,670 BTU, per constant 1970 dollar compared to 64,000 BTU per constant 1970 dollar for the U. S. The consequence on the model of the second limitation is illustrated graphically in Figure III-9 and on computer printouts included in Appendix A.

The problems identified by applying the model to Venezuela can be handled with proper conditional sub-routines. These would allow the application of the model to the whole range of the LDCs, and this second generation effort will be undertaken during 1980.

It is important to add that the model already has been modified to handle two developed nations, i.e. the U. S. and West Germany.

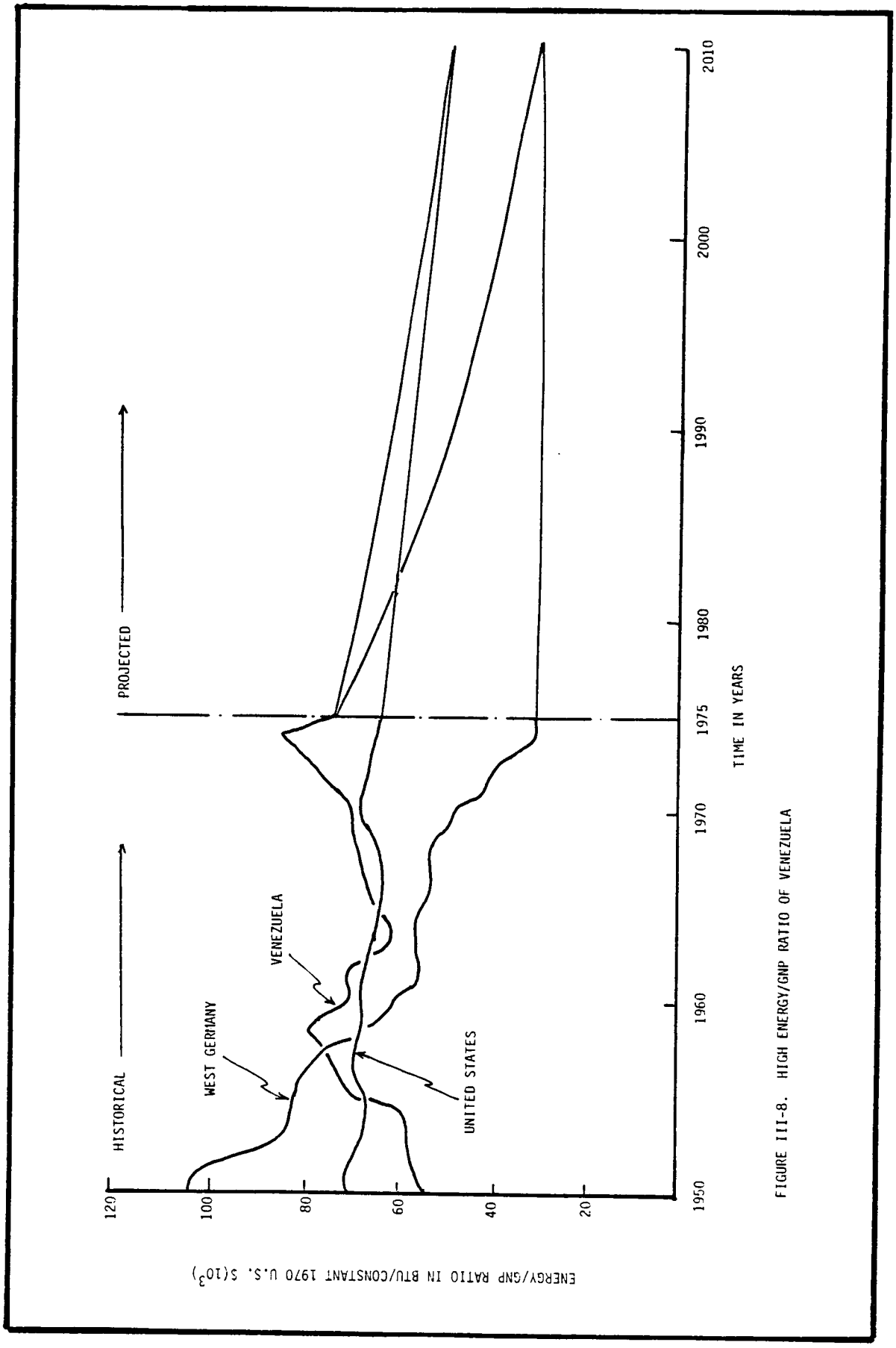


FIGURE III-8. HIGH ENERGY/GNP RATIO OF VENEZUELA

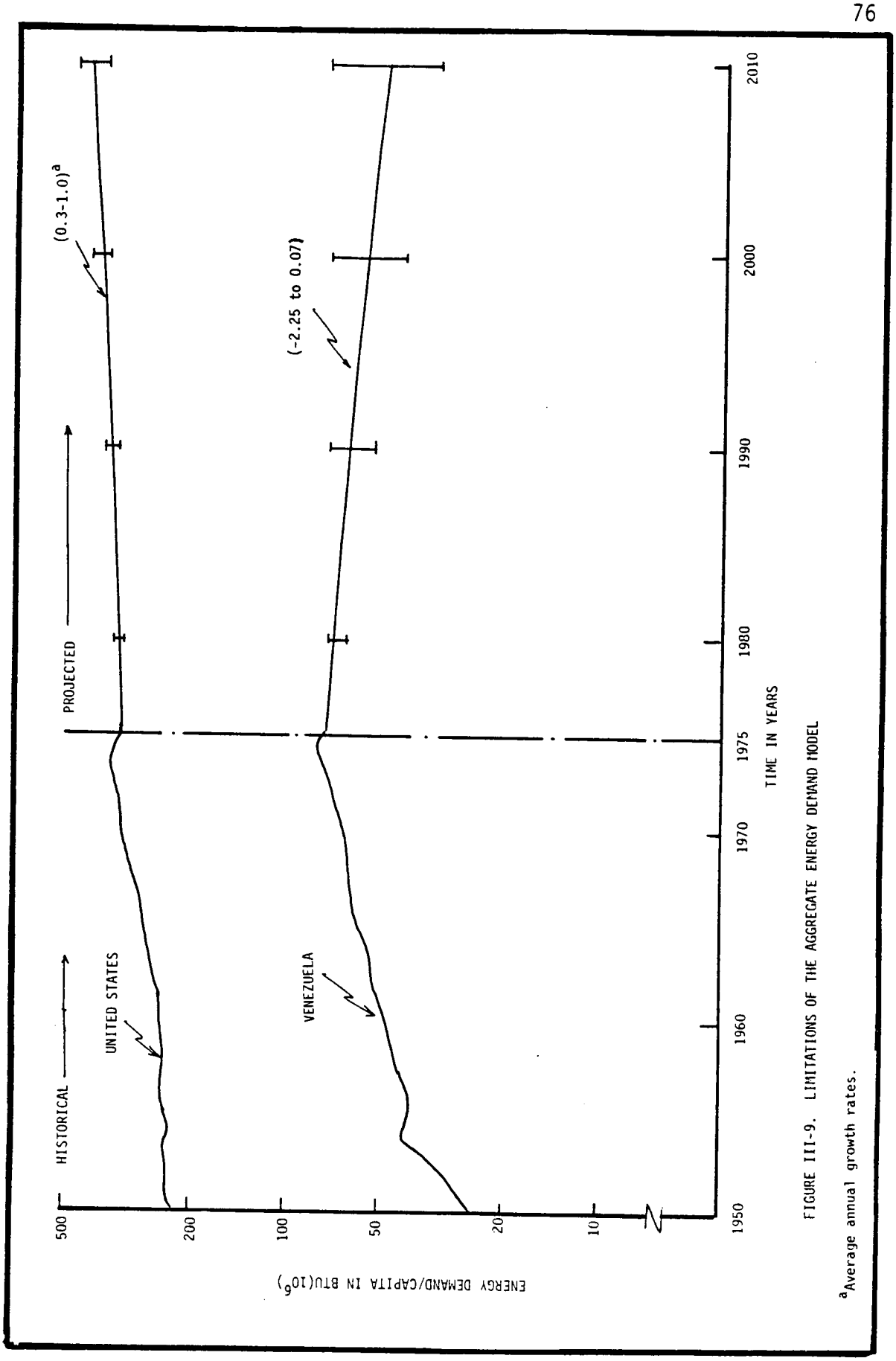


FIGURE III-9. LIMITATIONS OF THE AGGREGATE ENERGY DEMAND MODEL

[a]Average annual growth rates.

CHAPTER IV

ENERGY SUPPLY

A. General Discussion

The fossil energy which the world depends upon is finite. Several studies[34] have been undertaken by geologists, engineers, scientists and economists in order to estimate more reliably the amount of fossil resources in the three categories, coal, oil, and natural gas. For example, Ryman of the Standard Oil Company of New Jersey, Averitt of U. S. Geological Survey and Moore of U. S. Department of Interior, Office of Oil and Gas. Though the findings of such studies do disagree considerably the fact that only one to four centuries for coal, and a much shorter period of 20 to 50 years for natural gas and oil, is left is the common conclusion of all such studies.

Niehaus (1976)[35] argues that the above fossil resources are not limited by their actual size but rather by the level of carbon dioxide (CO_2) concentration the atmosphere can tolerate. Shortly after the turn of the century when the oil and natural gas era would be over, coal presumably would become the major supplier of fossil energy. Coal having a CO_2 emission factor which is 25% higher than oil and 45% higher than natural gas would increase the CO_2 buildup rate in the atmosphere. Thus Niehaus concludes that CO_2 pollution and the rise of temperature of the globe associated with it would limit the use of coal as energy source during the next century. This is discussed further in Section B.

As discussed earlier, economic growth is tied closely to energy demand. Thus, economists and policy makers are concerned about the

effects of energy shortages and energy price increases on individual nation's economies, especially for countries which have an economic structure which depends highly on imported fossil fuel. For example, it is evident from historical data[20] of the U. S. that there was a slow or almost zero growth in GNP per capita during the 1974/75 period which was caused partially by the 1973/74 oil embargo. Naturally there were many other factors which were also responsible for the short recession. The price of fossil fuel, which increases by almost five to fifteen percent at every OPEC meeting is a major cause of high inflation rates for countries depending heavily on imported fossil fuel. Considering the Iranian problems of March and November, 1979, the uncertainty of fossil fuel supply and price is apparent. Moreover, the increasing use of fossil fuel as an economic weapon already has been indicated during the November Iranian case. Any LDC which is entirely dependent on only one country for its energy needs will have to live at the mercy of its supplier of fossil fuel.

Conservation of energy, to the limit that it does not decrease the productivity of the nation, is a very powerful tool to overcome temporarily the problems associated with energy shortages and energy price increases. As discussed in Section D, conservation alone will not be able to solve permanently the long range energy problem.[36]

Thus, the above arguments lead to the need for new domestic sources of energy which would be renewable and long lasting, non-polluting, and economical. Such energy sources with some of these characteristics are not widespread as yet. However, several new sources are being investigated for the future. For example:

(i) Nuclear Energy: Fusion and Fission.

(ii) Magnetohydrodynamics.

(iii) Geothermal Energy.

(iv) Sea Waves and Tidal Waves.

(v) Several Aspects of Solar Energy.

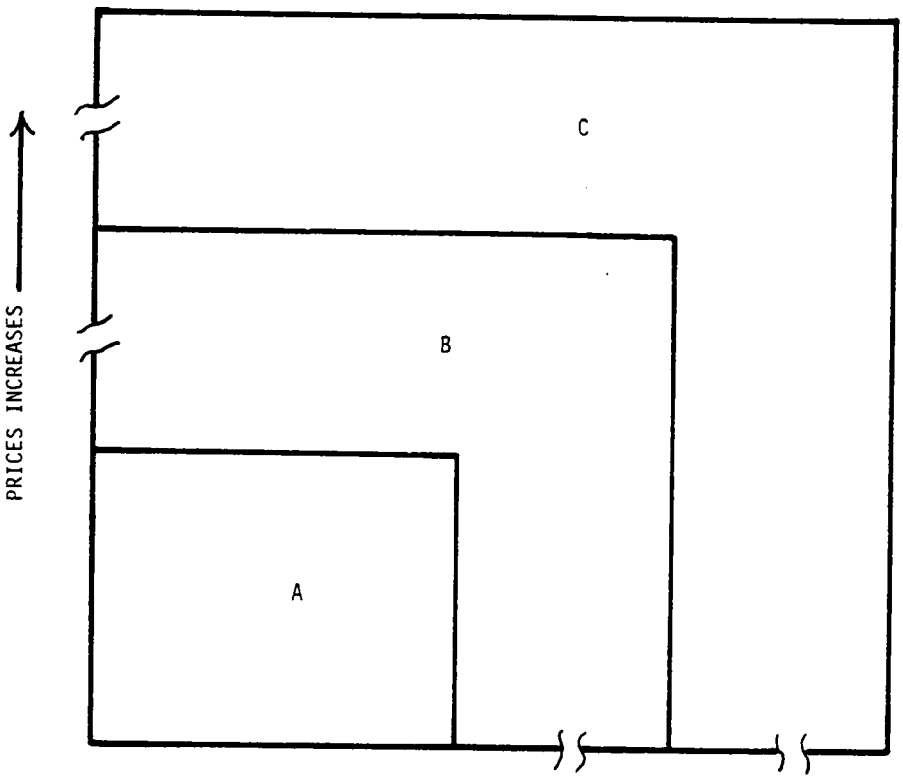
Some aspects of these energy sources are surveyed briefly in the next chapter. However, for the purpose of this dissertation the detailed analysis has been limited to biomass and more specifically to corn and sugar cane as an energy and chemical feed stock supplier for the three LDCs - Brazil, Mauritius, and Nicaragua.

B. Limitation of Fossil Fuel Reserves

1. Definitions and Concept of Consumption

The concept of fossil fuel reserves[37] is illustrated on Figure IV-1. The total amount of each category of fossil reserves is represented by the area of the rectangle and would change according to changes in market economy, technological advancement, and new reserve discoveries. The figure also illustrates that the total available energy, though uncertain, is still finite.

The second concept which relates fossil energy consumption to time was developed by Hubbert (1971)[34,38] and is illustrated on Figure IV-2. The upper part A of the drawing shows the variation of the cumulative amount of energy consumed with time. According to Hubbert an S-shaped trend approaching asymptotically the limit X is the idealized situation. The lower part B of Figure IV-2 illustrates annual consumption versus time. In an ideal case the peak of the bell-shaped curve coincides with the inflection point of the S-shaped curve. The area under the bell



A = KNOWN RECOVERABLE RESERVES, UNDER PRESENT ECONOMIC AND TECHNICAL CONDITIONS

B = ESTIMATED ADDITIONAL RESERVES, BASED UPON GEOLOGICAL INFERENCE

C = UNKNOWN AND/OR UNDISCOVERED RESERVES

A + B + C = FOSSIL RESOURCES

FIGURE IV-1. ILLUSTRATIVE DEFINITION OF RECOVERABLE RESERVES

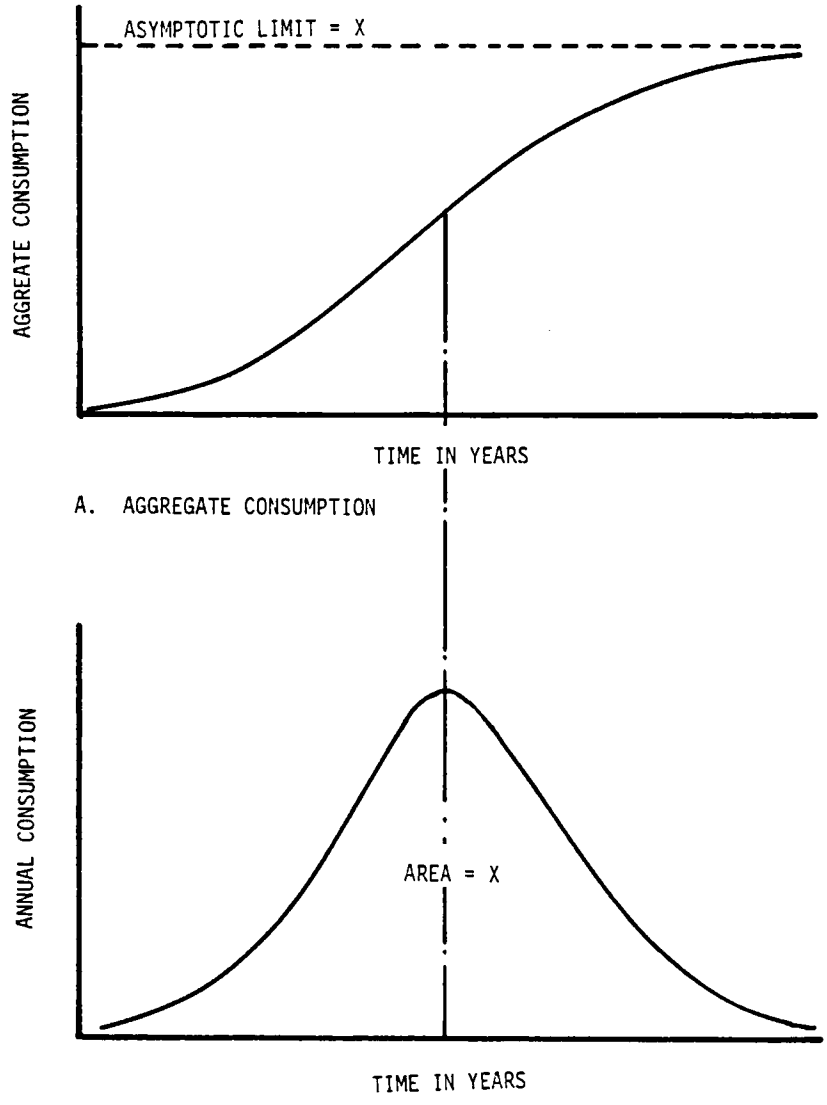
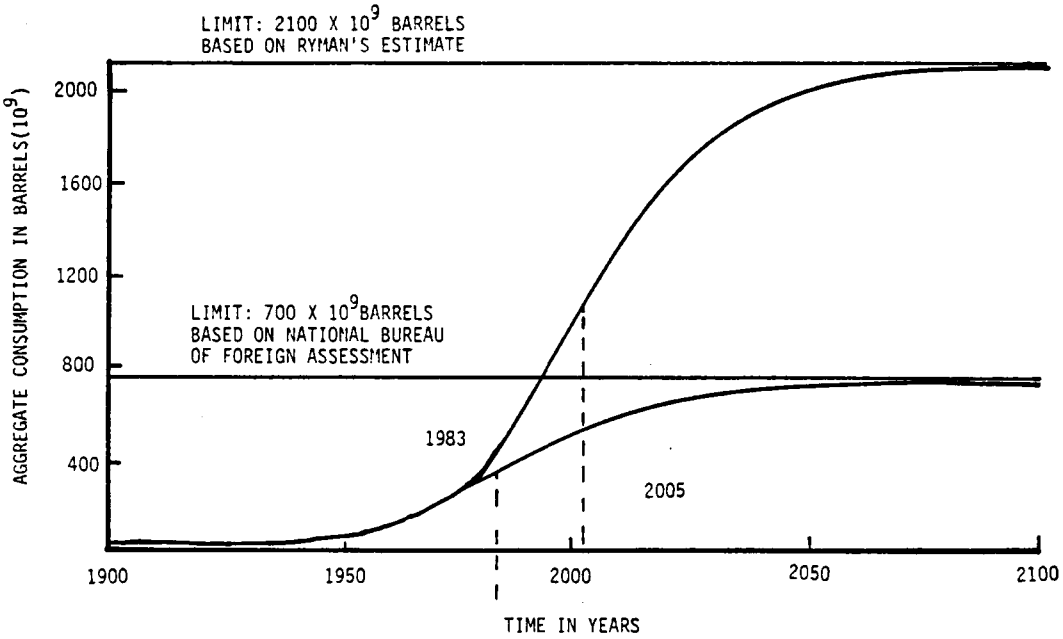


FIGURE IV-2. CONSUMPTION PATTERNS FOR NON-RENEWABLE RESERVES

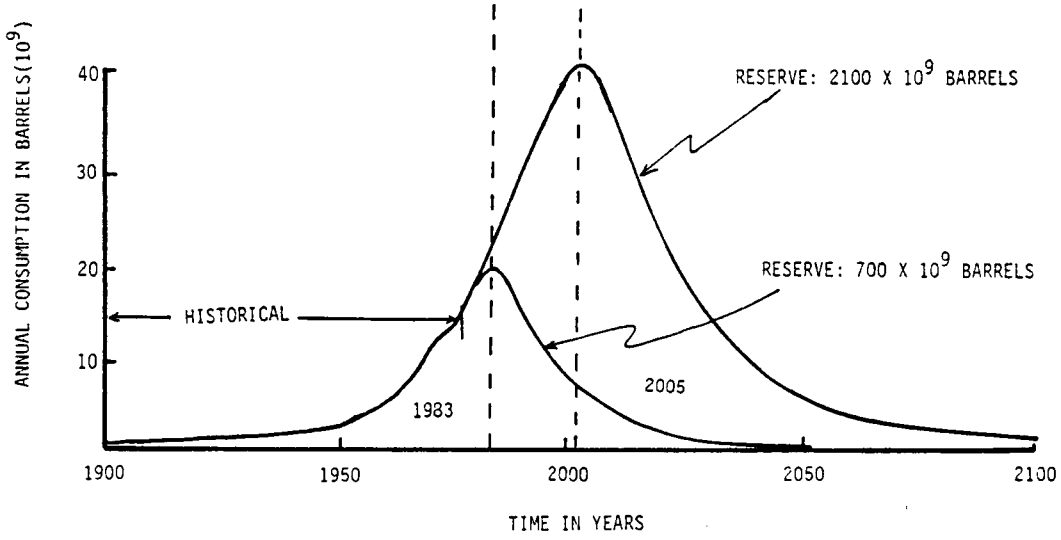
shaped curve should be equal to the asymptotic limit X. Changes in the factors mentioned in the preceding paragraph, i.e., market economy, technological advancement, and discoveries of new reserves would increase the limit X and the area under the bell shaped curve.

Both of the above concepts are illustrated on Figure IV-3 using two estimates of crude oil resources (refers to the total of all the three types of reserves defined on Figure IV-1, i.e., A, B and C). The first estimate of 2100 X 10^9 barrels, which lies in the upper range of the estimates of crude oil reserves, was made by Ryman[34] of the Standard Oil Company of New Jersey and is represented by the upper curves of both parts A and B of Figure IV-3. The lower curves represent an estimate of 700 X 10^9 barrels, which lies in the lower range of the crude oil estimates, was made by the National Bureau of Foreign Assessment.[39] The historical data on total production from 1900 through 1978 has been extrapolated. The result of the first estimate shows that if the current growth rate of production is maintained the peak would be reached shortly after the turn of the century, whereas, the second estimate shows that with the same growth rate in production the peak would be reached 10-15 years before the turn of the century. The difference in area under the two curves and the difference in their peak locations is related to the differences in the two estimates of recoverable reserves.

If the Hubbert concept is correct, similar curves would be obtained for other non-renewable energy resources, such as coal, natural gas, and uranium. While short term influences will produce irregularities in the curves, the historical data so appear to fit rather well, as in the case of crude oil. For the fossil fuels, environmental constraints



A. AGGREGATE CONSUMPTION OF CRUDE OIL



B. ANNUAL CONSUMPTION OF CRUDE OIL

FIGURE IV-3. CONSUMPTION PATTERNS FOR CRUDE OIL

such as potential CO_2 problems may reduce the area under the bell shaped curve by restricting the amount of the reserves that can be used. The CO_2 limitation, which would apply primarily to coal has been dealt with by Niehaus and is discussed further in the next subsection.

2. The Carbon Dioxide Problem

Although the data generated by Keeling (1976)[40] confirm that there has been a build-up of CO_2 in the atmosphere from 310 ppm in 1948 to 330 ppm by volume in terms of CO_2 in 1974, there are still great uncertainties associated with the effects it would have on the climate and the level of CO_2 concentration at which these effects would be significant. According to some publications,[41] it is likely that at about 500 ppm the climate change should be significant, and would be noticeable at 400 ppm, but how this change would be manifested is still questionable. Niehaus and many other climatologists believe that increase in CO_2 concentration in the atmosphere would cause an increase in the temperature of the globe.

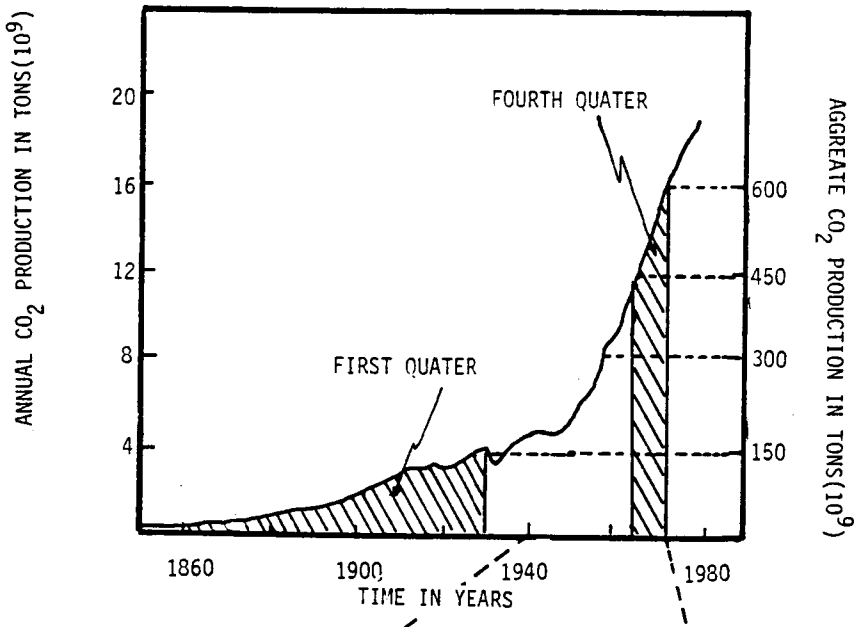
Because CO_2 absorbs infrared radiation at the earth's surface, a concentration increase would cause an increase in temperature of the atmosphere. This would increase the temperature of the surface layer of the ocean which would decrease the solubility for CO_2, thus increasing the partial pressure and reducing the absorption by the ocean. This would further enhance the build-up of CO_2 in the atmosphere. However, there are others who believe that CO_2 concentration increases would cause a cooling effect.[42]

An important factor to consider is the rate at which CO_2 has been produced. If the data given in Rotty's publication of 1979[43] are

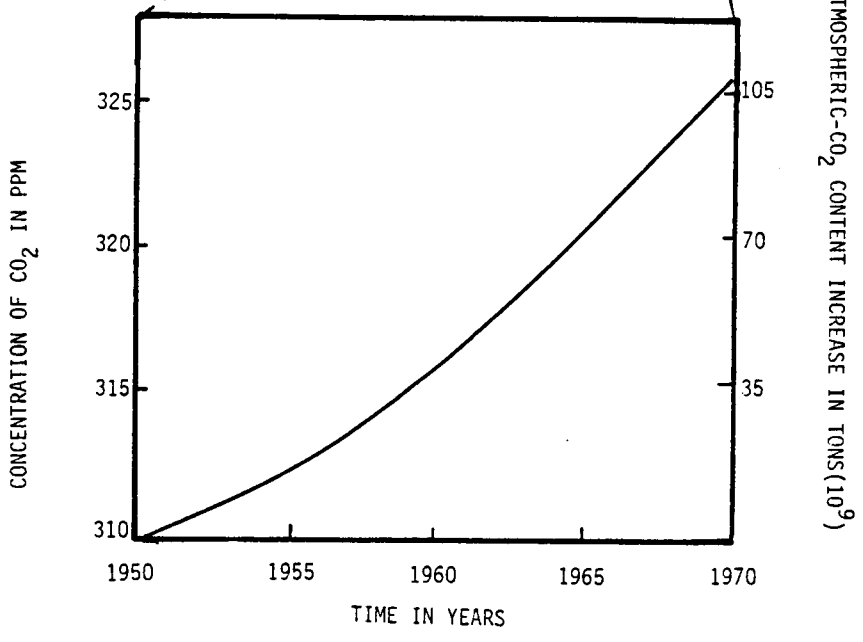
analysed as shown on Figure IV-4, it is apparent that the rate of production of CO_2 has increased tremendously during the last 100 years or so, i.e., from 2.0 X 10^9 tons per year in 1900 to 16 X 10^9 in 1970. Another way of looking at the rate of production is as follows: from 1860 through 1970 total man-made CO_2 emission was roughly 600 X 10^9 tons. Referring to Part A of Figure IV-4, it can be seen that it required approximately 70 years, i.e. 1860 to 1930, to produce the first 150 X 10^9 tons or the first quarter of the total emission, whereas, it took only 5 years to produce the last quarter, i.e., 1965 to 1970. It is evident from the curves that the rate of absorption has not kept pace with the rate of production. This is largely due to the increasing rate of fossil fuel use. Certainly, the question of atmospheric CO_2 equilibrium is far more complex. Nevertheless, these types of analyses have led Niehaus[35] to argue that shortly after the turn of the century the CO_2 in the atmosphere would be at such a level that it would preclude further increases in the use rate of coal (suggested very rough estimates 400 to 500 ppm by volume CO_2 and average temperature increase of 2°C).

In the next century if no alternative energy source is found, coal would be the major energy supplier and since coal produces 0.12 tons CO_2 per 10^6 BTU or approximately 25% more CO_2 than to oil and 45% more than natural gas for the same amount of energy supply thus, coal utilization would further increase the CO_2 build-up. According to Niehaus this would mean the use of only 10% of the total coal, i.e., about 800 X 10^9 tons out of 8000 X 10^9 tons. This has been illustrated in Table IV-1.

The above discussion illustrates that useful fossil fuel resources are limited not only by their actual amounts but also by environmental



A. PRODUCTION



B. ACCUMULATION

FIGURE IV-4. CARBON DIOXIDE PRODUCTION AND ACCUMULATION

Source: Rotty, R. M., "Uncertainties Associated with Global Effects of Atmospheric Carbon Dioxide," Institute for Energy Analysis, Oak Ridge Associated Universities, Oak Ridge, Tennessee, 1979.

TABLE IV-1

ESTIMATES OF WORLD FOSSIL FUEL RESERVES

Type of Fuel	Estimated Reserves	[a]Energy Equivalents 10^{15} BTU	[b]Limit to Which Reserve Can be Used 10^{15} BTU
Coal	8×10^{12} MTons[c]	200×10^{3}	20×10^{3}
Oil	2.1×10^{12} Bbls[d]	11.5×10^{3}	11.5×10^{3}
Natural Gas	3×10^{15} SCF[e]	3.0×10^{3}	3.0×10^{3}
Total		214.5×10^{3}	34.5×10^{3}

[a]Average Heat Content: Coal: 12,000 BTU per pound.

Oil: 5.46×10^{6} BTU per Bbl.

Natural Gas: 1000 BTU per SCF.

[b]Amount of fossil fuel that can be used given the CO_2 and heat pollution tolerance limit estimated by Niehaus which limits use of coal only.

Units: [c]MTons: Metric tons = 2200 pounds.

[d]Bbls: Barrels = 42 U. S. gallons.

[e]SCF: Standard cubic feet.

conditions. Though considerable uncertainty is associated with these problems, they cannot be ignored.

C. Fossil Fuel Prices and their Implications

Because of the strong relationship between energy consumption and economic growth, as discussed in Chapter III, in terms of the E/GNP ratio, e.g., U. S. 64,000 BTU per constant 1970 dollars, economists are greatly concerned about the effects of shortages and high prices of energy upon future economic growth, especially if a nation's energy supply depends heavily on imports. For example, it is apparent from the speeches of economists of the White House staff that one of the major causes of inflation in the U. S. is the high dependency, roughly 50% amounting to 60 billion current dollars in 1978, on imported fuel for its energy supply. Certainly, the situation is more critical for nations which depend entirely on imported fuel for their energy need, e.g., many European countries and most of the non-oil producing LDCs.

Energy supply shortages already have been encountered twice during the past five years, i.e., fall and spring of 1973/74 and spring of 1979. A third problem may now be emerging in relation to Iran. Fortunately the duration of the peak shortages has been short and temporary, but the long term impact remains and may become more crucial in the future. The effect of the price increases has been experienced constantly by the consuming sectors ever since the 1973/74 oil embargo.

Figure IV-5 shows the prices of domestically produced fossil fuel in the U. S.[44] in constant 1970 dollars. It can be seen that the real price of coal and oil actually declined at an annual rate of 1.0 to 2.0% during the 1950 to 1970 period. However, the drastic increase of 60%

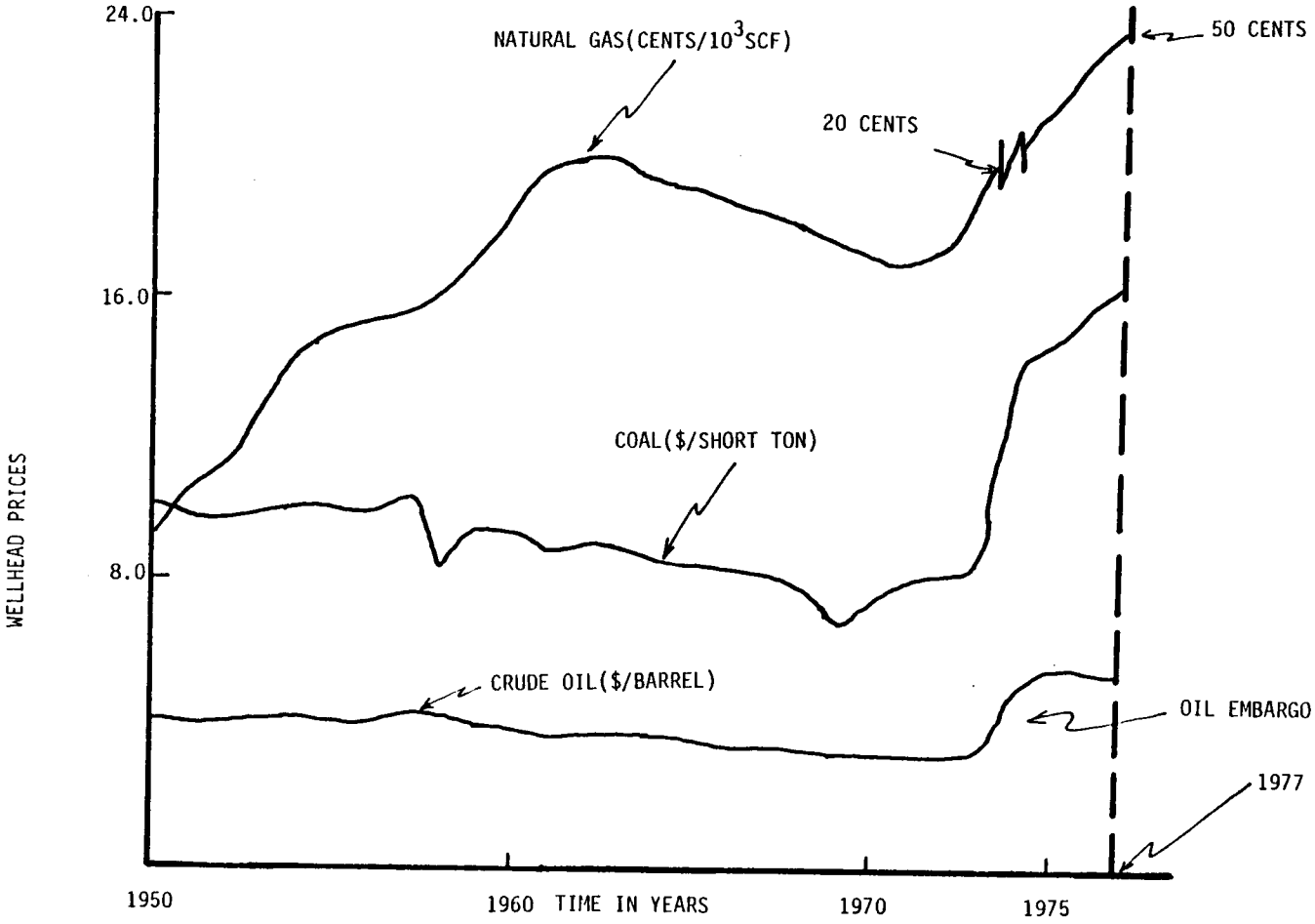


FIGURE IV-5. U. S. DOMESTICALLY PRODUCED FOSSIL FUEL PRICES IN CONSTANT 1970 U. S. $[a], 1950-1977

[a]Prices have been reduced to constant 1970 U. S. dollars.

Source: U. S. Deparment of Energy, "Annual Report to Congress, Statistics and Trends of Energy Supply, Demand, and Prices," Energy Information Administration, Washington, D. C., 1978.

in the 1973/74 period in the price of coal and oil and roughly 25% for the same period in the price of natural gas has aroused the attention not only of U. S. but the world as well. Ever since that 1973/74 period the price increase has been in the range of 0.5 to 5% annually for coal and oil, but the rate of increase in the price of natural gas has been higher. Since December 1978, the OPEC nations have raised their oil prices every time they have met, i.e., roughly at intervals of 3 months, which has caused gasoline at the pump to go up by 25%. One can reasonably assume that these upward trends in prices will continue.

Based on the arguments and assumptions listed below plus additional judgements and extrapolation the IEA[23] has projected a continuous increase in the price of fossil fuels, coal at 2.0% increase annually, the composite price of imported and domestically produced oil at 3 to 4%, and natural gas at 7 to 8%.

(i) Energy demand will grow continuously as projected by the IEA Sectoral Energy Demand Model.

(ii) Amount of remaining reserves will diminish.

(iii) Oil from old oil wells will eventually be depleted.

(iv) Cost of drilling is increasing continuously.

(v) Cost of coal mining is increasing.

(vi) Natural gas reserves will perhaps be depleted.

Such price increases would eventually bring the price (in 1970 dollars) of a barrel of oil from 7.50 dollars in 1975 to 25 dollars by 2010, a short ton of coal from 15 dollars in 1975 to 30 dollars in 2010 and one thousand SCF of natural gas from 32 cents in 1975 to roughly 4.3 dollars by 2010. The projected oil prices are for composite oil, i.e., domestic and imported, Table IV-2. It is important to note that the price of

TABLE IV-2

ESTIMATED PRICES OF FOSSIL FUEL COMPOSITE DOMESTIC PLUS IMPORTS

Period	Coal		Oil		Natural Gas	
	[a]Price in 1970 Dollars per Short Ton	Annual Percentage Increase	[a]Price in 1970 Dollars per Barrel	Annual Percentage Increase	[a]Price in 1970 Dollars per 10^3 SCF	Annual Percentage Increase
1975	14.79		7.53		32.1	
1975-1985		2.0		4.4		24.4
1985	18.04		11.60		206.0	
1985-2000		2.0		3.0		3.0
2000	24.40		18.10		321.0	
2000-2010		2.0		3.0		3.0
2010	29.58		24.32		430.0	

[a]Estimated the prices in 1975 dollars, but it has been adjusted to 1970 dollars in order to be consistent within this study.

Source: Weinberg, A. M., et al., "U. S. Energy Demand and Economic Growth, 1975-2010," Institute for Energy Analysis, Oak Ridge Associated Universities, Oak Ridge, Tennessee, 1976.

fossil fuel projected by the IEA already has proved to be too low. For instance, the price of oil already has gone to 16 dollars (in 1970 dollars) per barrel or 24 current dollars compared to the projected price of 11.60 dollars (in 1970 dollars) or 19.50 current dollars which was projected to be reached by 1985. This illustrates the high uncertainty associated with projection of fossil fuel prices.

Moreover, the overall price of composite oil is still cheaper in the U. S. than almost anywhere else in the world. Prices as high as 40 current dollars for a barrel of oil are not uncommon in the world spot market. Even the U. S. oil companies sometimes have to buy at that high price in the spot markets in order to meet domestic oil needs.

The continuous handicap to any nation's economy which depends upon very large amounts of imported oil would be inevitable and this is illustrated and discussed in future chapters. Especially for the LDCs it seems that the only way to fight the battle and to try to sustain a healthy economic growth is by gradually shifting to other locally available and renewable energy sources, e.g., biomass, and by adopting new development strategies which would lead toward energy independence. Further investigations and research still are needed in order to reach that stage. On the other hand, conservation measures which allow one to gain time until new technologies can be implemented must be enforced for all nations. This is discussed in the next section.

D. Some Aspects of Conservation

Energy conservation is a necessity for all nations of the world. Energy conservation to the limit that it does not decrease productivity will at least temporarily lessen the negative effects caused by increasing

costs and shortages of energy on the economy. Furthermore, the capital cost of saving a unit of energy via conservation in certain cases is less than the capital cost of providing that same unit of energy via new facilities and use of additional energy supplies. Moreover, conservation would help to postpone the problem until new solutions are found.

In the United States several energy conservation measures are being undertaken:

(i) Shifting from low mileage (10-15 miles per gallon) to higher mileage automobiles (25-30 miles per gallon), in order to decrease energy consumption in the transportation sector.

(ii) Keeping thermostats lower in winter and higher in summer, and at the same time providing good home and commercial insulation in order to cut down energy consumption in residential and commercial sectors.

(iii) Recycling of waste material and improvement of operational efficiency in the industrial sector.

However, it is unfortunate to see that the majority of people are not supporting these measures. One of the main reasons that is apparent from statistical surveys of the communication media is that almost 50% of the American people do not believe that an energy crisis exists.

On the other hand, energy conservation, even if it is accepted by the public, would not be able to solve the world energy problem permanently. Conservation and the level of efficiency are limited by the second law of thermodynamics. As illustrated in Appendix B, unless the population growth rate and/or per capita consumption of good and

services are stabilized conservation will have no permanent effects on long term energy demand growth rate, after the thermodynamic limit has been reached.[36] The problem chosen to illustrate the limitation of conservation deals with the consumption of a product "A" which has "X" unit of energy associated with it before conservation and "$X-X_c$" units after conservation, where "X_c" units of energy represent the energy saved through conservation.

The problem and its solution are illustrated clearly in Appendix B. The growth of total energy, associated with product "A," consumed by the population in the situation of no conservation fix is represented by the upper curve and the lower curve represents the situation with a conservation fix. Both curves assume the same per capita demand for goods and services. It can be seen that the slopes of both curves are same indicating that the energy consumption growth rates are equal after the conservation fix. The only difference between the two cases is that there has been a shift in the curve through "N_1" years. The result agrees with the previous statement, i.e., conservation by itself only allows one to gain time. If population and the per capita demand for the particular goods or services continue to grow, the energy demand curve will start its upward trend, whenever the conservation fix has been pushed to its maximum technical limit. Thus in a permanent sense energy demand is determined by population growth and to the demand for goods and services.

E. Problems Associated with Current Energy Supply

The above discussion on energy demand and the associated problems can be summarized as follows:

(i) Fossil resources are finite, roughly 200 to 400 years of supply left, but the oil era will end sooner, i.e., in approximately 50 years.

(ii) Fossil energy use also is limited by the build-up of CO_2 in the atmosphere and heat pollution associated with hydrocarbon combustion.

(iii) The high rate of price increase will handicap the economy of nations, developed and less developed, and especially those which are highly dependent on imported fuel for their energy needs.

(iv) Conservation by itself is only a partial solution which helps to gain time.

(v) The continuous growth rate of population and energy demand per capita would lead to a high level of annual energy demand, especially in the LDCs.

(vi) Increase in energy requirements for food production by the agricultural sector through mechanization in order to meet the ever increasing food demand would eventually lead to higher levels of energy demand in the agricultural sector.

(vii) High economic growth rates in the LDCs, which is a necessity for closing the economic gap between LDCs and developed nations, would certainly increase the energy demand by these LDCs in the future.

Thus the very obvious conclusion is that new sources of energy with the following characteristics are required in order to meet the future energy demand.

(i) New sources of energy should be renewable.

(ii) Minimum environmental disruption must be associated with the new sources of energy.

(iii) The energy cost should be as low as possible in order not to handicap any nation's economy and be competitive with traditional energy sources. Moreover, the new strategies and technologies should be directed in such a way as to make maximum use of locally produced raw materials.

(iv) Must be a socially and politically acceptable source.

Certainly no energy source that satisfies all the above characteristics exists as yet. Though several sources are being investigated, a solution to the world energy problem is still uncertain. A brief survey of several of the new energy sources is carried out in the next chapter, with special attention to the biomass energy source.

CHAPTER V

THE POTENTIAL OF BIOMASS AS AN ENERGY SOURCE

A. General Discussion

When all the four factors discussed in Chapters I to IV, i.e.,

(i) Population dynamics,

(ii) Economic development,

(iii) Energy demand associated with population and economic growth, and

(iv) Limitations of the traditional fossil energy sources

are considered the necessity to investigate new and renewable energy sources is apparent. The urgency is even more obvious when the Niehaus asymptotic model and potential limitations on fossil fuels discussed in Section B of this chapter are considered.[45]

It is obvious from literature surveys that investigations and research for new types of energy sources were not taken very seriously up until the Arab oil embargo of 1973/74, except for efforts to develop nuclear power. However, since this oil embargo era the whole spectrum of energy sources, i.e., from the very primitive energy source of burning wood to produce heat, steam, and electricity to the highly sophisticated energy source of fusion power is being investigated actively at present in the United States and other parts of the world. A brief survey of energy sources being investigated is given in Section C, from which it can be concluded that after over slightly half a decade of active research, no new energy source has been found which can substantially replace fossil energy sources at present. This may remain so for years to come.

On the other hand the primary source of world energy, the sun, still shines and provides enormous amounts of distributed energy to the globe.[46] At the same time the photosynthesis process, which was responsible for converting solar energy into fossil fuel reserves over millions of years still occurs. At present, by various agricultural and forestry practices, the same photosynthesis process produces the biomass (includes all material produced by photosynthesis), required for all the world food and most of its fibre production. Only a minor fraction, however, of the biomass produced is used as agricultural waste for soil conservation and conditioning purposes. If only part of the agricultural waste, which has a high heat content (approximately 7,500 BTU per dry pound), could be used for energy production purposes, it would represent not only a substantial energy source but also a renewable one.[47] Some general aspects of this renewable biomass energy source are discussed in Section D of the current chapter. The possibility of raising crops solely for the production of energy, on energy farms, also is considered in the same section.

Obviously any large scale use of biomass for energy supply raises important questions of ecology, environmental quality, land use, water resources, soil conservation, weather modification, etc. At the same time the energy and material balance, economic feasibility potential, competition with food production, and other factors must not be ignored.[36] Since it is beyond the scope of this dissertation to deal with all the problems associated with use of biomass as an energy source, the importance of the above problems is merely identified here, and the economic feasibility and energy material balance using sugar cane and

corn are emphasized. Some consideration also is given to the potential competition with production of sugar for consumption as food.

B. Asymptotic World Energy Model

Figure V-1 illustrates the asymptotic world energy model developed by Niehaus based on the following alternative concepts:[45]

(i) World population stabilizing at about 8 billion people and per capita energy consumption stabilizing at the present U. S. figure of about 330 MM BTU annually, or

(ii) World population stabilizing at about 16 billion people and per capita energy consumption stabilizing at the present West German figure which is about half that of the U. S., or about 165 MM BTU annually.

Either of the two concepts leads to a world total annual energy demand of 2,500 quads (1 quad = 10^{15} BTU) at the population stabilization level compared to the present 250 quads.* Since either of the two concepts assumes that the per capita energy consumption would reach a uniform and constant level worldwide, they also imply that the economic gap between the LDCs and the developed nations would be closed.

Because of the potential impact of carbon dioxide and other related environment considerations discussed in the previous chapter, Neihaus has assumed that only 35,000 quads out of the approximately 215,000 quads of the estimated fossil resource could be used. If

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*If the two alternatives here are treated on the basis of continued growth of the U. S. and German consumption, rather than present levels of consumption, the limit reached in 2050 would be about 8,000 quads annually. Either the 2,500 or 8,000 quad figures are so large as to dramatize the enormous magnitude of the world energy problem over the next 50-100 years.

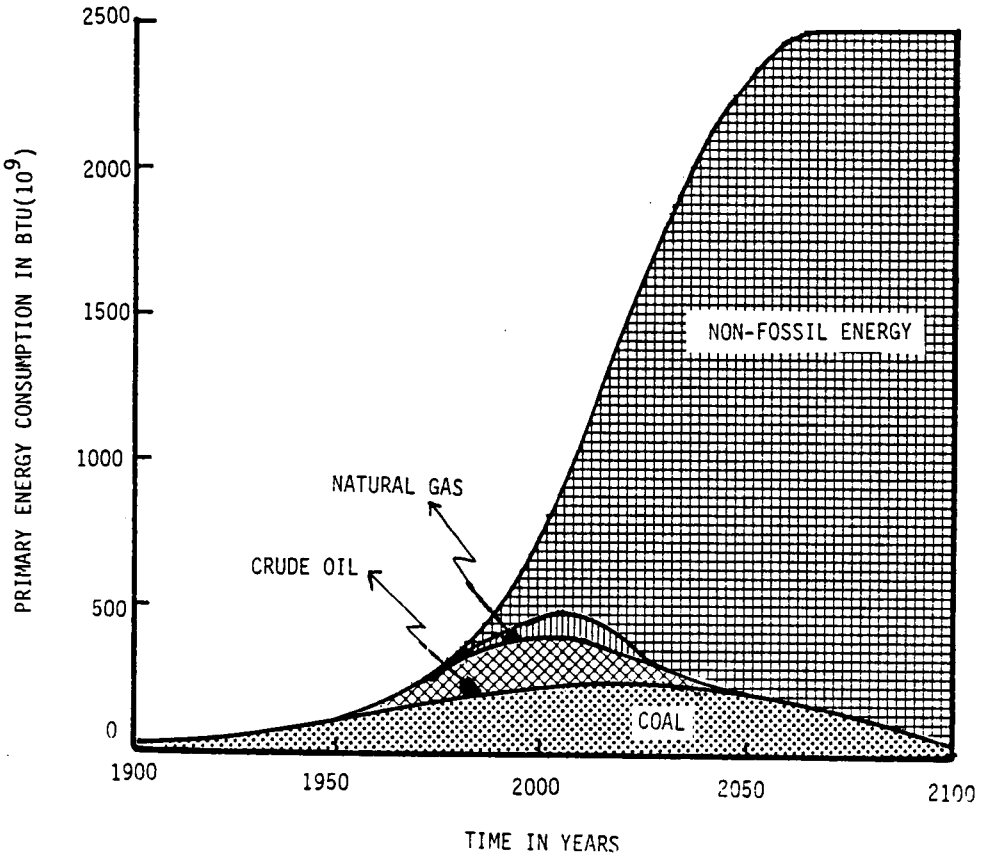


FIGURE V-1. PROJECTION OF PRIMARY ENERGY CONSUMPTION[a]

[a]Updated to reflect 1975 total energy consumption.

Source: Niehaus, F., "A Non-linear Eigth Tandem Model to Calculate the Future CO_2 and C-14 Burden of the Atmosphere," International Institute for Applied System Analysis, Laxxemburg, Austria, 1976.

Niehaus' assumptions are correct, the ability to substitute coal for oil would be handicapped seriously.[45]

Allowing for a substantial uncertainty range in the Niehaus concept, the need for research and development in order to meet the world energy demand still is quite obvious. As mentioned earlier, not much attention was given to the world energy problem before the early 1970's crunch, except for nuclear power development. This energy crunch has catalyzed research and development towards new energy strategies for the future, as well as increased emphasis on conservation. The Iranian crisis of November 1979 has demonstrated further the need to deal with these problems. The next section gives a brief survey of the possible energy sources being investigated and the problems associated with them.

C. Survey of Various Energy Sources Being Investigated

In this section the general spectrum of the energy sources currently being investigated is surveyed. The list given in Table V-1 classifies the sources into various categories, i.e., nuclear fusion and fission, direct and indirect solar, and miscellaneous sources, such as geothermal and tides and sea waves.

1. Nuclear Energy

a. Fusion Power

Fusion basically is the same reaction that takes place in the sun, i.e., the reaction between deuterium atoms, followed by other reactions, during which a tremendous quantity of heat is produced. The following equation gives a general idea of the fusion reactions now being investigated, and Figure V-2 illustrates the process scheme for energy production.[48]

TABLE V-1

CLASSIFICATION OF VARIOUS ENERGY SOURCES

1. Nuclear	2. Solar	3. Other Sources
a. Fusion	a. Direct Utilization	a. Geothermal
b. Fission	(i) Photoelectric cells	b. Tidal power and sea wave
	(ii) Solar heating and cooling devices.	
	(iii) Solar heating for thermo-electric power.	
	b. Indirect Utilization	
	(i) Wind Energy	
	(ii) Hydroelectric Power	
	(iii) Thermal gradient of sea water	
	(iv) Biomass	

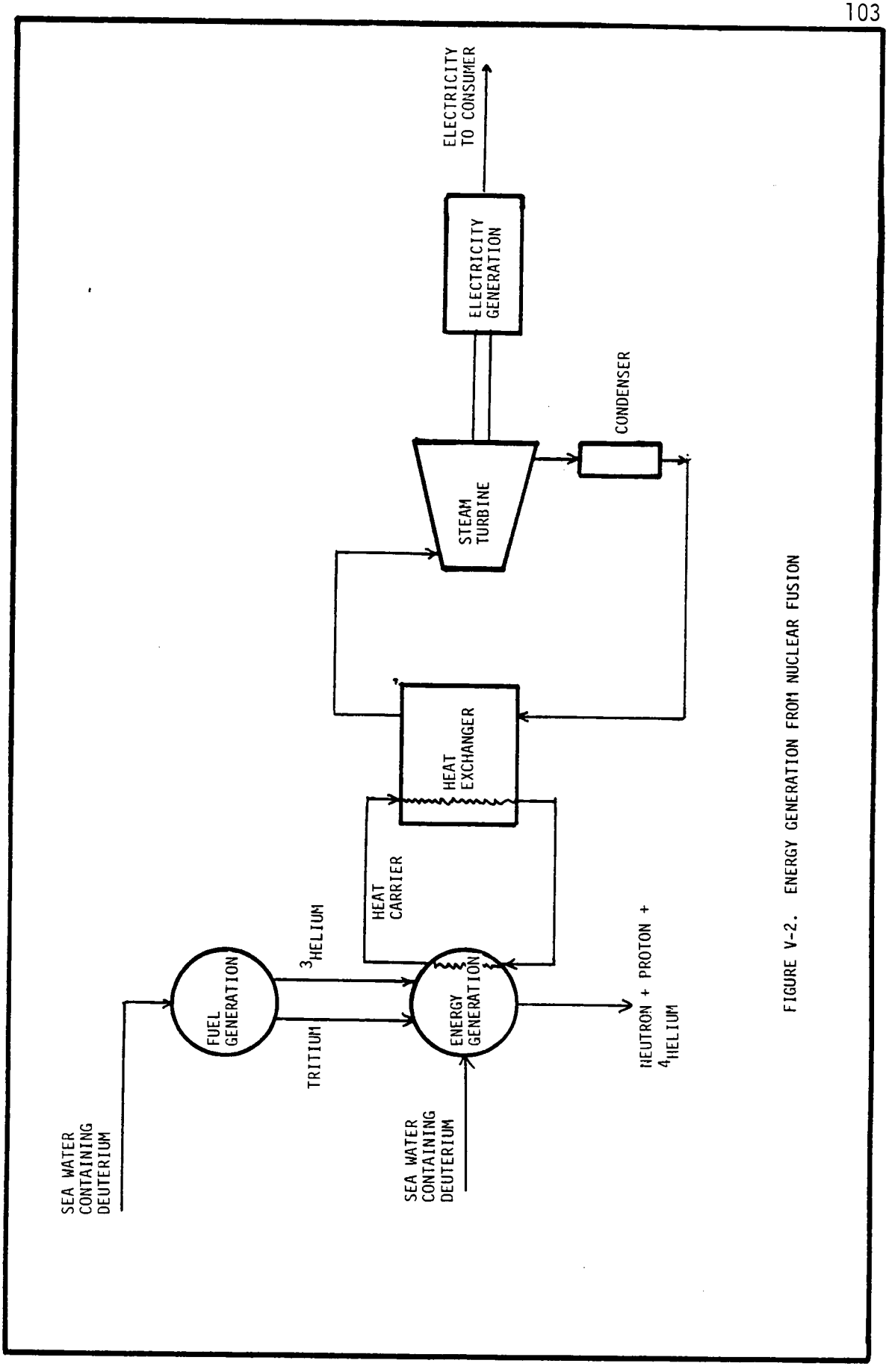
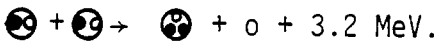


FIGURE V-2. ENERGY GENERATION FROM NUCLEAR FUSION

Fuel producing reactions:

(i) $D + D \rightarrow {}^{3}He + n + 3.2$ MeV.

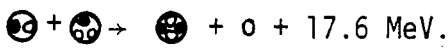


(ii) $D + D \rightarrow T + p + 4.0$ MeV.

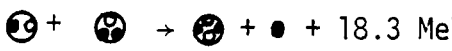


Energy producing reactions:

(iii) $D + T \rightarrow {}^{4}He + n + 17.6$ MeV.



(iv) $D + {}^{3}He \rightarrow {}^{4}He + p + 18.3$ MeV.



Overall reaction:

$$6D \rightarrow 2{}^{4}He + 2n + 2p + 43.1 \text{ MeV.}$$

Symbols:

D - Deuterium

T - Tritium

${}^{3}He$ - Helium-3

${}^{4}He$ - Helium-4

n - neutron (o)

p - proton (•)

MeV - Million electron volt

As classified above, the first two reactions produce the fuel, tritium and helium-3, which subsequently is used in reactions (iii) and (iv) to produce heat energy and helium-4. From the net reaction represented by equation (v) it can be seen that 6 deuterium atoms react to give 2 helium-4, 2 neutrons, 2 protons and 43.1 MeV (million electron volt) of energy in the form of heat. This means that roughly 7 MeV are obtained per deuterium reacting. Table V-2 gives an estimate of the

TABLE V-2

THEORETICAL DATA ON FUSION ENERGY

Basic Data:

(i) One deuterium atom per 6500 hydrogen atoms in sea water.

(ii) 7 MeV (million electron volt) energy produced by absorbtion of one deuterium atom.

Energy Equivalent of One Cubic Meter of Sea Water:

Number of deuterium atoms in one cubic meter = 1.71×10^{25}

Total energy equivalent $\equiv 12 \times 10^{12}$ joules

$\equiv 11.38 \times 10^{9}$ BTU

$\equiv$ 2000 barrel of oil (at 5.46×10^{6} $\frac{\text{BTU}}{\text{Bbl}}$).

potential of fusion power from sea water which contains one deuterium atom for every 6,500 hydrogen atoms. Using the theoretical figures of Table V-2 it can be shown that the energy content of one cubic kilometer of sea water is equivalent to that of 2000 billion barrels of oil, which represents the presently known world oil reserves. By carrying the calculation one step further, it can be shown that the energy content of the total volume of sea water is $1\frac{1}{2}$ billion times greater than the oil reserve mentioned above. Thus it can be safely assumed that if fusion power can be put to work economically, it would represent an essentially inexhaustible supply of energy.[49, 50]

Unfortunately fusion energy is far from being a practical source of energy at present.[48] Even those who are confident of the future of fusion energy would refer to it as a probable energy source of the 21st century, because of the many problems that have not been solved yet.

b. Nuclear Fission

Natural uranium[51] contains 0.71% by weight of the fissionable isotope uranium 235 (U^{235}) and the rest is almost entirely the non-fissionable isotope uranium 238 (U^{238}). At present the nuclear power plants are using only the U^{235} as fuel. This means that only 0.71% of the total energy content of uranium is being recovered, i.e., approximately 2.5×10^8 BTU per pound of natural uranium. Using the reasonably assured world supply of natural uranium of four million tons[51] the total energy supply from nuclear power plants would be in the vicinity of 2,000 quads. Thus the life time of nuclear power based upon U^{235} naturally available would be very brief.[34] By using the plutonium breeder reactor, on the other hand, the U^{238} isotopes can be converted to fissionable plutonium 239 which would bring the energy

equivalent of one pound of natural uranium to approximately 3.5×10^{10} BTU. That is equivalent to 6400 barrels of oil or 1460 tons of coal. Moreover, as shown in Table V-3, the energy available from the same source of uranium can be increased to approximately 275,000 quads, roughly equivalent to the energy content of the world's total fossil resources. Similarly with thorium breeder reactors thorium 232 can be converted to fissionable uranium 233 which would also increase the life time of nuclear power.

Nuclear (fission) power also is very uncertain due to the various factors given below.

(i) Social consequences of the atomic bombs of Hiroshima and Nagasaki still exist among the world's people.

(ii) Proliferation of nuclear power and eventual use as a weapon is believed to be a great danger.

(iii) Waste material disposal and storage from nuclear power plants and the eventual impact on environment and safety raises many questions.

(iv) The unfortunate recent accident at Three Mile Island has reinforced the questions raised by those who are protesting against nuclear power.

(v) The uncertainties associated with both the total uranium reserve and its price.

During recent years there has been increasing evidence of formal resistance to nuclear power in the U. S. as well as in other parts of the developed nations.[52] For instance in November of 1978 there was a referendum in Austria which produced a moratorium (ban) on nuclear

TABLE V-3

ENERGY FROM URANIUM RESERVE KNOWN

Total Reserve Known: 4.0×10^6 tons.

Percent U^{235} (by weight) - 0.71 [fissionable at present]

Percent U^{238} (by weight) - 99.29 [can be made fissionable with plutonium breeder]

Percent U^{234} (by weight) - very small

100.00

Heat content of fissionable uranium - 3.5×10^{10} BTU

≡ 6400 barrels oil (at 5.46×10^6 BTU/Bbl.)

≡ 1460 tons coal (at 24×10^6 BTU/ton)

Total energy equivalent of uranium

If only U^{235} used = 2,000 quads

If U^{238} made fissionable (plutonium breeder)

≡ 280,000 quads

≡ Total fossil reserve

power. All these controversial issues lead one to believe that the future of nuclear power is somewhat uncertain.

For the LDCs, in addition to the above problems, there would be many others associated with nuclear power. The first and the most crucial is the problem of the requirement of high capital investment, which most of the LDCs would be unable to provide. The second problem is associated with the optimum size. A typical size for a nuclear power plant is 300-1,000 Mw, i.e., almost three times the total electric generation capacity of Nicaragua (which was 300 Mw in 1976).[53] It can be argued that only one nuclear power plant would be enough to supply the electricity demand of Nicaragua, but it is not good energy system management to depend on only one power plant due to shut down requirements for maintenance, possible breakdowns, and refueling. Finally, import of uranium instead of fossil fuel will not solve the most crucial problem of the balance of payments being experienced by most of the LDCs.

2. Solar Energy

a. Direct Utilization

The direct utilization of solar energy generally consists of using the light radiated from the sun to produce electricity by means of photoelectric cells, or absorption to heat large volumes of water (or other liquids), and eventually transferring the heat to other processes. Fluctuations of the solar radiation within the day as well as within the year, and the problems associated with energy storage and expensive back-up system due to low load factor are some of the major limitations. Nevertheless, the possibilities of direct utilization of solar energy as an energy source are being investigated and quite a few useful systems have been suggested in this area.

Figure V-3 illustrates a solar water heater system in its simplest form. This type of solar heater already has been commercialized in several tropical countries, i.e., Australia and Israel, as a decentralized energy source for supplying hot water for domestic purposes.

Several cooling devices also have been suggested. One of them is the Solar-Mec unit[54] which uses the principle of desiccant cooling, proposed by the Institute of Gas Technology, and it seems to be promising. Nevertheless, the economic feasibility of direct utilization of solar radiation is still uncertain.

b. Indirect Utilization

The indirect utilization of solar energy involves the use of wind energy, hydroelectric power, thermal gradients of sea water, and biomass. As indicated earlier all the sources have their advantages and disadvantages and need careful investigation, with some now underway. This section summarizes some of the general conclusions of these investigations.

Figure V-4 gives the general layout of a wind mill which can be used to produce electricity. It must be noted that at the beginning of the 20th century, e.g., wind mills supplied an appreciable amount of electricity and rotational power (for running pumps) in many European countries, as well as in the U. S. in such states as Florida.[55] Wind mills have pumped water and provided mechanical power for centuries. The main reason for the fading out of these wind mills were:

(i) Natural gas and more oil were discovered, and wind mills became economically uncompetitive.

(ii) The variation of the wind speed energy storage problems were and still are the major limitations of wind mills.

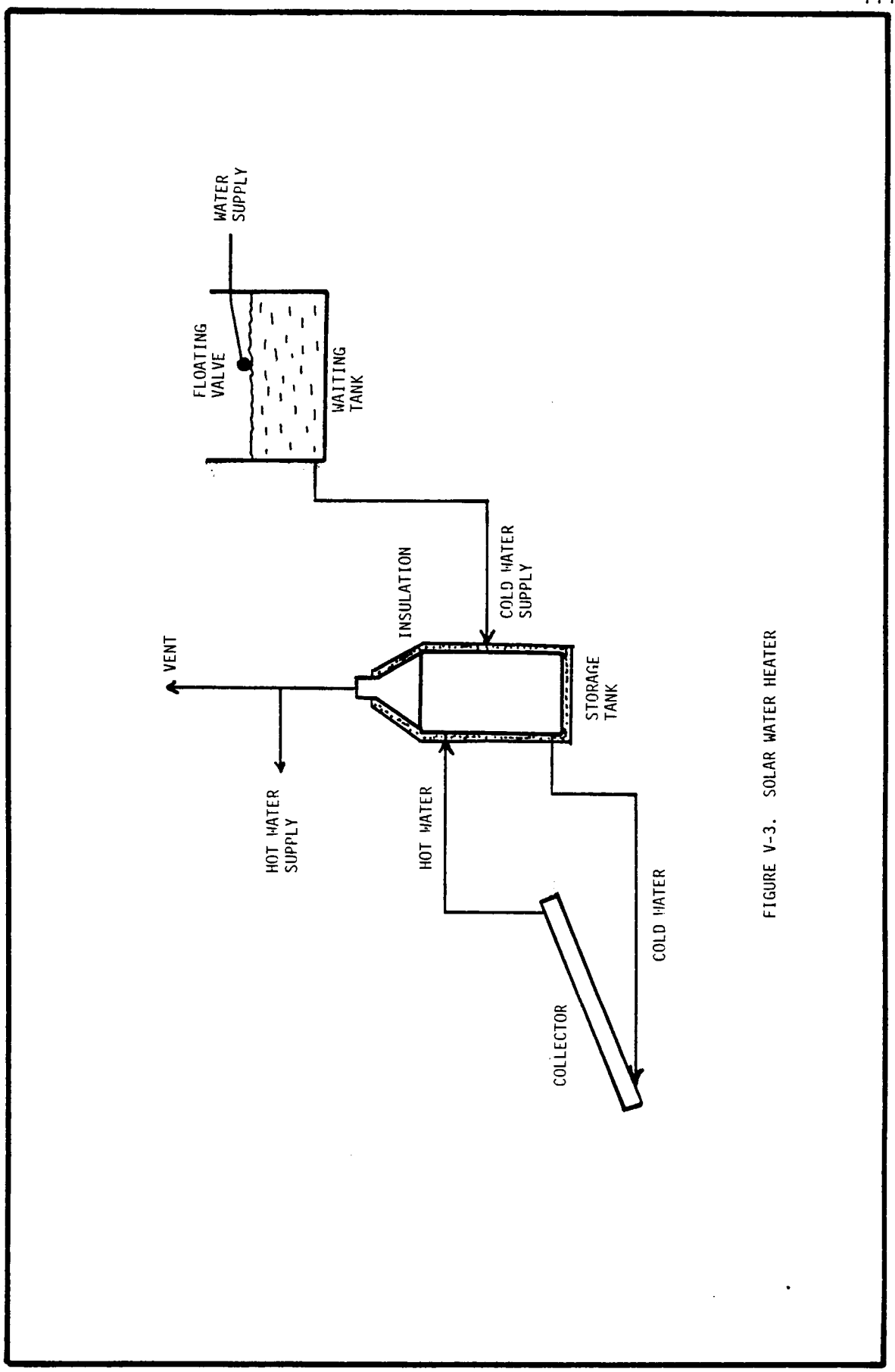


FIGURE V-3. SOLAR WATER HEATER

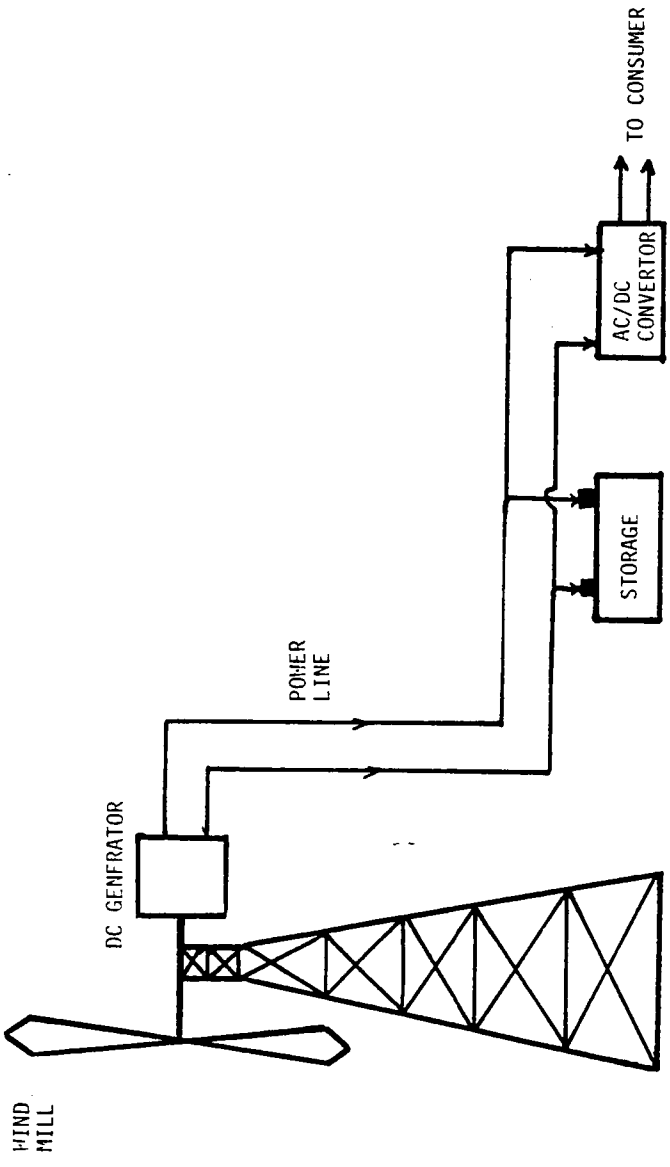


FIGURE V-4. POWER FROM WIND

Though new research has improved efficiency, wind mills are not yet economically feasible on a large scale.

Hydroelectricity obtained by converting the potential energy of a stream of water into kinetic energy and to electrical energy, either through utilization of naturally existing water falls or by construction of dams, provides roughly 24% of the world's electricity and about 14% of U. S. electricity demand.[29] World surveys have shown that the African, South American, and Asian continents have the most promising remaining sites for hydroelectric generation. However, the high capital investments required, which these countries have great difficulty in providing is a great handicap for future hydroelectric development. So far only 8.5% of the world's total hydroelectric generation capacity has been tapped.[34] Definitely the economic situation in the LDCs would determine the future of hydroelectricity. It must be recognized that, if capital can be made available and political problems associated with water rights are resolved, cost per unit of hydroelectricity could become very attractive.

Investigations on thermal gradients of sea water for future energy supply have revealed that at present this source is economically unfeasible and impractical.[56]

The utilization of biomass as an energy source can be separated into three major categories:

(i) Utilization of agricultural and forestry wastes or by-products.

(ii) Utilization of the whole agricultural crop which is raised solely for energy source.

(iii) Utilization of miscellaneous urban and animal wastes.

All of these make use of the photosynthesis process which converts solar energy into carbohydrates and cellulose, plus some hydrocarbons.[57] Though the average efficiency of the process is only about one percent, which seems low, it may have great potential as a future energy source.[46]

One of the great advantages of biomass from the photosynthesis process is that the product can be used either as an energy source or as chemical feed stock. Moreover, different forms of energy can be produced, e.g.,

(i) Production of heat, steam, and electricity by direct combustion.

(ii) Production of methane by anaerobic digestion.

(iii) Production of alcohol liquid fuel by fermentation and distillation.

(iv) Possible production of hydrocarbon liquid fuels.

The potential of biomass as an energy source is discussed in general in Section D of this chapter.

3. Miscellaneous Energy Sources

a. Geothermal Energy

Geothermal power is obtained by extracting heat stored temporarily in the earth by such sources as volcanoes, and hot water filling the sands of deep sedimentary basins.[58] So far only a few geothermal fields have been explored and a few wells are in operation. For example, the geothermal system in El Salvador is operating a 96 megawatt installed capacity power plant and providing 30% of the country's electricity demand.[59] Figure V-5 illustrates the layout of the process.

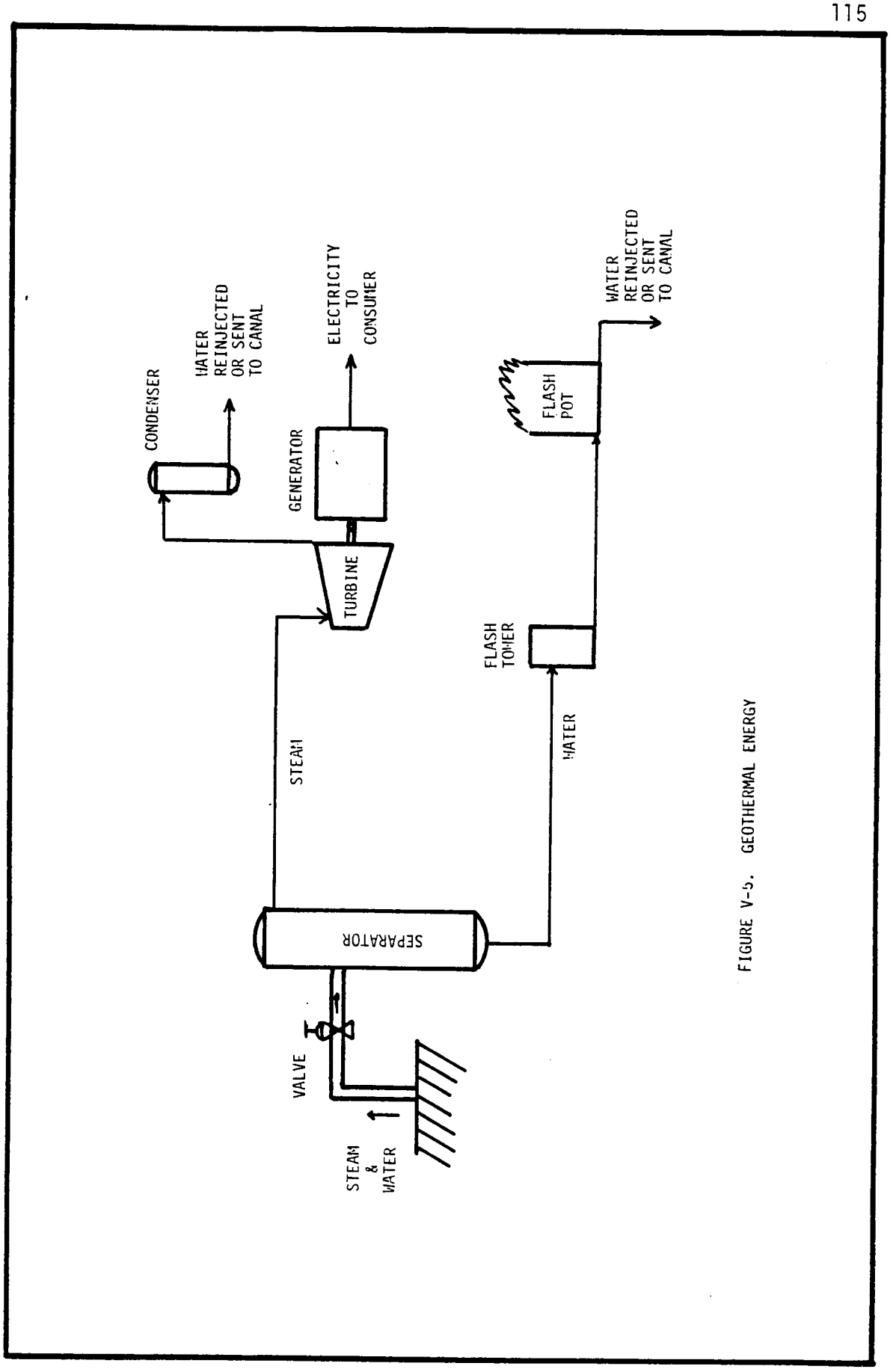


FIGURE V-5. GEOTHERMAL ENERGY

In Nicaragua a 100 megawatt capacity power plant is under construction.[60] However, it is obvious that high capital investment is still a problem. Though geothermal power plants are in operation in the U. S., Italy, New Zealand, and El Salvador, the future of geothermal energy is still uncertain.

b. Tidal Power and Sea Waves

At present, only one power plant, on Channel Island on the coast of France, is being operated on tidal power.[34] It involves the filling and emptying of Rance estuary on which the power plant is located. At present, energy from sea waves has not proved to be economically feasible.

D. The Potential of Biomass to Supply Energy

The photosynthesis process, which is represented by the equation below, is the sole supplier of the world's food.

$$\left[E_{solar} + \text{Carbondioxide} + \text{Water} \xrightarrow[\text{Chlorophyll}]{\text{Presence of}} \text{Carbohydrates} + \text{Oxygen.} \right]$$

The reaction is in fact more complex than it looks and has a very low average efficiency of about one percent.[46] Though the efficiency is low, it is a naturally occuring process that has been going on since the creation of the earth, and as pointed out earlier it is not only responsible for the current food supply but also for the world fossil fuel reserves. It has taken billions of years for the accumulation of such large fossil reserves.

Scientific experiments have shown that after various reflection and filtering losses an average of 1500 BTU per square foot per day of solar radiation reaches the ground.[47] This means that an agricultural

crop with an average photosynthestic efficiency of 1% converts approximately 15 BTU per square foot per day into usable (food and biomass) energy. The actual world potential of biomass as an energy source as classified into two categories is discussed below.

1. Biomass from Agricultural Wastes

Figure V-6 illustrates the process used for food production. The 1975 statistical figures on the area under agriculture for food production[61] (excluding area under forest), the total amount of food consumed and total amount of agricultural waste produced world-wide have also been included in the same figure. It can be seen that only about 1.5 to 2.0% of the total energy stored in biomass was consumed as food and roughly 98% of the product was returned to the soil. There are several reasons for returning the wastes to the soil.

(i) Agricultural wastes, when returned to the soil, improve its physical nature and return some nitrogen.

(ii) Returning of agricultural wastes helps control soil erosion.

(iii) Since the costs of collection and transportation are expensive, farmers have little incentive to collect the wastes.

Since the early 1970's energy crunch, the economics have changed and it now appears that the agricultural wastes may possibly become a substantial energy source. If part or all the agricultural wastes can be collected and used as chemical feed stock or converted into usable energy it would increase the overall farming revenue.

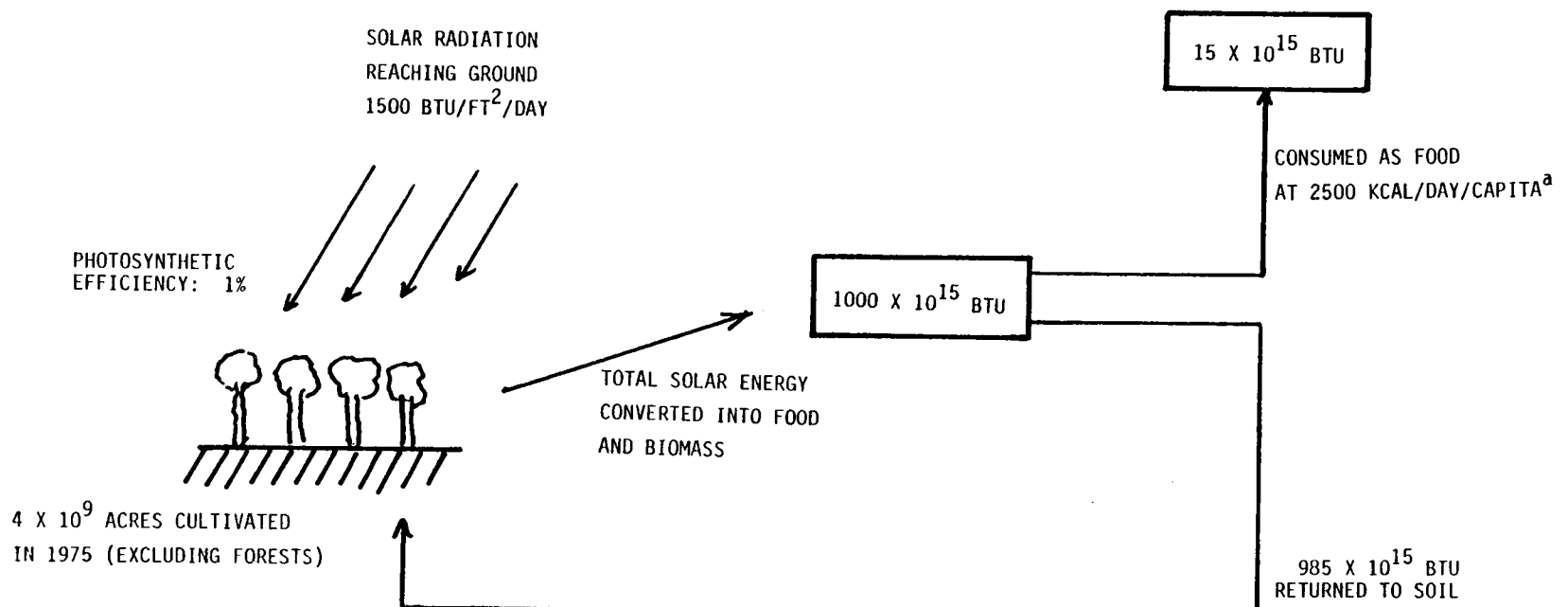


FIGURE V-6. FOOD AND BIOMASS PRODUCTION

[a]Lower than the acceptable nutrition level of 3000 Kcal. per day per capita recomended by U. N..

As can be seen from Table V-4 which summarizes the figures on an annual basis, using 1975 as an example, approximately 4 times the total world energy consumption was contained in the agricultural wastes. The question of how much of this energy can be made available given the current technology and economy has not been answered. Several factors such as overall energy balance of the farm, the economics of conversion processes, collection and transportation, and the environmental impact involved need to be considered in trying to answer the above question. Some of these factors have been analyzed in detail in Chapter IV which deals with some aspects of biomass utilization.

2. Energy Farms

The above route for energy production made use of food crops which generally have low photosynthesis efficiency (1%). This means much larger area of cultivation which leads to higher transportation and collection costs. In order to overcome these problems, other alternatives are being investigated. One of them is the creation of energy farms.[62] This involves growing crops with higher photosynthetic efficiency. Because of the possible competition for land between energy and food (the most essential commodity) production which might result from the concept of energy farms, it would be more advantageous to find plants which could be grown on marginal land. Unfortunately there has not been much success yet along these lines.

From the photosynthetic point of view two agricultural crops which are very attractive for energy farms at present are sugar cane and corn,[46, 47] with efficiencies of approximately three and two percent respectively. It must be mentioned, however, that they are not

TABLE V-4

TOTAL ENERGY FROM AGRICULTURAL WASTE - 1975

Total cultivated land (excluding forests)	4×10^9 acres
Total energy converted into usable food and biomass (at 1% photosynthesis efficiency and 1500 BTU/feet^2/day solar radiation reaching the ground)	1000×10^{15} BTU
Total energy consumed as food [a](by 4×10^9 people at 2500 Kcal/capita/day)	$\sim 15 \times 15^{15}$ BTU
Total energy contained in agricultural wastes returned to soil	985×10^{15} BTU
Total world energy consumption (1975)	250×10^{15} BTU

[a]According UN this is below acceptable nutrition level of 3000 Kcal/day/capita.

suitable for marginal land and at the same time they are two important cash crops for many LDCs and developed nations. The theoretical potential of these two crops, if they were to be used on energy farms, is summarized in Table V-5. From the table it can be seen that either sugar cane yield from 10% or corn yield from 14% of the total arable land could have provided the total energy requirement of the world in 1975. It must be emphasized that these are inferences based on theoretical data only. The fact that the situation is quite different from a practical point of view is discussed in chapters that follow.

E. General Comments and Problems Associated With Biomass Strategy

At this stage it is clear that new energy strategies for the future are essential in order to enhance the economic growth in the LDCs as well as to sustain the level of economy in the developed nations. It is also obvious, from the asymptotic model illustrated in Section B of this chapter, that by the end of the century renewable energy sources with substantial energy output must be found. But from Table V-6 which summarizes the discussion in Section C, it can be said that no new energy source has yet been found which can totally replace the traditional fossil energy.

However, biomass as illustrated in Section D of this chapter, seems to be the most promising future supply of renewable energy. Depending on the availability of land either agricultural wastes or the whole crop from energy farms can be used as biomass sources. Though there are many problems associated with biomass strategy, it is evident from Tables V-4 and V-5 that further investigations would be worthwhile. Moreover, the fact that the biomass strategy does not require highly

TABLE V-5

SUGAR CANE AND CORN AS ENERGY FARM CROPS

	Sugar Cane (3.0% photosynthesis efficiency)	Corn (2.0% photosynthesis efficiency)
Total solar energy converted into biomass energy/year/ acre	7.0×10^8	4.5×10^8
Total area required to produce 250 quads of energy (1975 world consumption)	3.6×10^8	5.6×10^8
Percentage of total 4 billion acres cultivated in 1975 for food production	10%	14%

TABLE V-6

SUMMARY OF POSSIBLE ENERGY SOURCES

Energy Source	Basic Principles	Remarks
1. Nuclear		
a. Fusion	D-D Reaction or D-T Reaction	Still in experimental stage, commercialization uncertain. If developed would represent "inexhaustible" energy source. Producing 5 to 6% of developed nations' electricity, social and political problems very crucial for future development.
b. Fission	Heavy metal fission, Uranium	
2. Solar		
a. Direct Utilization		
(i) Photoelectric Cells	Solar radiation directly converted to electricity.	Storage and seasonal variation problems, uneconomical so far.
(ii) Solar heating and cooling	Solar heat used directly.	Storage and seasonal variations problem, applicable to decentralized system.
b. Indirect Utilization		
(i) Wind Energy	Conversion of wind kinetic energy to electricity by using wind mills.	Storage problems and uneconomical so far.
(ii) Hydro-electricity	Conversion of potential and kinetic energy of streams into electricity, dams and falls.	Providing 24% of world electricity. High capital investment required for future development.
(iii)Thermal gradient of sea water	Using temperature difference of sea water at different depths.	Experimental stage, preliminary results show that it is uneconomical.
(iv) Biomass	Using agricultural wastes, energy farm crops, or urban and animal wastes produced by photosynthesis, can be used to produce liquid or gaseous fuel, and chemical feed stocks.	Becoming very attractive with price of fossil fuel increasing. Higher photosynthesis efficiency crop would be favorable. Most promising for LDCs. Land availability and environmental impacts need to be investigated.
3. Miscellaneous Sources		
a. Geothermal	Making use of steam stored underground in volcanoes and sand.	Commercially operating plant can be seen in some countries. Limited by availability of long lasting wells and lack of capital investment.
b. Sea Waves and tidal power.	Wave movement to turn wheel or turbine. Filling and emptying bays and estuaries. Both produce electricity.	Wave energy is still at experimental stage. Tidal power limited by site availability, only one operating commercially, coast of France. Both uneconomical so far.

sophisticated technology is another reason which justifies further investigations.[63] For that same reason the biomass strategy can be adapted easily to the LDCs where the need for domestic energy is much more important. This would not only lead towards energy independence but would at the same time help to increase food production for local consumption or even exportation purposes, especially in the case where agricultural wastes are going to be used for energy production.

On the other hand, some of the problems and consequences of biomass utilization for energy purposes that need serious attention and investigation are identified below.

(i) Environmental and ecological effects of deforestation.

(ii) Competition for land between food and energy production.

(iii) Availability of water.

(iv) Overall thermal efficiencies.[64]

(v) The effects of seasonal variations on supply.

It must be noted that investigation of all the problems associated with biomass utilization are beyond the scope of this study however, some of them have been considered in Chapters VI and VII.

Figure V-7 illustrates some of the various biomass materials which can be converted, by the four major conversion process, into energy and chemical feed stocks. Taking into account all the problems and uncertainties associated with fossil fuel discussed already in the preceding chapter and at the same time the inevitable problems associated with the new energy sources as discussed in this current chapter, it is essential that all the biomass strategies be investigated.

The Iranian case which indicates the use of oil as a weapon is a prime example indicating the need to investigate other alternatives for

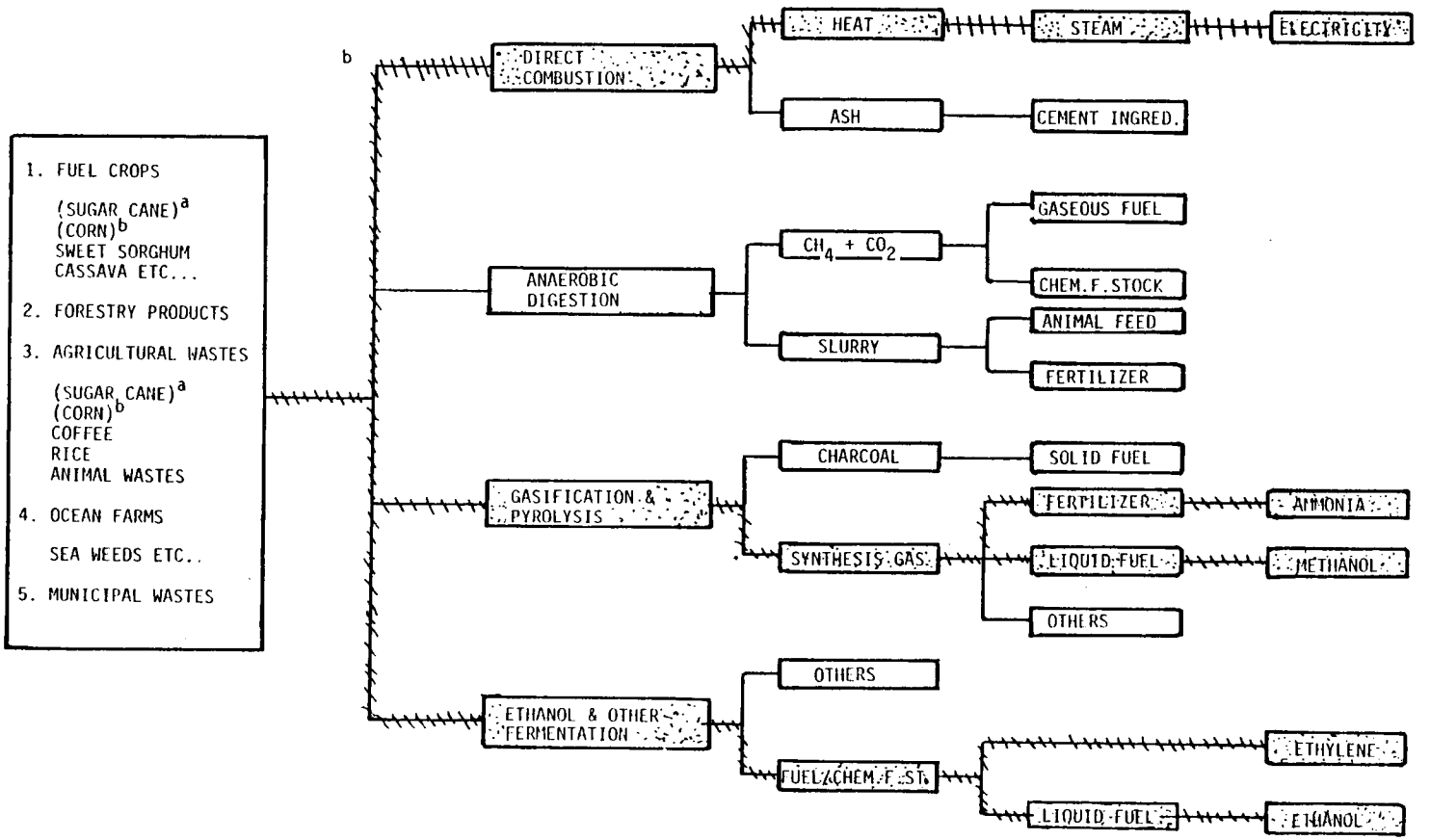


FIGURE V-7. BIOMASS UTILIZATION, ROUTES CONSIDERED

[a]Raw materials considered in this study.

[b]Shaded lines and blocks show routes considered in this study.

energy. However, in this dissertation the investigation has been limited to sugar cane, corn and their wastes for production of energy and chemical feed stocks, i.e., ethyl alcohol, methanol, electricity, ethylene, and ammonia. These are dealt with in the next chapter.

CHAPTER VI

BIOMASS UTILIZATION

A. General Discussion

Biomass can be utilized for the production of several chemical feedstocks and various liquid, solid, or gaseous fuels. The economics of only a few are favorable, however. In this chapter the use of sugar cane and corn as biomass sources for the production of ammonia, ethyl alcohol, methyl alcohol, ethylene, and electricity are considered as illustrated in Figure VI-1. Sugar cane is used in order to illustrate the potential of the biomass route for a specific raw material, but the results of the analyses associated with corn, which can be utilized in almost the same way as sugar cane, are illustrated in Appendix C and summarized in Section G.

Ammonia, which is the most important source of agricultural nitrogen fertilizer,[65] is produced primarily from natural gas and petroleum raw materials. The continuous increase in the cost of raw materials for the manufacture of ammonia has been a major drawback to the agriculture of most of the LDCs, which are heavily dependent on imported nitrogen fertilizer. Moreover, in order to keep up with increases in world food demand, the demand for ammonia for nitrogen fertilizer production has been increasing at roughly 10% annually.[66] Chemical processes to convert biomass into ammonia do exist but the feasibility of the actual system still has to be determined. Certain technological and economic aspects are dealt with in Section B of this chapter.

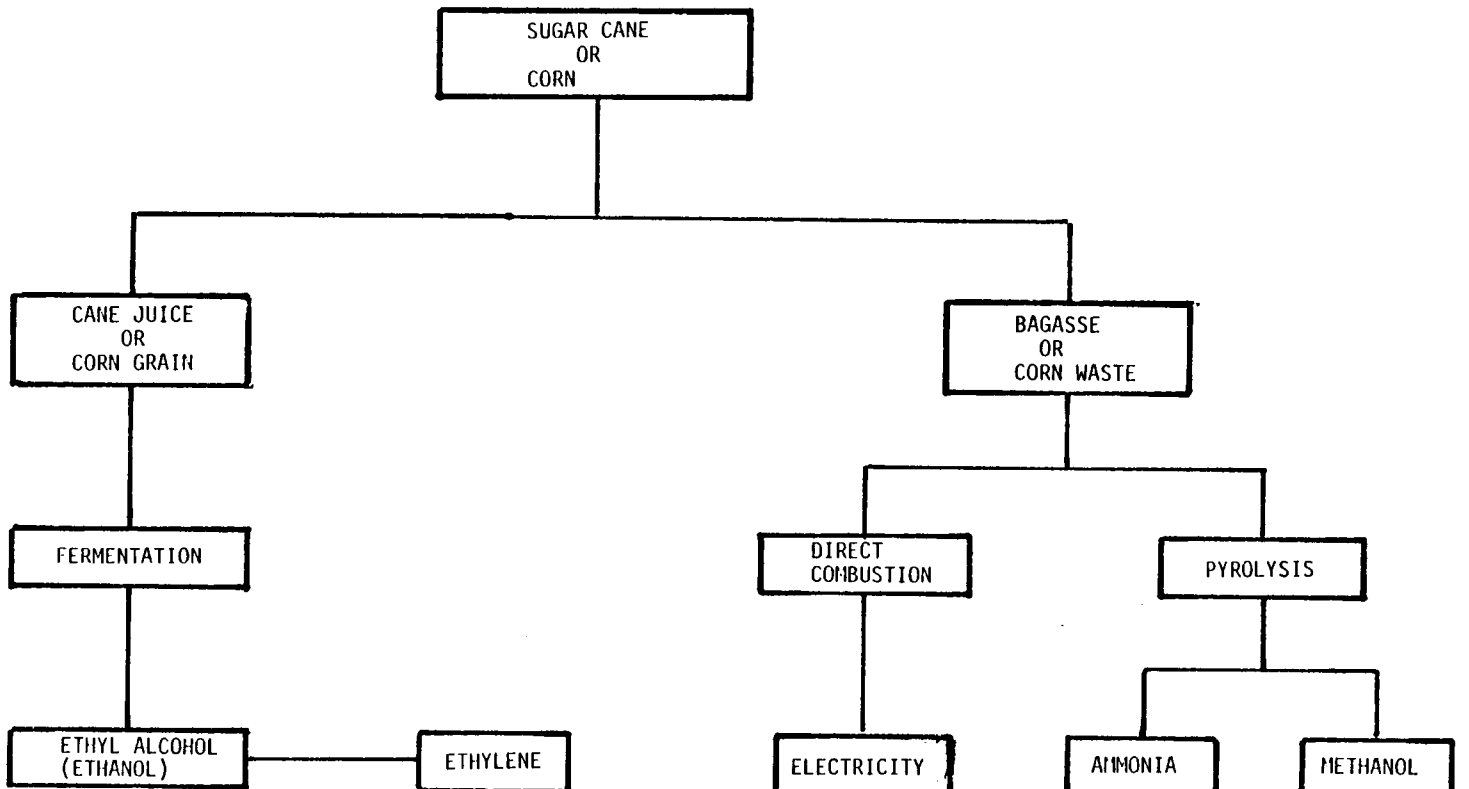


FIGURE VI-1. USE OF SUGAR CANE AND CORN AS BIOMASS, ROUTES CONSIDERED

Ethyl alcohol has been produced primarily from natural gas and other hydrocarbons,[66] with some beverage and industrial alcohol produced from grains and sugars. Thus, the increase in cost of these raw materials during the last five years has directly affected ethyl alcohol production costs. The fermentation of sugar, which has been known for centuries and is fairly simple process for fuel grade ethyl alcohol production, has not proved to be economically feasible in countries where the cost of crude oil has been 12 dollars per barrel or less.[67] However, recent OPEC oil price increases as well as the escalating problems related to the import of oil, call for re-investigation of this fermentation process. Furthermore, ethyl alcohol is a very attractive liquid fuel which may possibly be a good substitute for gasoline in the future. The technological and economic aspects of ethyl alcohol production are discussed in Section C of this chapter. The production of methyl alcohol, which is another attractive liquid fuel is discussed in Section D.

The demand for ethylene, which is important in the plastic industry, has been increasing at an annual rate of roughly 10% during the last two decades.[66] Increases in the cost of ethylene have been almost parallel with the cost of its major raw material, natural gas. On the other hand, the biomass route of fermentation to produce ethyl alcohol, and then conversion to ethylene, is technically feasible but the economics have not yet been attractive. Since the economics are changing rapidly both the economic and technical aspects need to be re-investigated. This is included in Section E of this chapter.

Electricity is another very important energy carrier, the demand for which has been increasing constantly in the developed nations as

well as in the LDCs. For example, the world average annual growth rate in electricity demand has been roughly 6 to 7% during the last two decades.[29,68] This growth probably will be higher in the LDCs in the near future, because of efforts to improve the quality of life in urban as well as in rural areas. Apart from a few countries which produce electricity by burning agricultural wastes, most electricity production is either from hydro, thermal (by burning oil, coal, or natural gas) or nuclear. Future prospects for using agricultural waste to produce electricity are illustrated in Section F of this chapter.

There are several other chemicals and forms of energy which can be produced from sugar cane and corn but the technological and economic feasibilities are still uncertain. Thus, at present the products shown in Figure VI-1 appear to remain the major targets of the biomass strategy. Finally Section G gives a summary of the results.

B. Ammonia

1. General Background

Before the First World War, Chili Saltpeter was the primary source of fixed nitrogen for agricultural purposes.[66] After Haber in 1913 found that ammonia could be produced by direct reaction between hydrogen and nitrogen under high pressure and temperature in the presence of a catalyst the situation changed in favor of synthetic ammonia. Before the Second World War, water gas from the reaction between steam and coke was the source of hydrogen. After the war natural gas became the major source of hydrogen as a result of its low cost and general availability. Thus, in 1974 almost 80% of the ammonia produced world wide came from natural gas. The process most commonly used is illustrated in Figure VI-2.

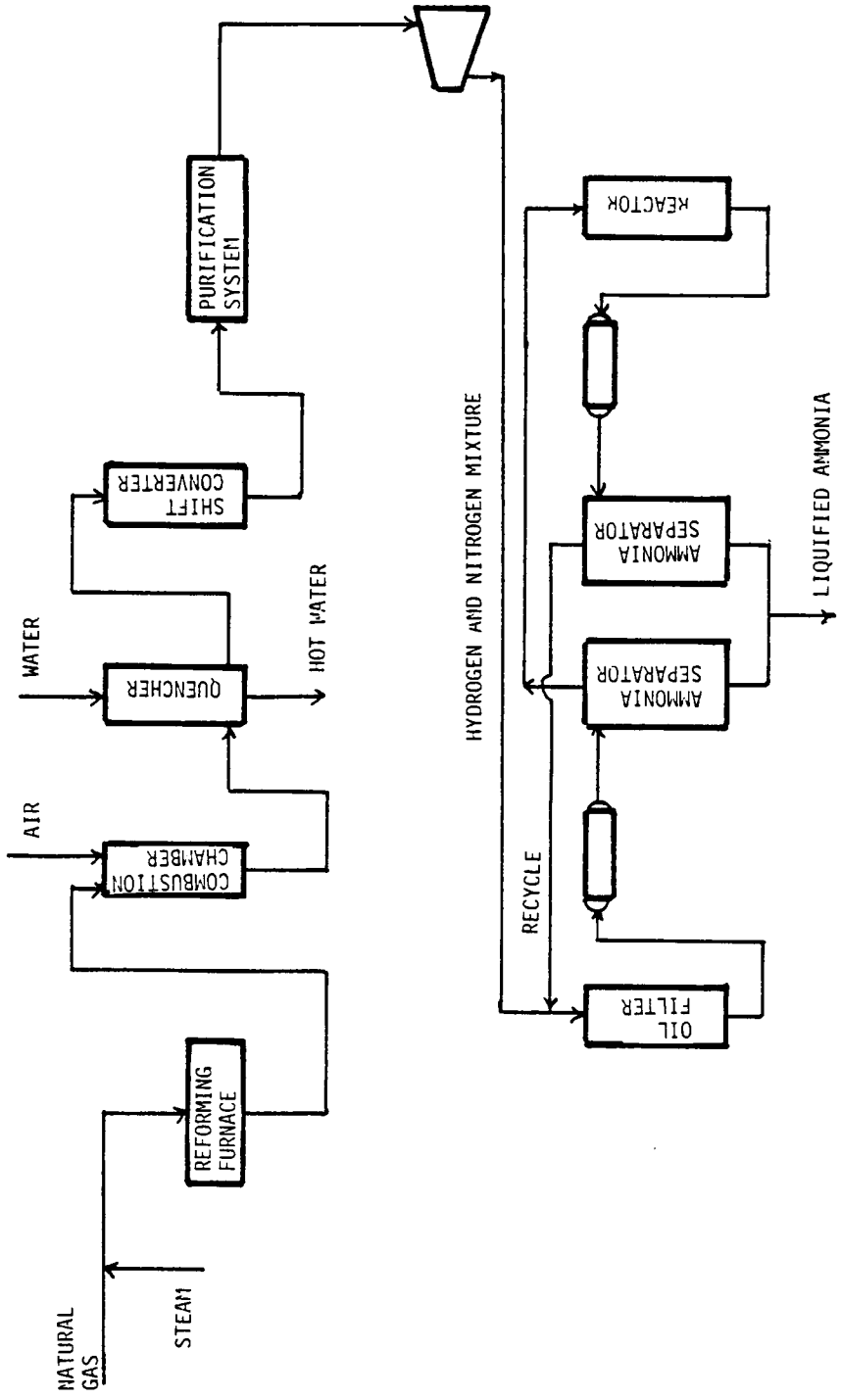


FIGURE VI-2. AMMONIA PRODUCTION BY CATALYTIC SYNTHESIS OF NITROGEN AND HYDROGEN

Source: Lowenheim, F. A., and Moran, M. K., "Industrial Chemical," John Wiley and Sons, New York, 4th. Edition, 1975.

Ammonia in one form or another, i.e., urea, ammonium nitrate, ammonium sulphate, ammonium chloride, and liquid ammonia is the most important source for nitrogen fertilizer in the agricultural sector. In order to keep up with world food requirements the demand for nitrogen fertilizers, i.e., ammonia, has been increasing at an annual rate of approximately 10% for the period 1950-1975, from roughly 4 million in 1950 to 44 million tons in 1975,[33] as illustrated in Figure VI-3. At present the amount of ammonia produced in the world, by the catalytic reaction of hydrogen and nitrogen, is exceeded only by sulphuric acid in the petrochemical industry. Roughly 80% of the ammonia produced goes into the manufacture of nitrogen fertilizer.[66]

Because of the gradual depletion and rapid price increase of natural gas the cost of ammonia, as of nitrogen fertilizer has been increasing very rapidly. Thus, it is obvious that replacement of natural gas by a new raw material for the manufacture of ammonia is essential. The next subsection illustrates the potential use of bagasse, which is the fibrous by-product of the sugar industry, for the manufacture of ammonia.

2. Manufacture of Ammonia from Bagasse

The manufacture of ammonia from bagasse consists of two main steps. The first step is the manufacture of synthesis gas by the Purox or similar processes and the second step is the conversion of synthesis gas to ammonia.[69] Bagasse obtained from the sugar cane grinders is dried or fed directly to a vertical furnace through the bottom of which oxygen is supplied. Oxygen at less than stoichiometric amounts goes through the furnace and reacts with the bagasse at around 3000°F to

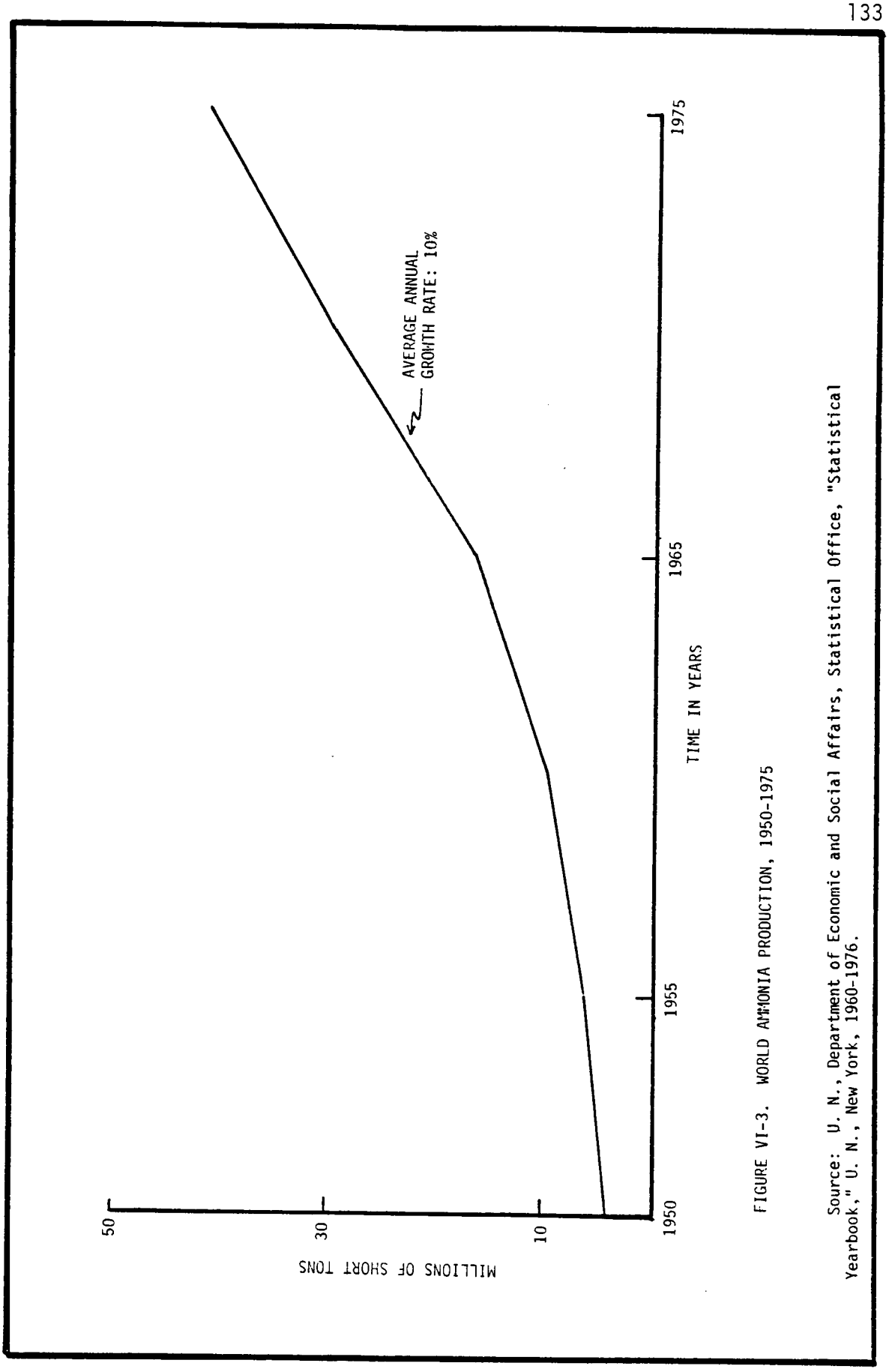


FIGURE VI-3. WORLD AMMONIA PRODUCTION, 1950-1975

Source: U. N., Department of Economic and Social Affairs, Statistical Office, "Statistical Yearbook," U. N., New York, 1960-1976.

produce synthesis gas in which the hydrogen to carbon monoxide ratio is about 0.6. The details of purification and acid gas removal are shown in Figure VI-4. The synthesis gas then is fed to the ammonia plant where further purification is carried out, then compressed and fed to a shift reactor. At this stage the process becomes similar to the one used for catalytic synthesis of nitrogen and hydrogen, as illustrated in Figure VI-2. The material and energy balance and the cost of production have been worked out in detail in Appendix C and given in summary form at the end of this chapter.

C. Ethyl Alcohol (Ethanol)

1. General Background

Only forty years ago 90% of the world's ethyl alcohol demand was supplied by the fermentation of agricultural products containing various sugars and starches.[66] Due to the rapid change in the availability and cost of fossil products in the early forties and fifties, the fermentation process was almost entirely replaced by synthesis processes which use a range of hydrocarbons as raw material for ethyl alcohol production. Synthetically produced ethyl alcohol, also known as industrial alcohol, supplied more than 90% of the world's ethyl alcohol needs in 1970.

Figure VI-5 illustrates the catalytic hydration of ethylene which is one of the major processes used at present for the production of industrial alcohol. The equation below represents the overall reaction involved in the process.

$$C_2H_4 + H_2O \xrightarrow{H3PO4} C_2H_5OH.$$

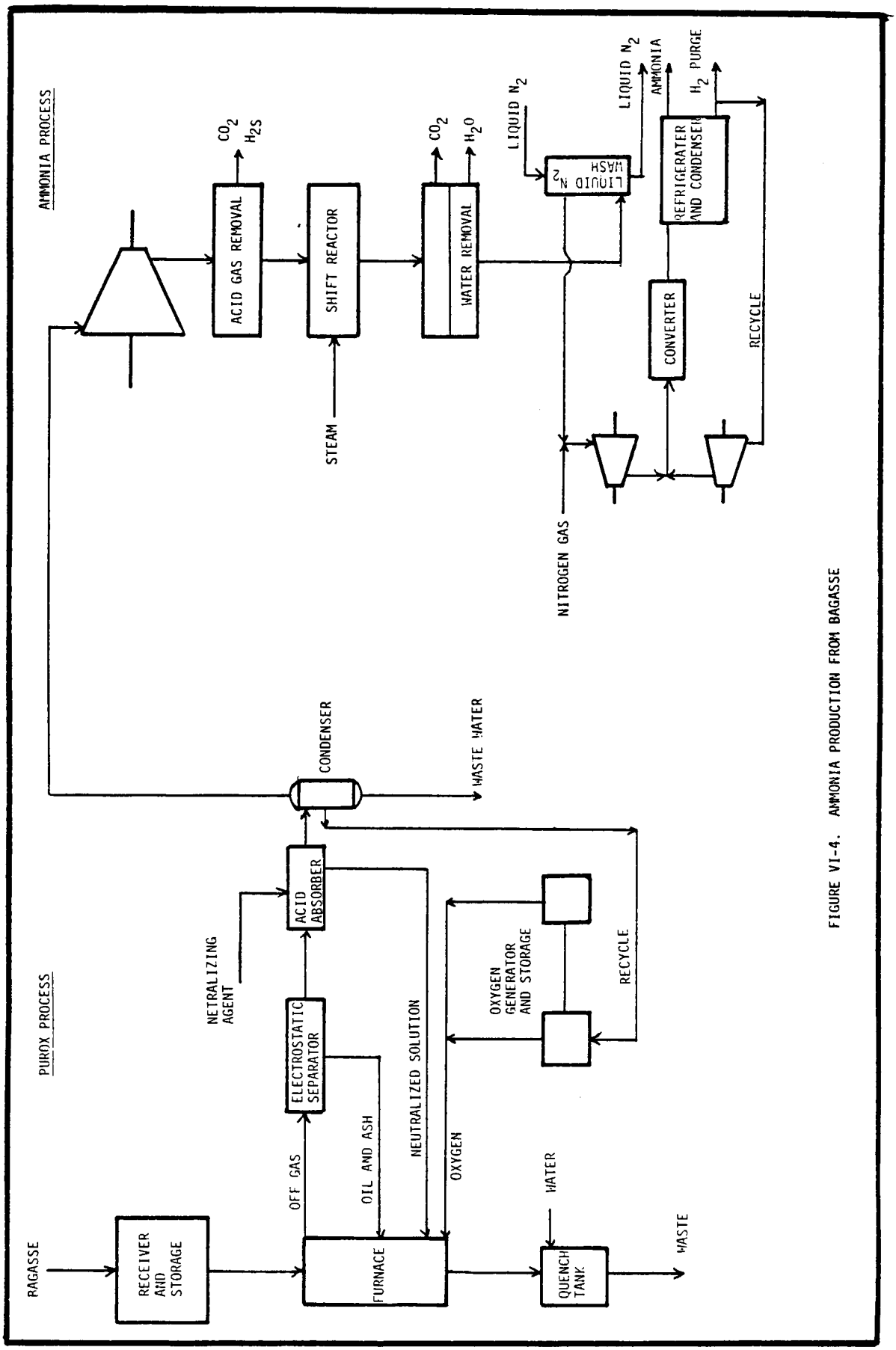


FIGURE VI-4. AMMONIA PRODUCTION FROM BAGASSE

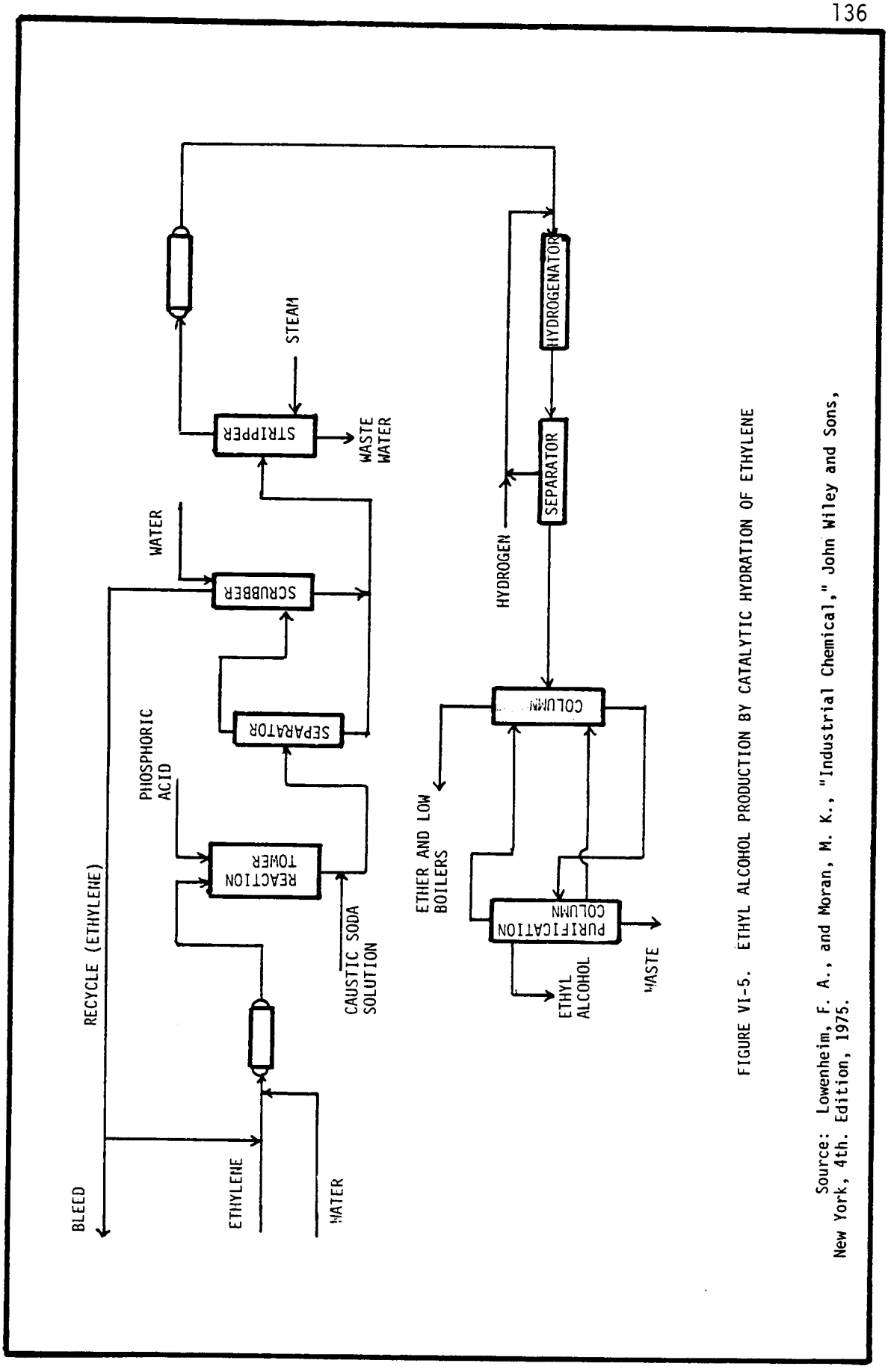


FIGURE VI-5. ETHYL ALCOHOL PRODUCTION BY CATALYTIC HYDRATION OF ETHYLENE

Source: Lowenheim, F. A., and Moran, M. K., "Industrial Chemical," John Wiley and Sons, New York, 4th. Edition, 1975.

In addition to its use as a solvent, industrial alcohol is used as the raw material for manufacture of glycol ethers, ethyl chloride, amimes, ethyl acetate, vinegar, acetic acid, and acetaldehyde. During the period 1970-1976, the demand for industrial alcohol in the world has grown by almost 6% annually[33] as illustrated in Figure VI-6.

The cost of the industrial ethyl alcohol produced by the above process is a function of the cost of the raw material ethylene which in turn is a function of the cost of natural gas and other oil products.[67] The cost of industrial ethyl alcohol in the U. S. has followed similar increasing trends as those of the fossil products during the last five years. For example, the price of ethyl alcohol went from 38 cents a gallon in 1970 to 60 cents a gallon in 1976, which translates into an average annual increase of roughly 8%.

By late 1979 those prices (FOB, freight on board) had increased to \$1.30-1.60 per gallon.[70] This reflects the fact that, since the oil embargo of 1973, the mix has been reversed. The escalating price of fossil materials coupled with their scarcity call for a re-evaluation of the fermentation process. Moreover, ethyl alcohol as one of the few liquid fuels available from renewable sources, and also its relatively high heat content of 12,500 BTU per pound (or 82.4×10^3 BTU per gallon compared to 123.8×10^3 BTU per gallon for gasoline) has attracted considerable attention during the last five years; current widespread utilization in Brazil is an example.[71,72]

Production of ethyl alcohol by fermentation for fuel and chemical feedstocks should be re-evaluated in the light of the new oil prices of 24 current dollars a barrel or higher. It also is important to investigate the overall material and energy balance of the whole system. A

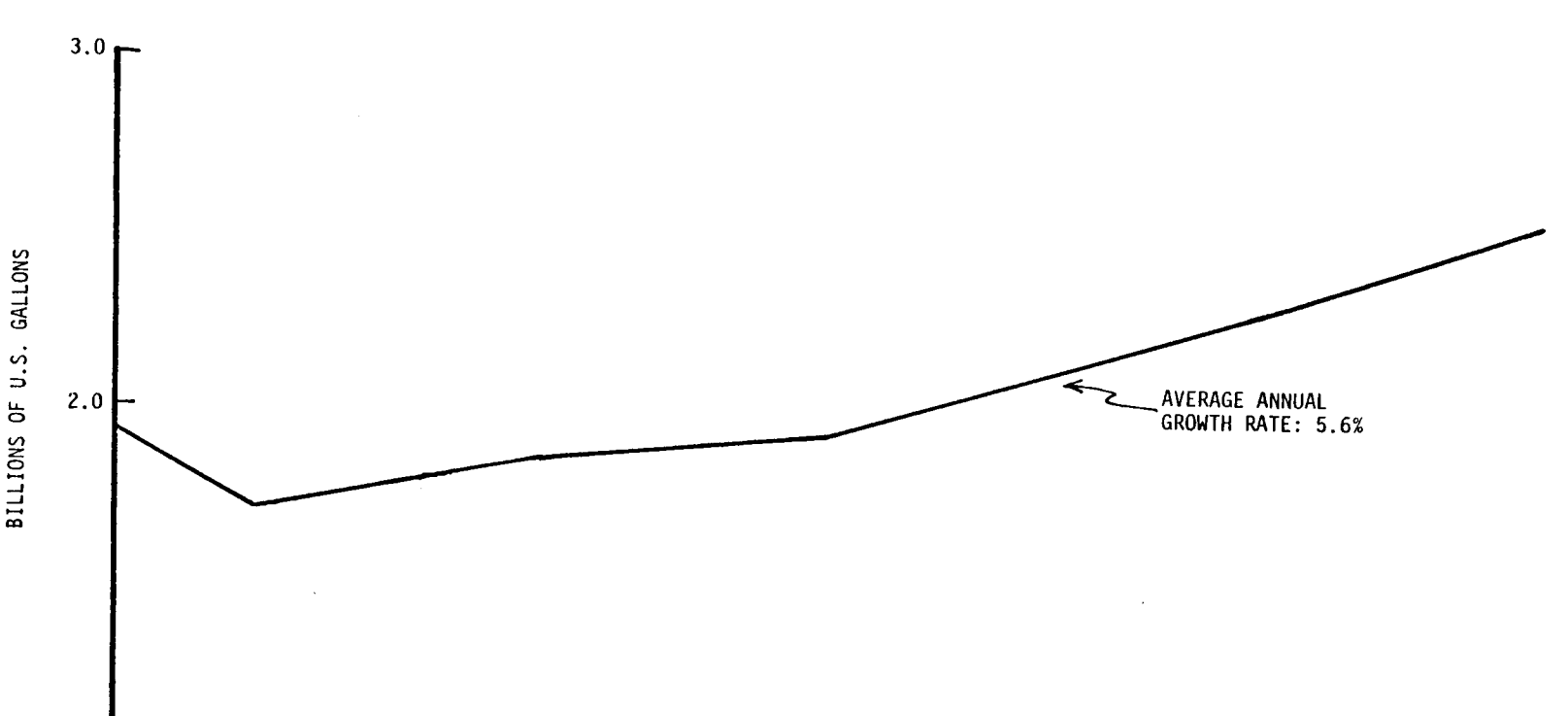


FIGURE VI-6. WORLD ETHYL ALCOHOL PRODUCTION, 1965-1975

Source: U. N., Department of Economic and Social Affairs, Statistical Office, "Statistical Yearbook," U. N., New York, 1960-1976.

description of the process used for the manufacture of ethyl alcohol from sugar cane and the general economics and material and energy balances associated with it are included in the subsections that follow.

2. Production of Ethyl Alcohol by Fermentation of Sugar.

Ethyl alcohol manufacture by fermentation has been known for centuries and is widely used in countries where the availability of mosasses (a by-product of sugar industry, containing 50% of fermentable sugars) is fairly regular. The process is based on the fermentation of sucrose to ethyl alcohol.[69] The first reaction is the inversion of sucrose to glucose and fructose by the enzyme invertase, followed by the conversion of both glucose and fructose to ethyl alcohol by the enzyme zymase. Both of the enzymes utilized are obtained from yeast.

$$\underset{\text{sucrose}}{C_{12}H_{22}O_{11}} + H_2O \xrightarrow{\text{Invertase}} \underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{fructose}}{C_6H_{12}O_6}$$

$$C_6H_{12}O_6 \xrightarrow{\text{Zymase}} \underset{\text{ethyl alcohol}}{2C_2H_5OH} + 2CO_2$$

The batch fermentation requires 30 to 72 hours depending on pH and temperature. The liquid contains more than 10% alcohol which is separated by distillation. Some other minor by-products such as aldehydes and fusel oil also are obtained. The process is illustrated in Figure VI-7.

As shown in the flow chart, sugar cane juice with a sucrose content of 12 to 15% also can be diverted towards the manufacture of ethyl alcohol. The use of sugar cane juice for the process depends very strongly on the market for sugar as compared to the market for ethyl alcohol. So far

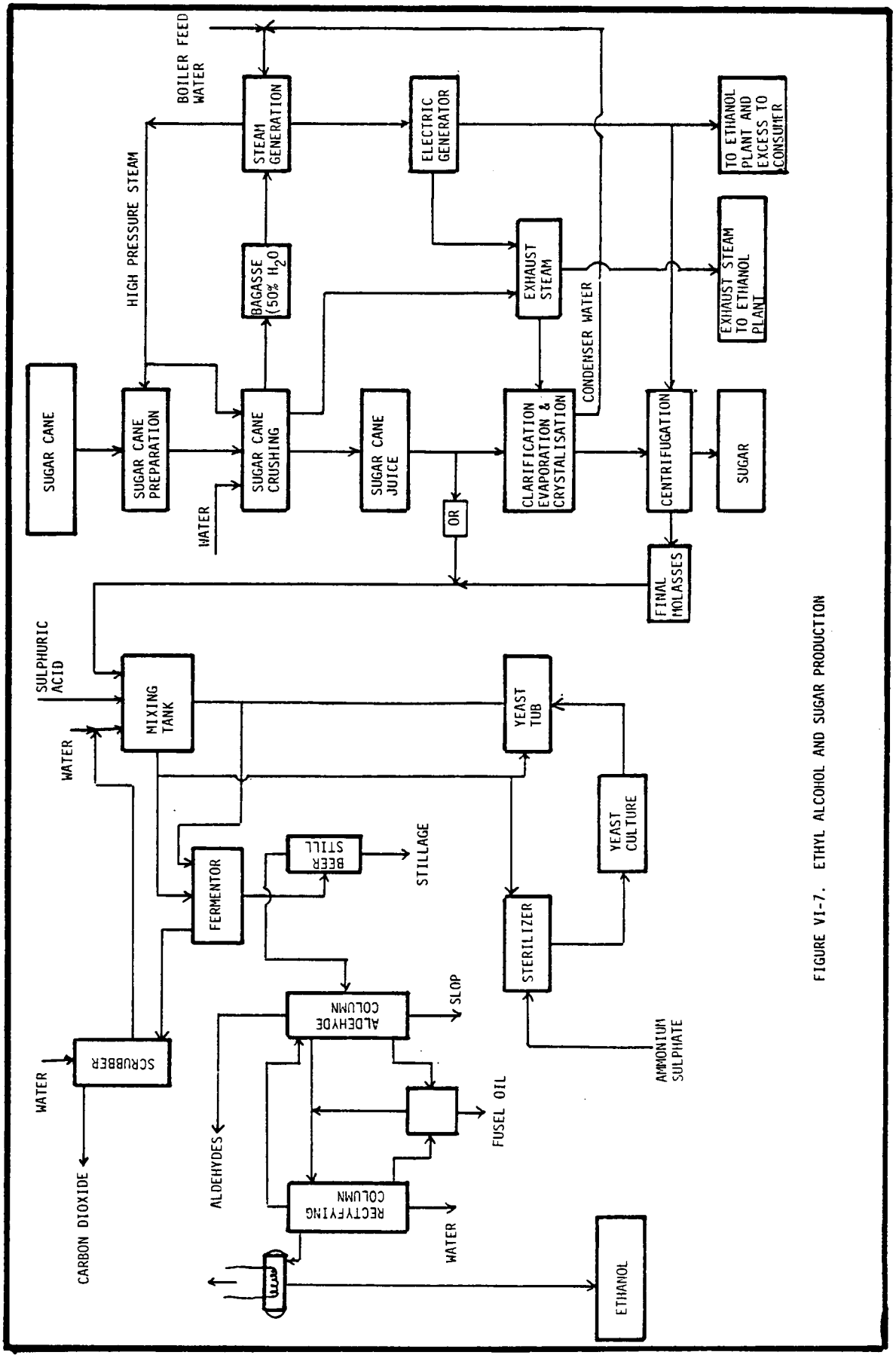


FIGURE VI-7. ETHYL ALCOHOL AND SUGAR PRODUCTION

the price of sugar has been so attractive that only a few countries have diverted some of their sugar cane juice to the ethyl alcohol production process. The diversion of more sugar cane juice for alcohol production can become very attractive if the use of ethyl alcohol as a liquid fuel substitute for gasoline is proved to be practical.

The overall material balance for both routes, i.e., using molasses and using sugar cane juice as raw material are illustrated in Appendix C which also includes the economics of the process. A summary of the material and energy balances and economics is included at the end of this chapter.

D. Methyl Alcohol (Methanol)

1. General Background.

Methanol is used as a raw material for the manufacture of formaldehyde and miscellaneous organic solvents. So far the 3.5 million tons (1975) of methanol required annually in the U. S. is obtained by a process based on the catalytic reaction between hydrogen and carbon monoxide, which required fossil resources to produce the synthesis gas.[66]

In recent years, because of the shortage and the high price of fossil fuels, consideration has been given to the use of methanol as a liquid fuel. Its non-polluting characteristics and good octane rating make the use of methanol as a liquid fuel attractive, but a number of unresolved problems remain.[73,74] Furthermore, the economic feasibility of large scale methanol production has to be investigated. The next subsection illustrates the use of synthesis gas obtained from biomass for the production of methanol.

2. Manufacture of Methanol From Synthesis Gas Obtained From Biomass.

Synthesis gas manufactured from a renewable energy source (bagasse) via the Purox or other similar processes can be used for methanol manufacture.[69] Figure VI-8 illustrates the process. Synthesis gas,[69] the analysis of which is given in Table VI-1, is compressed and fed to a shift reactor similar to the one discussed in the ammonia process. Carbon dioxide is removed and the ratio of CO to H_2 is brought to 1:2 before sending to the converter for catalytic reaction. The product is condensed and distilled.

It must be noted that the process is similar to the one commonly used to produce methanol from synthesis gas obtained from fossil resources. The economics and the material and energy balances are dealt with in Appendix C, and results summarized in Section G.

E. Ethylene

1. General Background.

The increase in ethylene demand has been spectacular since World War II. The advent of the commercial styrene industry in the early forties, greater demand for ethyl chloride in the late forties, and increasing use of polyethylene as a major plastic since the early fifties have contributed to the great increase in ethylene consumption.[66] It is anticipated that the demand will continue increasing at roughly 8 to 10% annually during the next 10 to 15 years.[75] Figure VI-9 illustrates the increasing trend of the ethylene demand in the world.

In 1970 ethane and propane from natural gas provided raw materials for almost 70% of the U. S. ethylene production. The hydrocracking process used is illustrated in Figure VI-10. With the recent increases

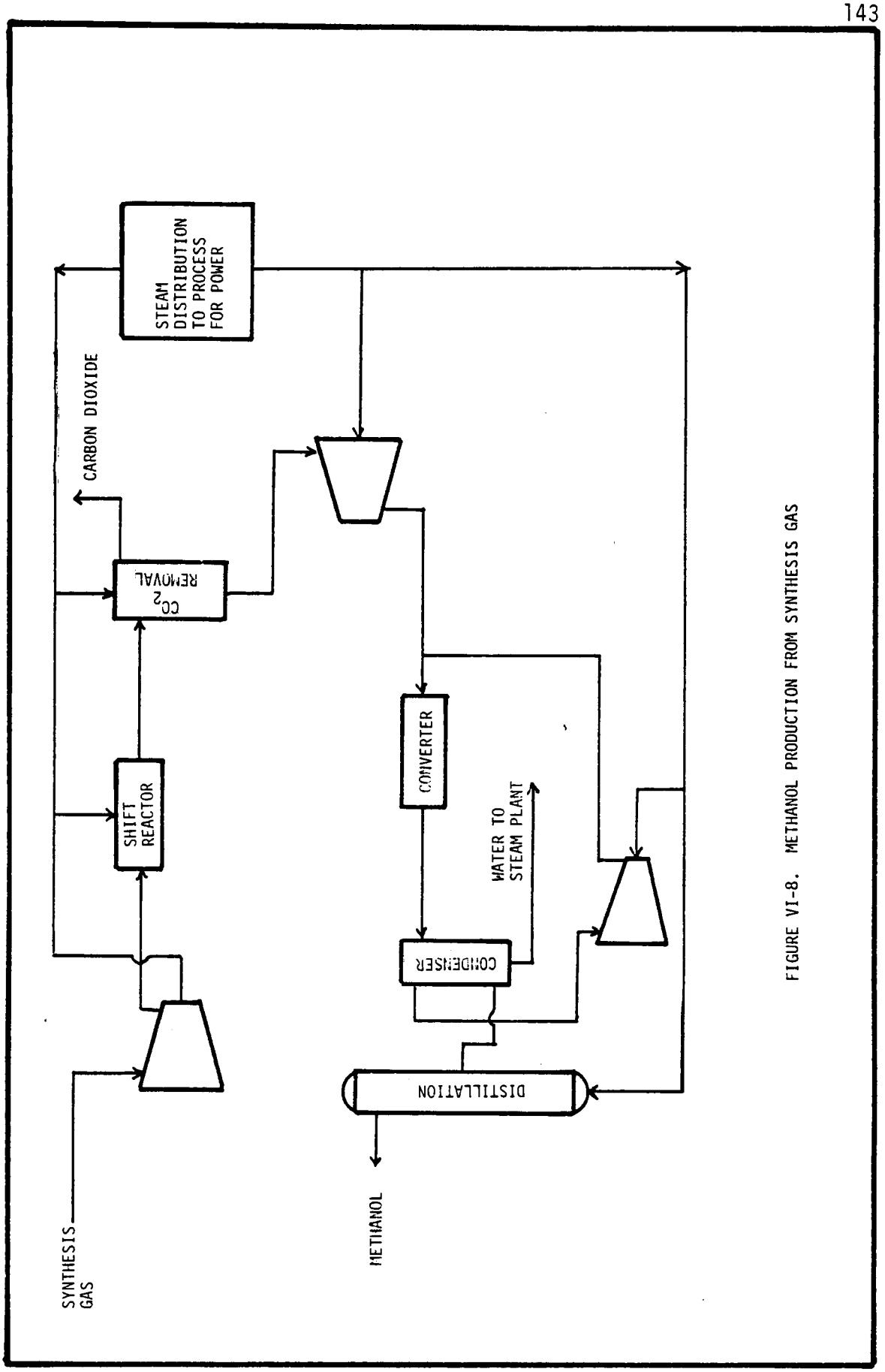


FIGURE VI-8. METHANOL PRODUCTION FROM SYNTHESIS GAS

TABLE VI-1

PUROX GAS ANALYSIS

Components	Mole Percent
CO	47.9
CO_2	11.8
H_2	30.1
CH_4	5.2
H_2S	0.02
Others	5.0
	100

Source: Cosidine, D. M., "Energy Technology Handbook," McGraw Hill Book Company, New York, 1977, p. 4.

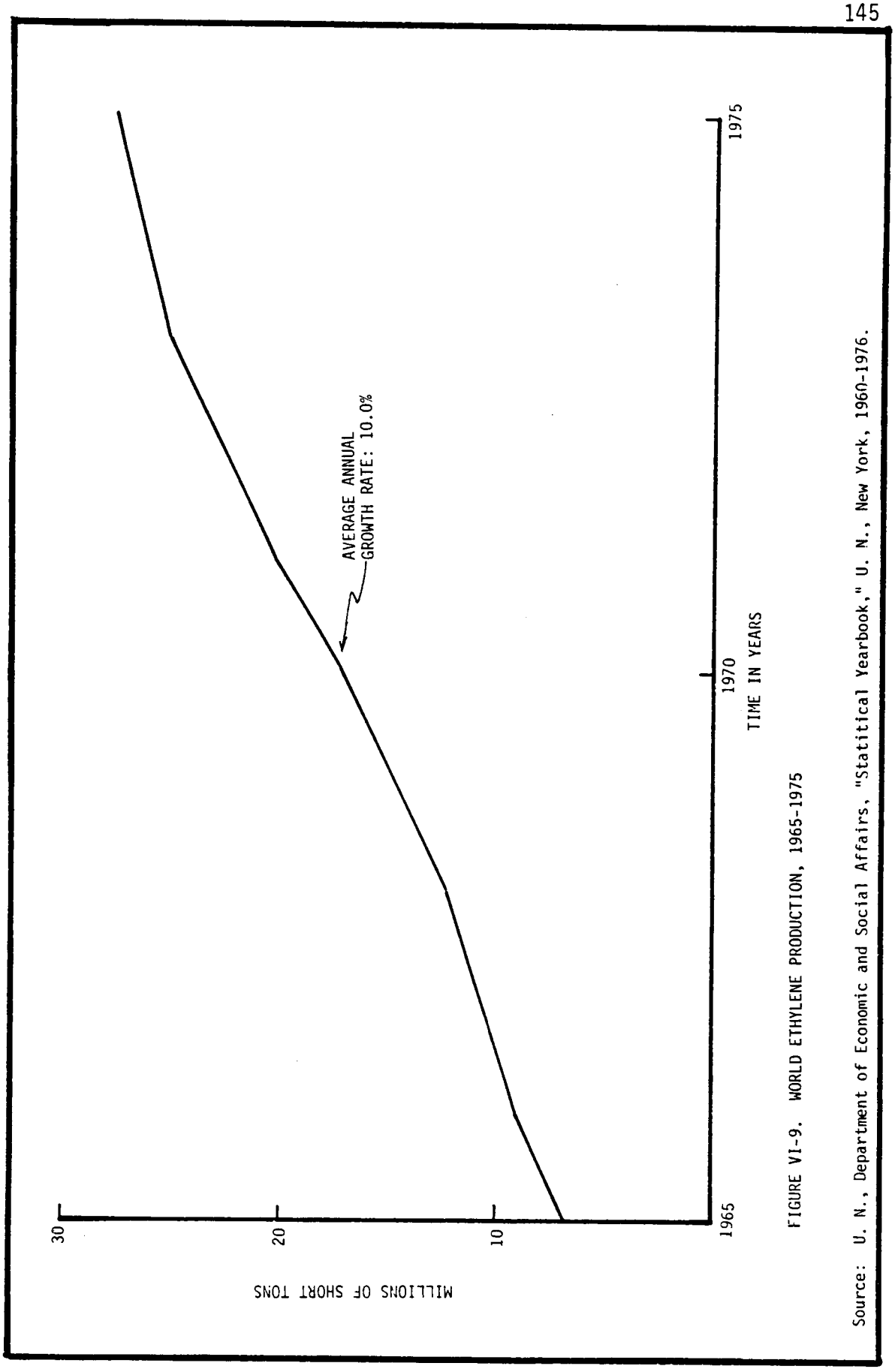


FIGURE VI-9. WORLD ETHYLENE PRODUCTION, 1965-1975

Source: U. N., Department of Economic and Social Affairs, "Statitical Yearbook," U. N., New York, 1960-1976.

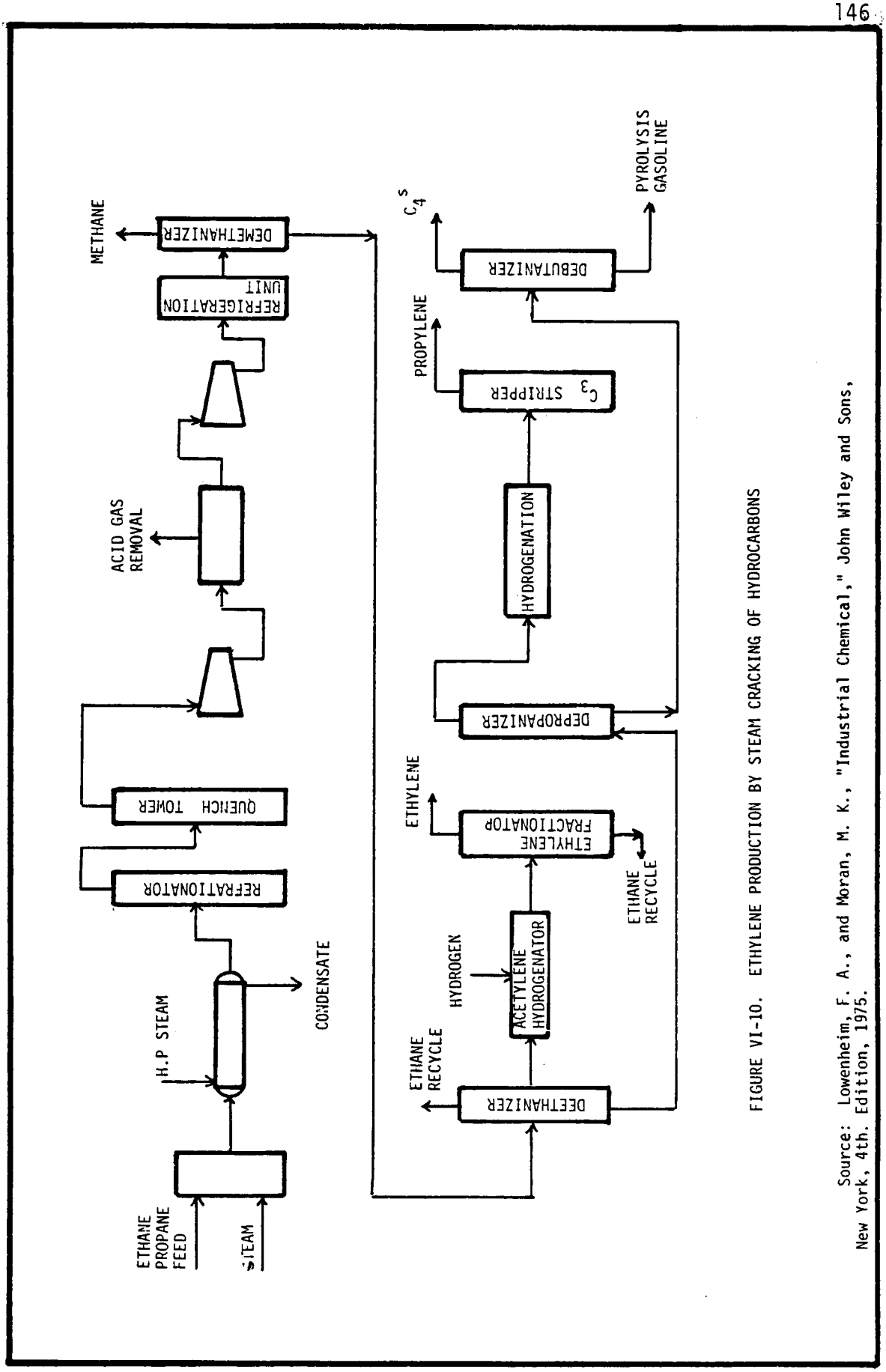


FIGURE VI-10. ETHYLENE PRODUCTION BY STEAM CRACKING OF HYDROCARBONS

Source: Lowenheim, F. A., and Moran, M. K., "Industrial Chemical," John Wiley and Sons, New York, 4th. Edition, 1975.

in natural gas prices and the great uncertainty in its supply, many ethylene manufacturers have moved to naptha and heavy oil as raw materials.[75] It is true that the cost of ethylene is somewhat higher using these raw materials instead of natural gas, but this is compensated for by several by-products which have good markets. The cost of ethylene has been projected to rise from 14 to 24 cents a pound or even higher in the next 10 years.

Plastic goods consumption is fairly high world wide. However, only a few countries which have hydrocarbon reserves are the producers of plastics and plastic goods. Thus, most of the LDCs are heavily dependent upon imported plastic goods. As illustrated in the next subsection ethylene can be produced from ethyl alcohol, which in turn can be produced by fermentation of agricultural materials which are locally available. This can provide a domestic raw material source for the LDCs.

2. Production of Ethylene From Ethyl Alcohol Produced From Biomass.

Although at present industrial alcohol is produced by the catalytic hydration of ethylene, the process can be reversed. The question of whether the reverse process is favorable depends on the economics of the market situation. For countries which do not have any hydrocarbon reserves, ethylene can be produced by using the locally available ethyl alcohol obtained by fermentation of agricultural products. The process is fairly simple and is based on the following chemical reaction:

$$C_2H_5OH \longrightarrow C_2H_4 + H_2O$$

From the material balance calculation shown in Appendix C, it can be concluded that even at 100% conversion, for every unit weight of ethylene 4 units of fermentable sugar are required. For this reason the process does not appear to be attractive at present.[76] The 1975/77 Battelle Columbus Laboratories [BCL][67] studies have shown that the cost of oil must rise to 30 dollars per barrel for the process to become competitive with the current processes. This route has been re-evaluated here, and the economic and the material balance have been summarized at the end of this chapter, with detailed illustration included in Appendix C.

F. Electricity

1. General Background.

Electricity is a desirable energy carrier. The total world energy electricity demand as illustrated on Figure VI-11 has been increasing at roughly 8.0 % annually since 1950. Electricity is produced from various energy sources and Table VI-2 gives the breakdown of the 1975 world electricity production.[29,67]

There is certainly a great potential for the expansion of hydro-electricity, which is a renewable source, in the LDCs. Surveys have shown that only 8.5% of hydropower world wide has been tapped. The greatest potential however, is found in the Asian, African, and South American continents where availability of capital for expansion is very low.[34] On the other hand, there are many other renewable sources of electricity but the most attractive one may be the utilization of biomass. This is the subject of discussion of the subsection that follows.

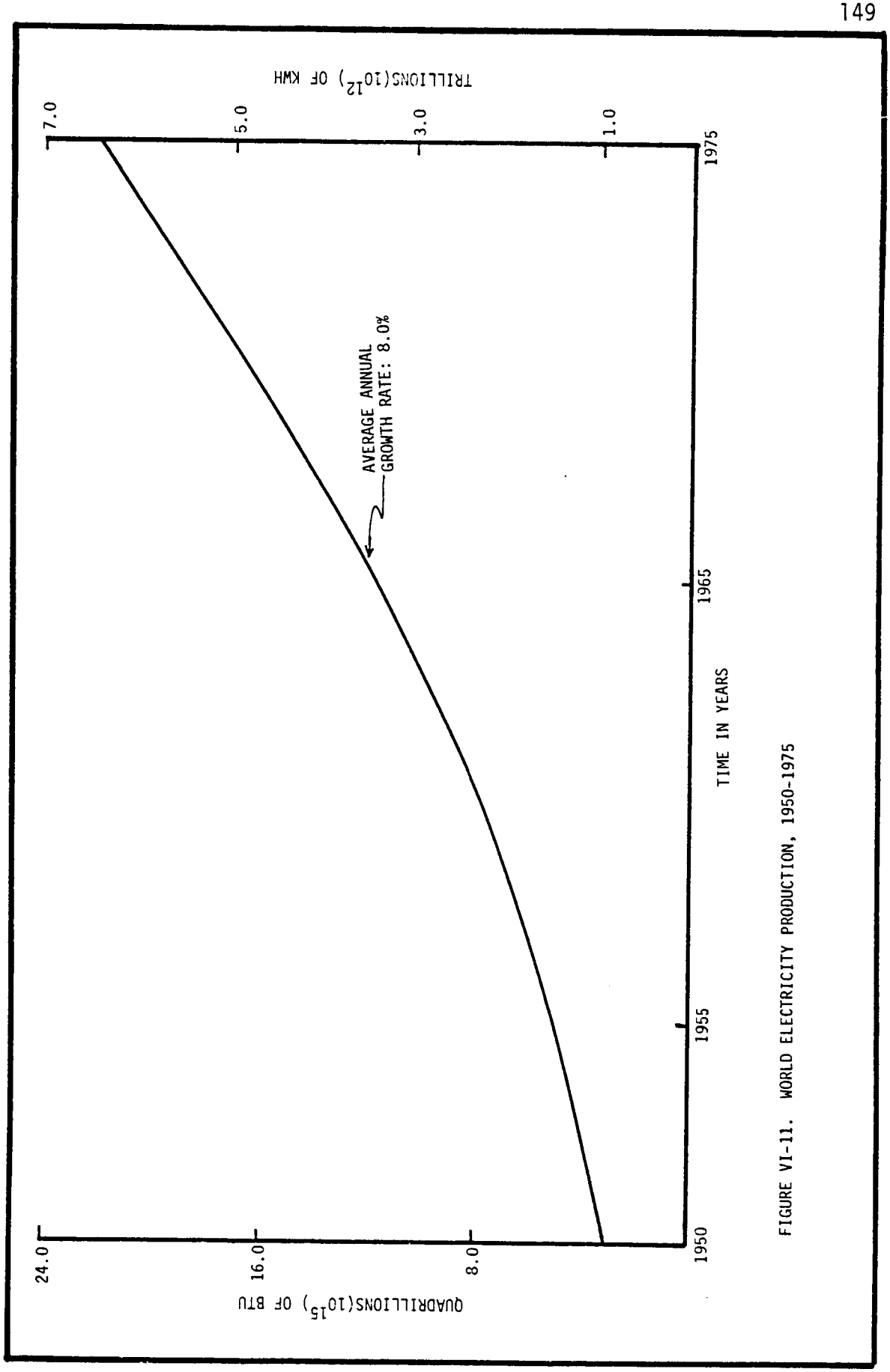


FIGURE VI-11. WORLD ELECTRICITY PRODUCTION, 1950-1975

TABLE VI-2

WORLD ELECTRICITY PRODUCTION - 1975

Sources	Production		Percentage
	10^9 KWH	10^{15} BTU[a]	
Thermal	4638.306	15.815	72.1
Hydro	1458.410	4.973	22.6
Nuclear	342.202	1.167	5.3
Total	6438.918	21.957	100.0

[a]Conversion unit used: 1 KWH ≡ 3410 BTU.

Source: U. N., Department of Economic and Social Affairs, Statistical Office, "World Energy Supplies, Statistical Papers, Series J No. 20," U. N., New York, 1977.

2. Electricity Generation From Biomass.

Figure VI-12 shows the production of electricity as a by-product from the sugar cane industry. Bagasse which is a by-product of the sugar industry has a relatively high heat content of 5000 to 6000 BTU per pound at 50% moisture. This is directly fed at present to a furnace for production of steam which is then used to run turbines and eventually to produce electricity.[77]

This process accounts for approximately 25% of the Hawaiian and 15% of the Mauritian[78] electricity supply. It also is practiced in Queensland, Australia and in South Africa which are sugar producing nations. The economics and energy balance are discussed in detail in Appendix C and summarized in Section G of this chapter.

G. Results and Comments

Figure VI-13 illustrates all the processes, analyzed in detail in Appendix C, for the production of fuel and chemical feedstocks from sugar cane. The results of these analyses have been summarized in Figures VI-14 and VI-15. The second most attractive biomass feedstock which can be utilized in ways very similar to sugar cane has been analyzed briefly using BCL[79] data and the results included in Figures VI-16 and VI-17. Table VI-3 summarizes the cost estimate of products from both sugar cane and corn.

From the results in all the tables and figures mentioned above it is evident that biomass offers a potential alternative for production of energy and chemical fuel feedstocks, especially in the LDCs, for reasons already mentioned. Thus, it is recommended that all of the LDCs should analyze the biomass strategy vis-a-vis their own economy, their own energy use patterns, and their agricultural systems.

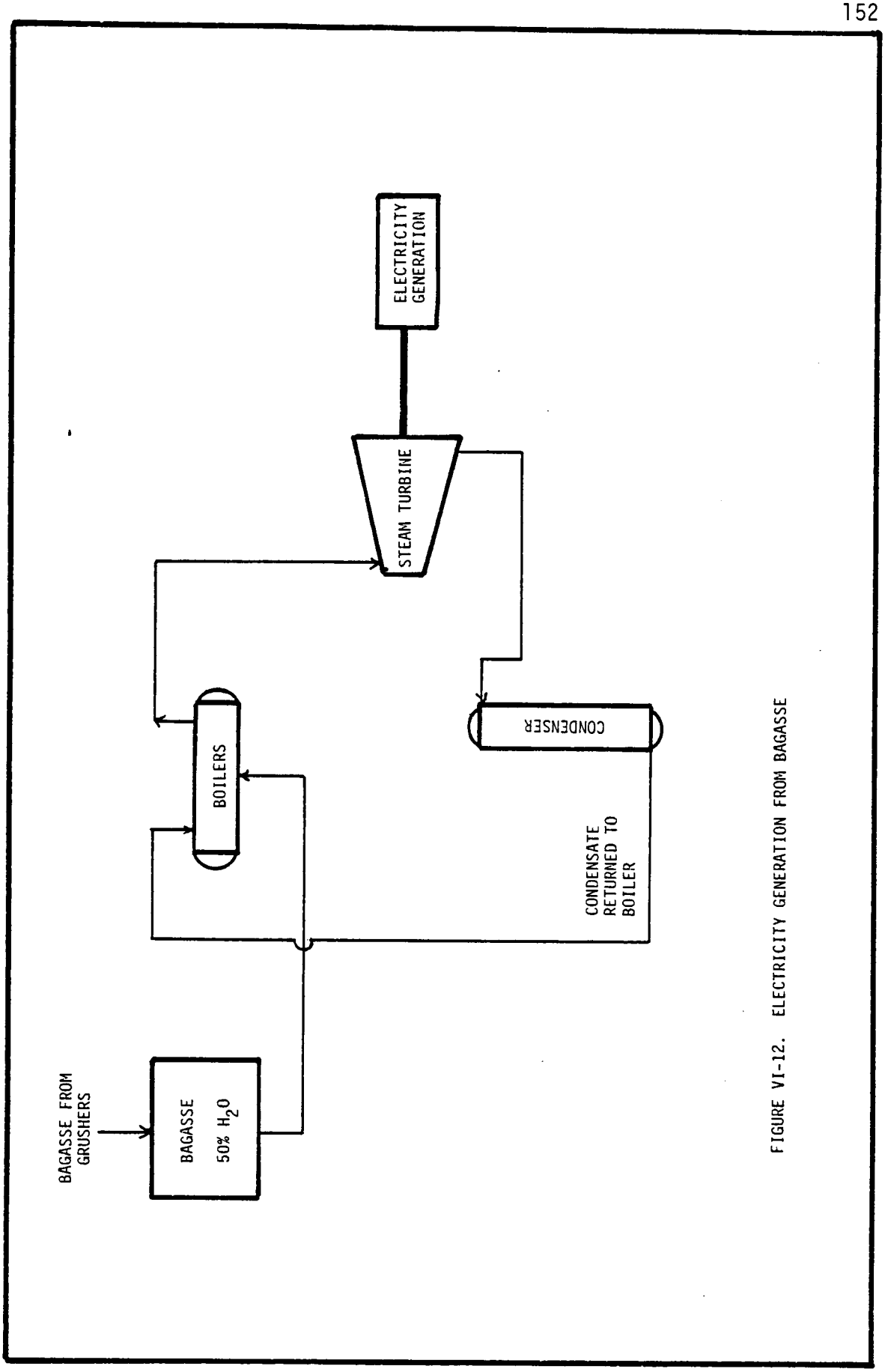


FIGURE VI-12. ELECTRICITY GENERATION FROM BAGASSE

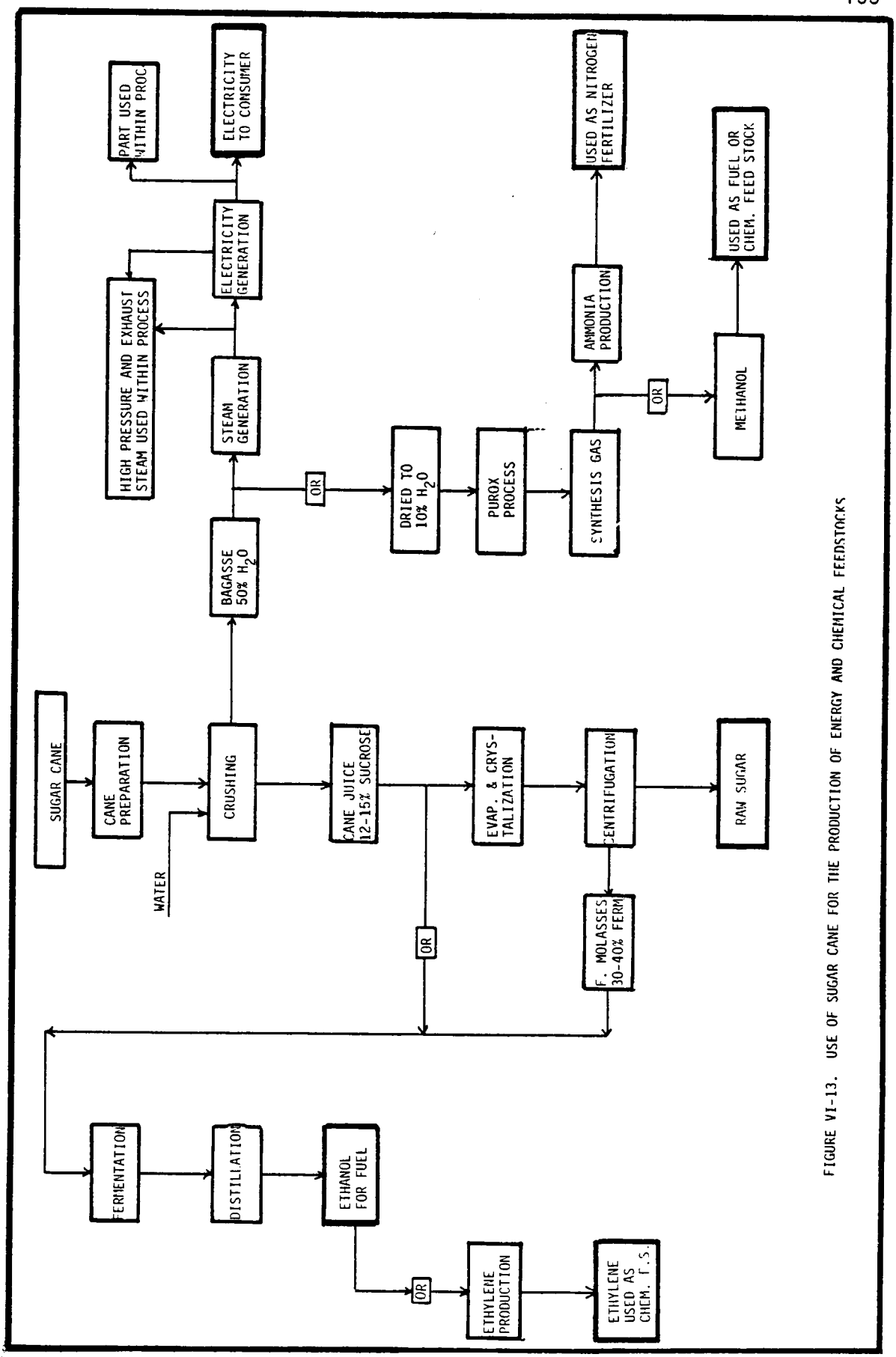


FIGURE VI-13. USE OF SUGAR CANE FOR THE PRODUCTION OF ENERGY AND CHEMICAL FEEDSTOCKS

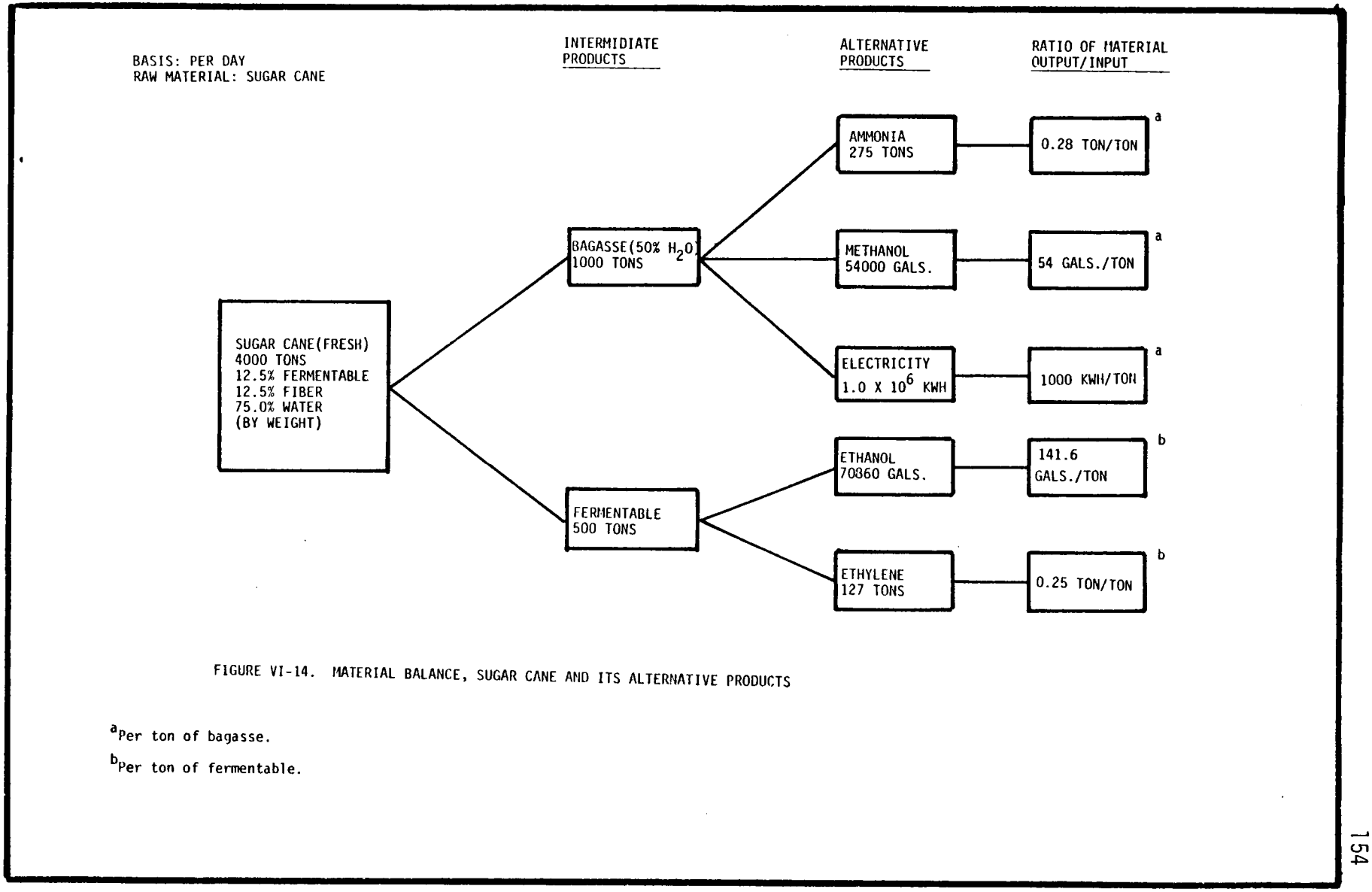


FIGURE VI-14. MATERIAL BALANCE, SUGAR CANE AND ITS ALTERNATIVE PRODUCTS

[a]Per ton of bagasse.

[b]Per ton of fermentable.

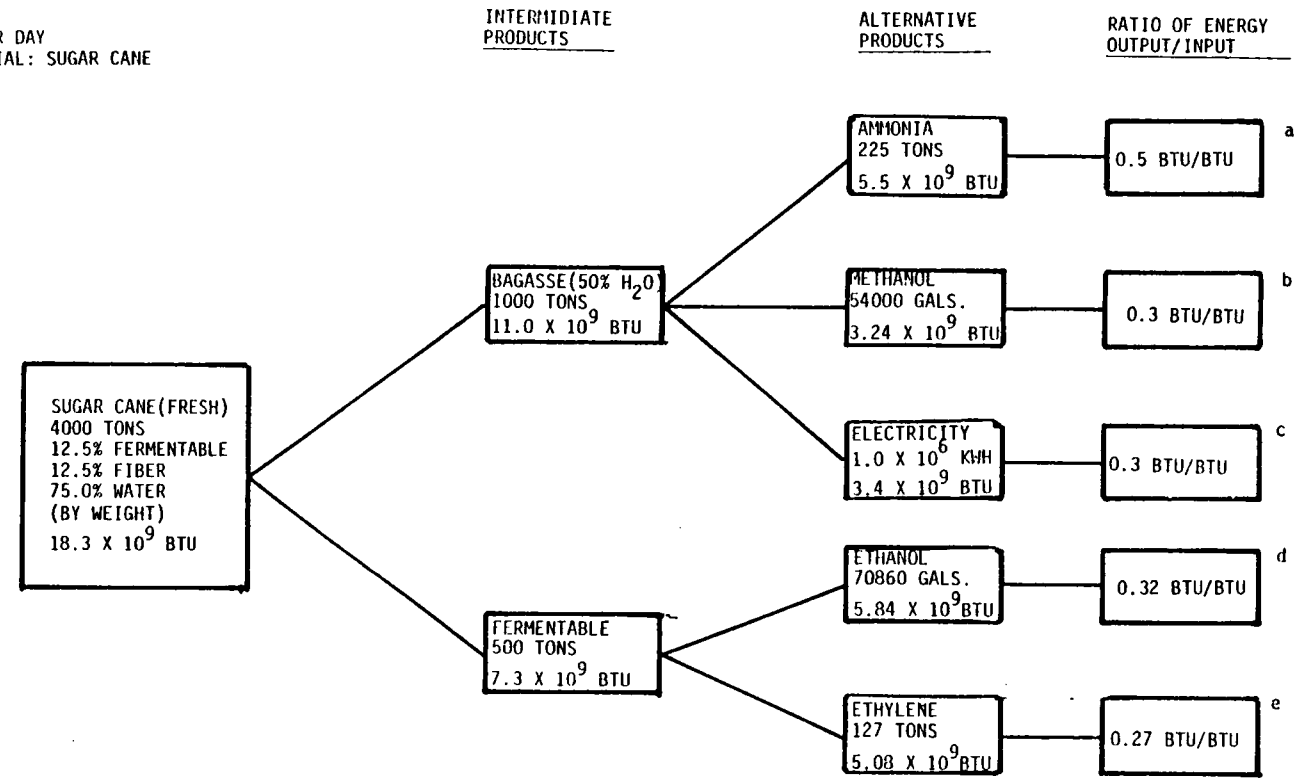


FIGURE VI-15. ENERGY BALANCE, SUGAR CANE AND ITS ALTERNATIVE PRODUCTS

[a]Energy input based on heat content of raw material and of steam required and energy output based on heat content of product.

[b]Energy input based on heat content of raw material only and energy output based on heat content of product.

[c]Based on net energy input and output(excluding energy required by the agricultural sector).

[d]Based on net energy input and output(excluding energy required by the agricultural sector).

[e]Energy input based on heat content of raw material only and energy output based on heat content of product.

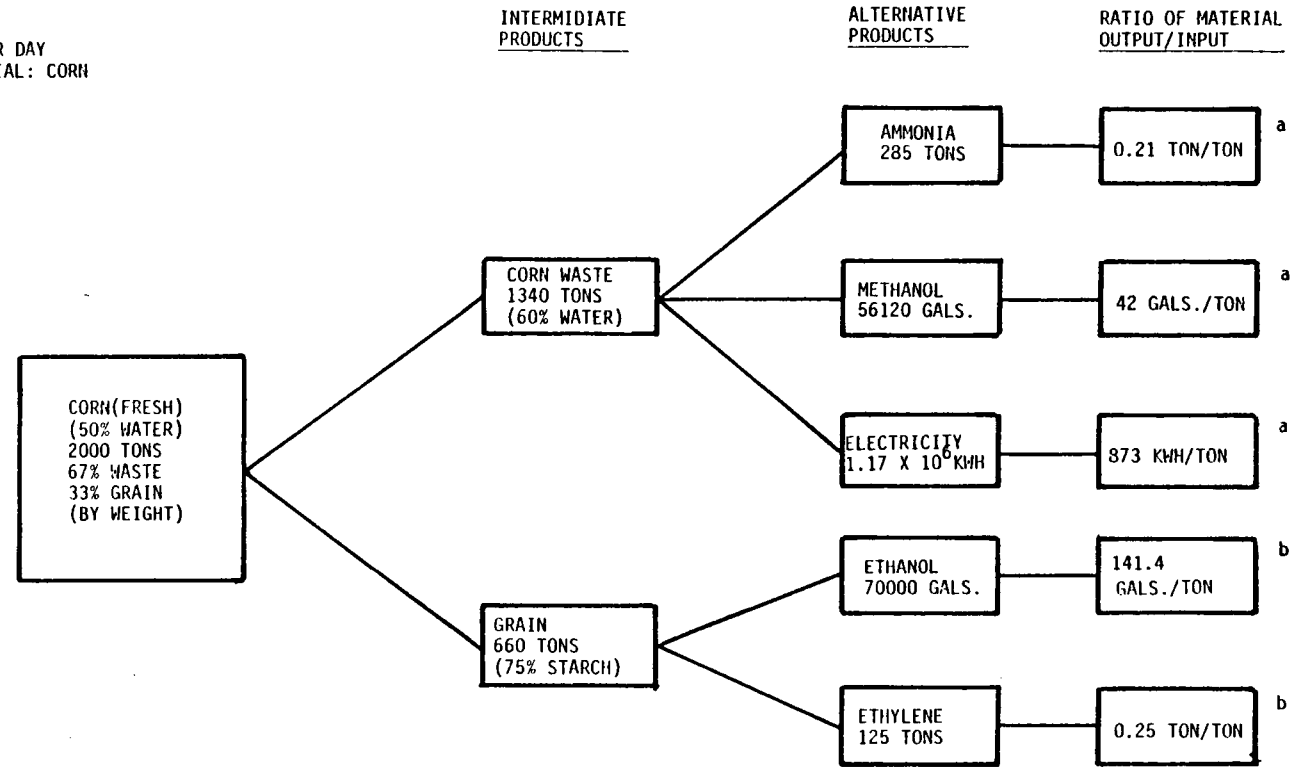


FIGURE VI-16. MATERIAL BALANCE, CORN AND ITS ALTERNATIVE PRODUCTS

[a]Per ton of waste.

[b]Per ton of starch.

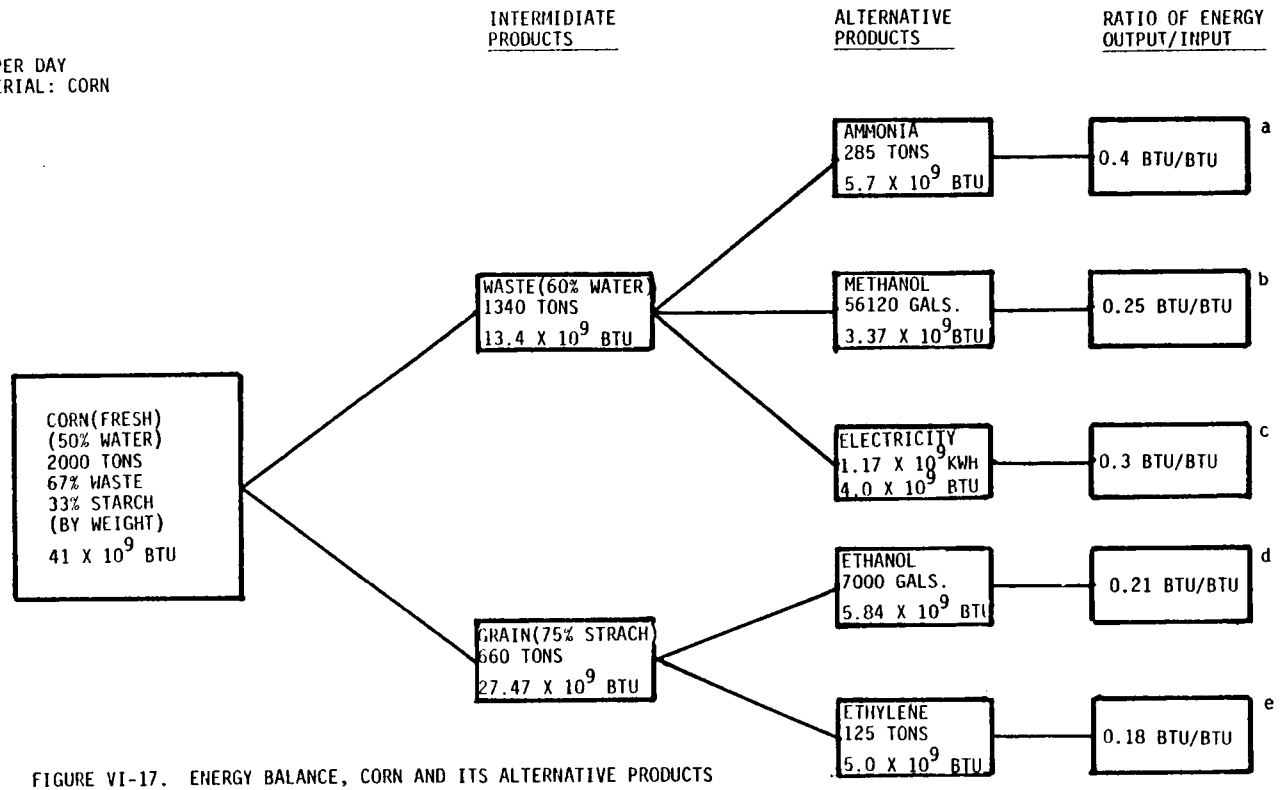


FIGURE VI-17. ENERGY BALANCE, CORN AND ITS ALTERNATIVE PRODUCTS

[a]Energy input based on heat content of raw material and of steam required and energy output based on heat content of product.

[b]Energy input based on heat content of raw material only and energy output based on heat content of product.

[c]Based on net energy input and output(excluding energy required by the agricultural sector).

[d]Based on net energy input and output(excluding energy required by the agricultural sector).

[e]Energy input based on heat content of raw material only and energy output based on heat content of product.

TABLE VI-3

COST OF ENERGY AND CHEMICAL FEEDSTOCKS
FROM SUGAR CANE AND CORN IN
NOVEMBER 1979 DOLLARS

Products	From Sugar Cane	From Corn	Current Cost In U.S.
Ammonia [Dollars per short ton]	247	283	140
Ethyl Alcohol [Dollars per U. S. gallon]	1.51	1.58	1.30-1.60
Methyl Alcohol [Dollars per U. S. gallon]	0.95	1.16	0.60
Ethylene [Cents per pound]	51	54	15
Electricity [Cents per KWH]	3	4	3.5

Alcohol produced from biomass obviously could be burnt in combustion turbines or under boilers for the generation of electricity. Successful tests on the use of alcohol in combustion turbines have already been conducted. In the case of Brazil, at least one pilot plant is coming on stream which has a modified co-generation design at Forteleza to use the alcohol to drive a turbine, and the exhaust heat from the turbine to provide process heat for other processes in the plant.[71] Additional co-products from the fermentation residues include organic fertilizers and cattle feed.

The Brazilian strategy is related to their need to provide small scale electric power generating capacity in remote areas where the cost of transmission and distribution lines would otherwise make the cost of electricity to the consumer very high.

Use of bagasse for production of electricity is another example of biomass utilization. The electric power situation in the U. S. is different, however, and there probably is much less justification for using a synthetic liquid fuel such as biomass derived alcohol for electric power generation. The relative merits of using such synthetic alcohol fuels in the transportation and electric power sectors are not yet fully resolved, however.

The next chapter illustrates the potential of biomass (sugar cane) production and utilization, as well as its overall implications on energy supply and economic development for Brazil, Mauritius, and Nicaragua.

CHAPTER VII

USE OF SUGAR CANE AS BIOMASS IN BRAZIL, MAURITIUS, AND NICARAGUA

A. General Discussion

From the general discussion of Chapters V and VI it is apparent that apart from providing a commercial cast crop, i.e., sugar, sugar cane has great potential for producing energy and chemical feedstocks, especially in tropical and sub-tropical regions. This chapter examines the possibilities for utilizing this great potential in order to supplement the energy supply of Brazil, Mauritius, and Nicaragua, which are tropical and sub-tropical regions. There are, of course, several other crops that could be used for energy and chemical feedstock production. For example, corn, as discussed in Chapters V and VI, is one of them.[66] This chapter focuses upon sugar cane because it is more appropriate to the three countries selected for this dissertation.

In Chapter VI the use of sugar cane and its by-products to produce ethanol, methanol, ammonia, ethylene, and electricity was discussed. In this chapter the first three products, i.e., ethanol, ammonia, and electricity are examined in further detail. The reasons for this selectivity are that the economics for production of these three products are more favorable and the demand for these three products is much greater in the selected LDCs.

The production of ammonia from bagasse as the source of nitrogen fertilizer to sustain the already existing as well as the new sugar cane plantations has been considered in each of the three LDCs, Brazil,

Mauritius, and Nicaragua. The primary focus is placed upon the energy output and its potential for assisting the economy of each country.

Because of the great differences in their areas and populations, e.g., Brazil 3,286,000 square miles and population 109 million, Mauritius 720 square miles and population 0.9 million, and Nicaragua 50,200 square miles and population 2.23 million, the biomass development strategies have to be different in the three nations. The differences among the three countries in fact was a major reason for choosing them for this dissertation. The production and utilization of biomass and the economic implications of the biomass development strategy are considered separately in the three Sections B, C, and D that follow. Finally, Section E provides some general comments on the analyses carried out in this chapter.

B. Biomass as an Energy Source in Brazil

1. Biomass Production.

Table VII-1 summarizes the land utilization in Brazil in 1975. It can be seen that 90 million acres of arable land (see list of definitions included in Table VII-1) were utilized for crop production. According to Food and Agricultural Organization studies,[80] a major portion of the 320 million acres referred to as "other land," which also includes residential areas, highways, etc. . ., can easily be used for agricultural purposes. Thus it would be logical to expect that an opportunity for significant agricultural expansion exists in Brazil.

FAO statistics[80] also show that Brazil produces some 7.5 million tons of sugar annually by cultivating sugar cane on 5 million acres of the arable land area. Since sugar has a good market in the world,

TABLE VII-1

LAND UTILIZATION IN BRAZIL, 1975

	Area	
	10^3 Square Miles	10^6 Acres
Total Area[a]	3286	2103
Inland Water Bodies	21	13
Land Area[b]	3265	2090
Arable Land and Permanent Crop[c]	141	90
Forest and Woodland[d]	1970	1260
Permanent Meadows and Pastures[e]	656	420
Other Land[f]	498	320

[a]Total area refers to the total area of the country, including area under inland water bodies.

[b]Land area refers to total area including area under inland water bodies, i.e., lakes and rivers.

[c]Arable land refers to land under temporary crops (double cropped areas are counted only once); permanent crops include crop which go beyond 5 years, e.g., tea and coffee.

[d]Forest and woodland refers to land under planted and natural forest and bushes.

[e]Permanent meadows and pastures refers to land used permanently for herbaceous forage crops, either cultivated or growing wild.

[f]Other land refers to unused but potentially productive land, built-on areas, waste land, parks, roads, lanes, etc.

Source: Food and Agricultural Organization (FAO) of the U. N., "Production Yearbook," U. N., Rome, Italy, Vol. 30, 1977.

diverting sugar cane produced at present in Brazil for production of energy and chemical feedstocks instead of sugar production might have a negative effect on the nation's economy. However, by increasing the yield of present plantations and by putting more land under sugar cane production it would be possible to maintain the raw sugar output and at the same time have extra sugar cane left for energy and chemical feedstock production.

Based on studies which deal with improvement of sugar cane yield[81,82] and the availability of sugar cane land in Brazil, estimates regarding the potential for increased sugar cane production are illustrated in Figure VII-1. The assumptions and factors associated with the estimates on improvement of the already existing 5 million acres of sugar cane plantation are:

(i) Move to close cropping, i.e., distance between rows reduced from average of $4\frac{1}{2}$ to $2\frac{1}{2}$ feet.

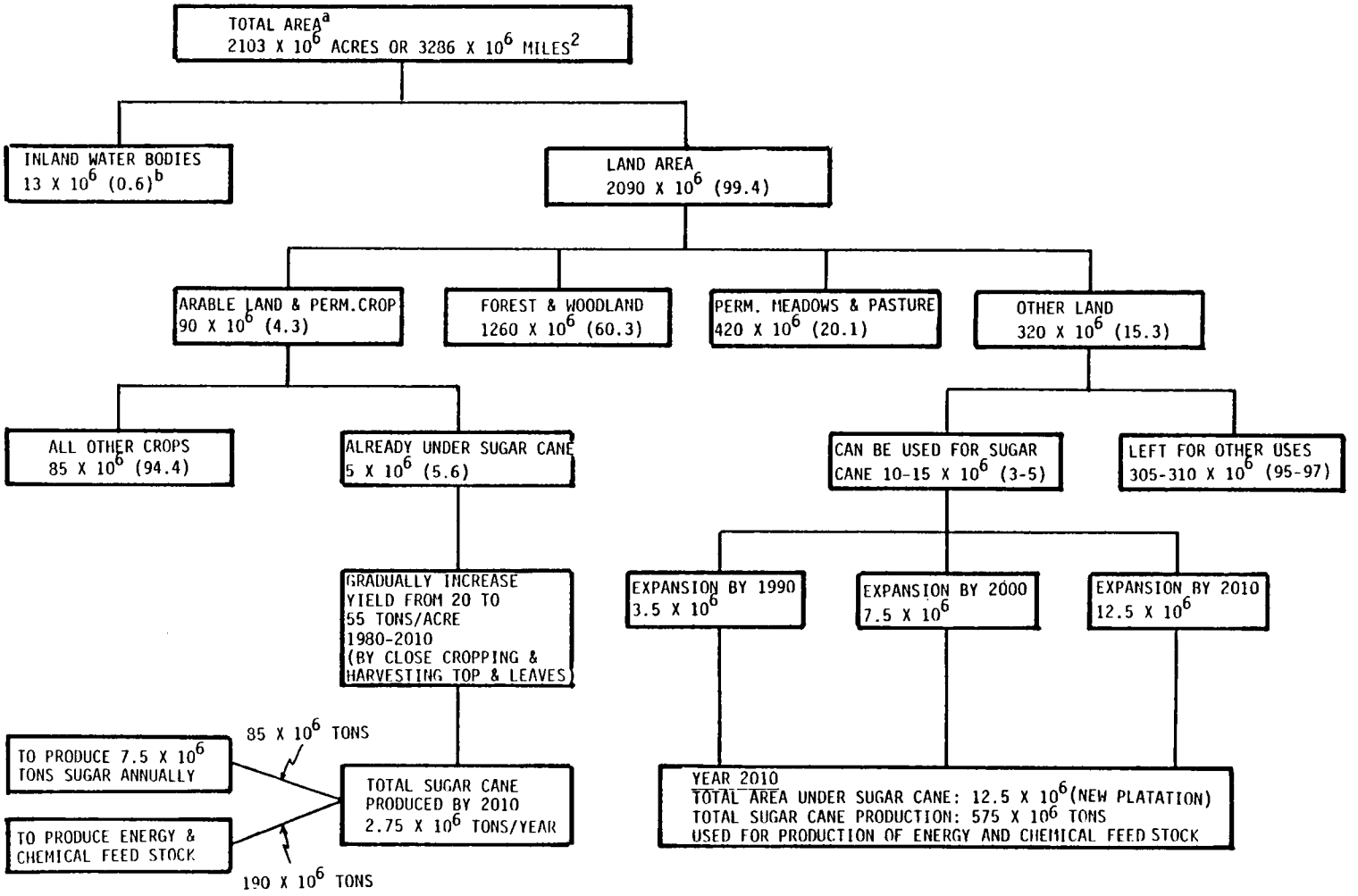
(ii) Top and leaves harvested and brought in for processing.

(iii) Both (i) and (ii) would increase the yield from the current average of 20 tons per acre per year in Brazil to 55 tons per acre per year.[81]

(iv) Seven and a half million tons of raw sugar production maintained for economic reasons, and excess cane used for energy and chemical feedstock production.

Additional assumptions and factors associated with the estimates for new land put under sugar cane plantation are:

(i) Close cropping and harvesting of top and leaves would yield 55 tons per acre.



[a]All areas in acres.

[b]Percentage.

FIGURE VII-1. SUGAR CANE LAND DEVELOPMENT PLAN, BRAZIL 1975-2010

(ii) Ten to 15 million additional acres on new land gradually put into sugar cane production by 2010.

(iii) Sugar cane from new plantations used for alcohol, electricity, and ammonia only.

Table VII-2 summarizes the potential production of sugar cane in Brazil if the development plan suggested above is implemented. It is important to note that 85 million tons of sugar cane obtained from the already existing 5 million acres would be used for the production of sugar. The rest of the cane obtained from the new plantations, as well as that obtained by improvements in yield of the old plantations would be utilized for production of alcohol, ammonia, and electricity as discussed in the section that follows.

2. Biomass Utilization.

In Brazil, in order to maintain the 7.5 million tons of sugar production which is important to the nation's economy, and at the same time to make use of any excess sugar cane left as an energy and fertilizer source, two different systems are considered. The first system uses the sugar cane produced by the already existing 5 million acres of sugar cane plantation to produce sugar as the major product and only the by-products and excess sugar cane juice are used for energy and chemical feedstocks. The second system, which is designed to use sugar cane coming from the new plantations as raw material, is allocated solely for energy and fertilizer production.

Since the first system is responsible for the nation's sugar supply, it makes use of the already existing factories. However, three major changes in the already existing Brazilian sugar industry are

TABLE VII-2

PROJECTED SUGAR CANE PRODUCTION FOR SUGAR, ENERGY AND FERTILIZER PRODUCTION, BRAZIL 1975-2010

	From Already Existing Sugar Cane Plantation[a]				From New Plantation			
Year	10^6 Area Acres	Total Sugar Cane 10^6 Tons	Sugar Cane Used For Sugar Production 10^6 Tons	Sugar Cane Used For Energy and Fertilizer Production 10^6 Tons	Area[b] 10^6 Acres	Sugar Cane Used For Energy and Chemical Feedstock 10^6 Tons	10^6 Area Acres	Total Sugar Cane For Energy and Fertilizer Production 10^6 Tons
1975	5	85	85	-	-	-	5	-
1980	5	85	85	-	-	-	5	-
1990	5	150	85	65	3.5	192	8.5	257
2000	5	215	85	130	7.5	412	12.5	542
2010	5	275	85	190	12.5	688	17.5	878

[a]Note that total production of sugar cane increases due to increase in yield by close cropping and harvesting of top and leaves.

[b]Area includes land used for road construction, housing and plant site.

necessary. The first change deals with the modification of the milling department of sugar factories. The average milling capacity, which is approximately 125 tons per hour for the already existing sugar factories,[72] must be increased to around 200 tons per hour by 2010 in order to handle the additional sugar cane produced by improvement in the yield of the already existing 5 million acres of plantation. This increase in capacity can be achieved by adding a fourth roller to the additional three roller mills.[83] This has already been proved to work in many sugar producing countries. The second change deals with the addition of the ethyl alcohol and the fertilizer producing units, and at the same time increasing the capacity of the power house. The third change deals with the extension of the sugar cane harvesting season from around 160 to 330 days per year, i.e., the maximum number of working days per year, as indicated in Appendix C. This would double the actual capacity of sugar factories and at the same time it would turn the sugar industry into a continuous rather than seasonal source of energy. It would also resolve part of the energy storage problem associated with most of the solar energy sources.

The overall material and energy balance of this first system as it would be at its maximum capacity by 2010 have been computed based on assumptions similar to those discussed in detail in Appendix C, and summarized below for easy reference.

(i) Sugar cane yield increased from approximately 20 tons per acre per year to 50 to 60 tons per acre per year by close cropping and harvesting top and leaves. This would increase total production of the already existing 5 million acres sugar cane plantation from around 85 to 275 million tons by 2010.

(ii) Crushing capacity of already existing sugar factories gradually increased from 125 to 200 tons per hour, i.e., 2500 to 4000 tons per day.

(iii) Imbibition water percent sugar cane by weight is 25%. Note that imbibition is the process of adding water and recirculation of juice to enhance extraction of sugar.[77]

(iv) Average fermentable content in sugar cane juice is 12.0% by weight.

(v) Bagasse (50% wet) production is equal to 37.5% of sugar cane by weight and heat content is 5500 BTU per pound.

(vi) Production of ammonia is equal to 0.275 ton per ton of bagasse (50% wet).

(vii) Thermal efficiency at power house is 30%.

(viii) Energy consumption for grinding and fermentation and distillation is 60% of total energy generated from bagasse, and a major part of 40% goes for electricity generation.

(ix) Ethyl alcohol production is approximately 146 gallons (at 95% dry) per ton fermentable.

(x) Heat content of ethyl alcohol is 12,500 BTU per pound or 82,400 BTU per U. S. gallon and specific gravity of 0.788.

(xi) Energy consumption in transportation is 1000 BTU per ton mile.[23]

(xii) Energy associated with labor and agricultural equipment has not been included.

It can be seen that by 2010 the 5 million acres of already existing sugar cane plantations would produce 7.5 million tons of sugar and an

equivalent of 0.4 X 10^{15} BTU of energy annually, plus enough ammonia fertilizer to sustain the plantation. The material and energy balance of this first system is illustrated in Figure VII-2.

As mentioned above the second system is designed to produce ethyl alcohol, electricity, and enough ammonia to meet the nitrogen fertilizer requirements for the new sugar cane plantations which provide the raw material. The material and energy balance of one unit which uses the sugar cane produced from 55 to 60 thousand acres of land have been computed based on similar assumptions already listed for the first system and discussed in detail in Appendix C. The "factory area" has been limited to a maximum of 60 thousand acres so as to keep the sugar cane hauling distance within $7\frac{1}{2}$ miles, which from personal experience of the author is close to the optimum distance in order to keep transportation costs at a minimum. To absorb the raw material produced from such "factory areas," the crushing capacity of each of the new factories should be around 400 tons per hour or around 8000 tons per day compared to the 200 tons per hour or 4000 tons per day, i.e., improved capacity of the already existing sugar factories. In order to handle the sugar cane produced from the 12 .5 million acres of new plantations which would be developed by 2010, several such units would have to be built. The energy output of such units is illustrated in detail in Figure VII-3 and summarized in Table VII-3 together with the results of the first system.

From the results it can be concluded that when both systems are combined, in addition to sugar production, energy and fertilizer also can be produced from the raw material sugar cane. Moreover, the system is attractive because energy both in the form of liquids and electricity,

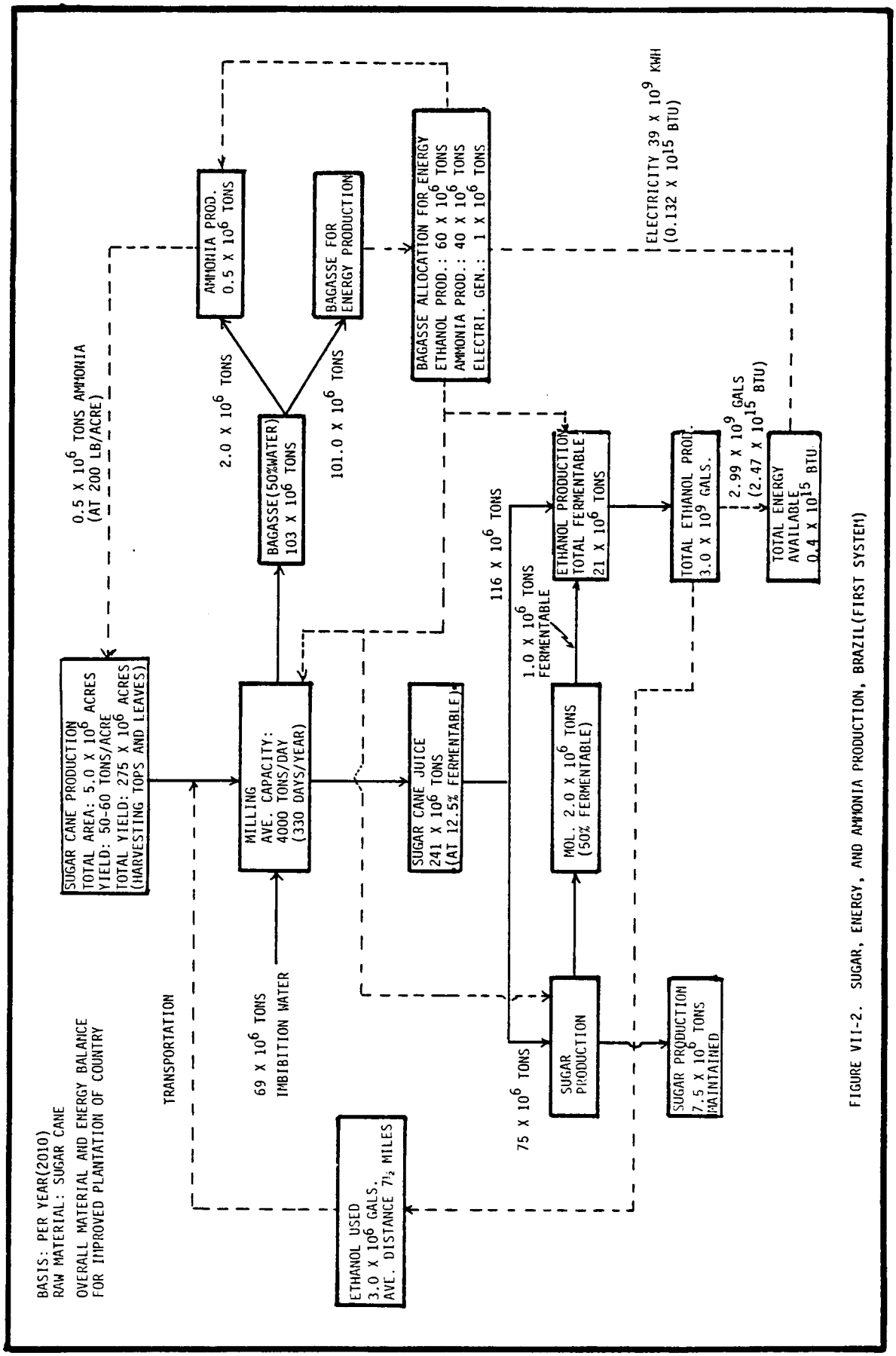


FIGURE VII-2. SUGAR, ENERGY, AND AMMONIA PRODUCTION, BRAZIL(FIRST SYSTEM)

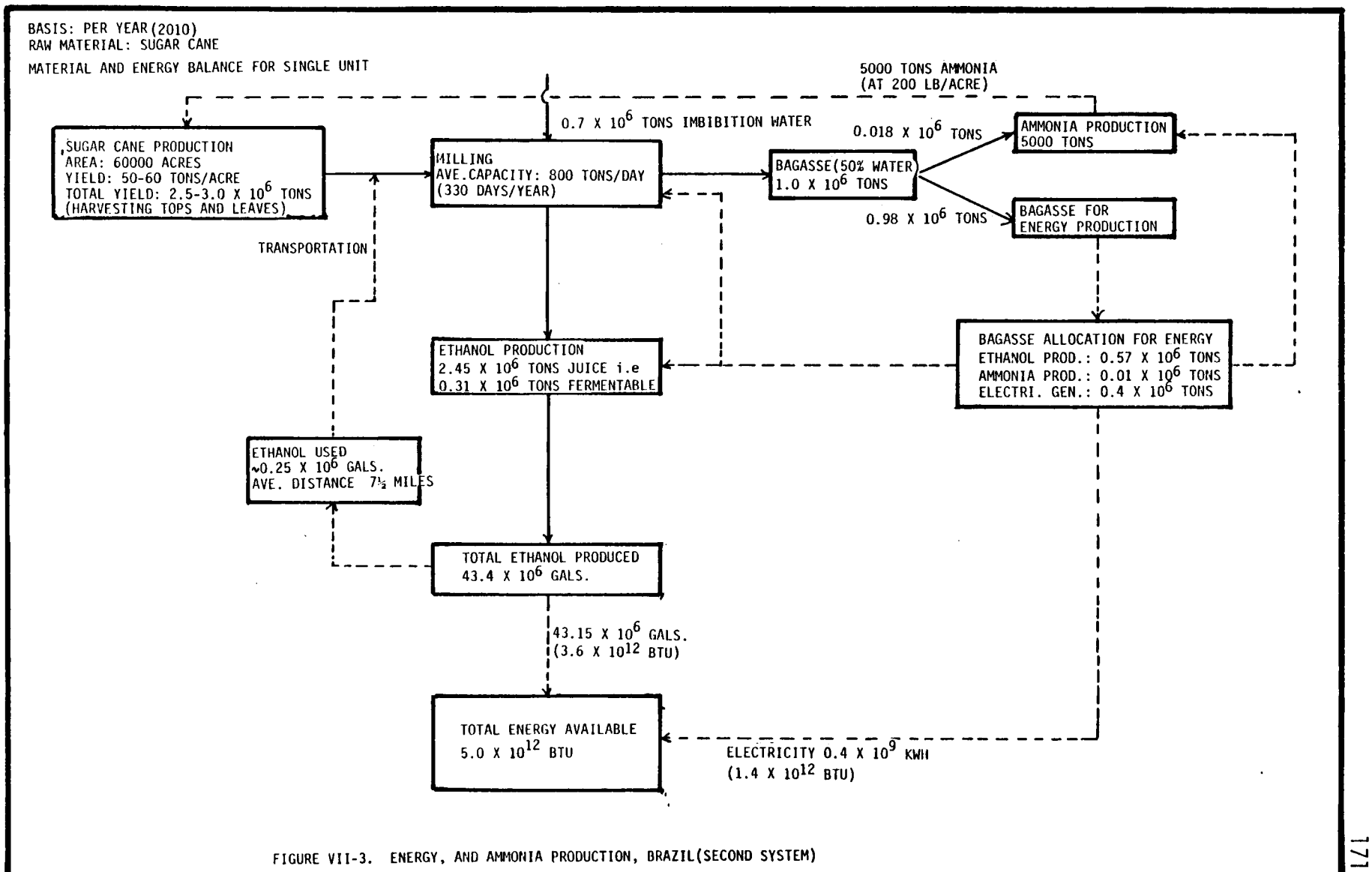


FIGURE VII-3. ENERGY, AND AMMONIA PRODUCTION, BRAZIL(SECOND SYSTEM)

TABLE VII-3

PROJECTED ENERGY AND SUGAR PRODUCTION OF FIRST AND SECOND SYSTEMS, BRAZIL 1975-2010

Year	First System[a] Sugar 10^6 Tons	First System[a] Energy 10^{15} BTU	Second System[b] Energy 10^{15} BTU	Total Energy[c] 10^{15} BTU
1975	7.5	-	-	-
1980	7.5	-	-	-
1990	7.5	0.14	0.30	0.44
2000	7.5	0.28	0.65	0.93
2010	7.5	0.40	1.08	1.48

[a]Note that 7.5 million tons of sugar production maintained only excess sugar cane used for energy production and enough fertilizer produced to sustain plantation.

[b]Sugar cane from new plantation used for energy production only, except enough fertilizer produced to sustain plantation.

[c]Total of liquid fuel ethyl alcohol and electricity.

which are in great demand, can be produced. Before making any strong recommendations the economics of the systems and overall impact of economic development and total energy demand of Brazil need to be analyzed. The analysis is discussed in the next section.

3. Overall Impact of Biomass Strategy on Energy Supply and Economic Development.

Using economic analysis similar to those discussed in Chapter VI and Appendix C, the average cost (in current U. S. dollars) of production of ethyl alcohol, electricity and ammonia from the two systems suggested for Brazil would be the following:

Ethyl Alcohol	\$1.30* to 1.50	per gallon
Electricity	\$0.03	per KWH
Ammonia	\$247	per ton

It must be noted that these costs are quite competitive with the costs of the products if they were produced from fossil fuels. The main reason is that Brazil has essentially no fossil reserves and depends almost entirely on imported fossil fuels. In the case of ethyl alcohol the 1.30 to 1.50 dollars per gallon cost is within the range of 1.00 to 2.00 dollars per gallon estimated by other similar studies.[69,84] Though the system appears attractive, its overall impact on the energy supply and economic development as discussed in the next two subsections that follow, needs to be analyzed further before making any strong recommendation.

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*This figure is for the system which is based upon modification of the existing production. The other three figures in this table (and in similar tables later in this chapter) are for the new system. Both systems have been discussed in preceding sections of this chapter.

a. Impact on Energy Supply

Figure VII-4 illustrates the probable energy demand for Brazil as derived from the parametric energy demand projections of Chapter III. The figure also shows the total energy that would have to be imported if no domestic energy system is developed. This represents roughly 65% in 1975[29] and 95% in 2010 of the total energy demand. Hopefully, with future biomass systems and other energy source development the percentage of imported energy would decrease. For example, if the sugar cane biomass system is developed by 2010 roughly 12.5% of the total importation of energy in Brazil could be replaced by this system only. This is illustrated in Figure VII-4 and in Table VII-4. There are of course other biomass systems and other energy sources that can be developed in the future which would increase the domestic energy supply, thus making Brazil more energy independent and helping to improve its economy.[71]

b. Impact on Economic Development

In 1975 Brazil spent roughly 2.6 billion dollars (constant 1970 dollars), which represented approximately 4.5% of the nation's total GNP.[17] World oil price increases, coupled with the rapidly growing energy demand in Brazil, will increase the balance of payment problem.[31] Thus economic development increasingly will be handicapped. However, the potential for producing domestic energy in order to reduce the imports does exist, especially in the case of Brazil where vast lands are still available. Thus the sugar cane biomass systems have been suggested as discussed earlier in this chapter, and Figure VII-5 and Table VII-5 summarize the overall economic implications of the

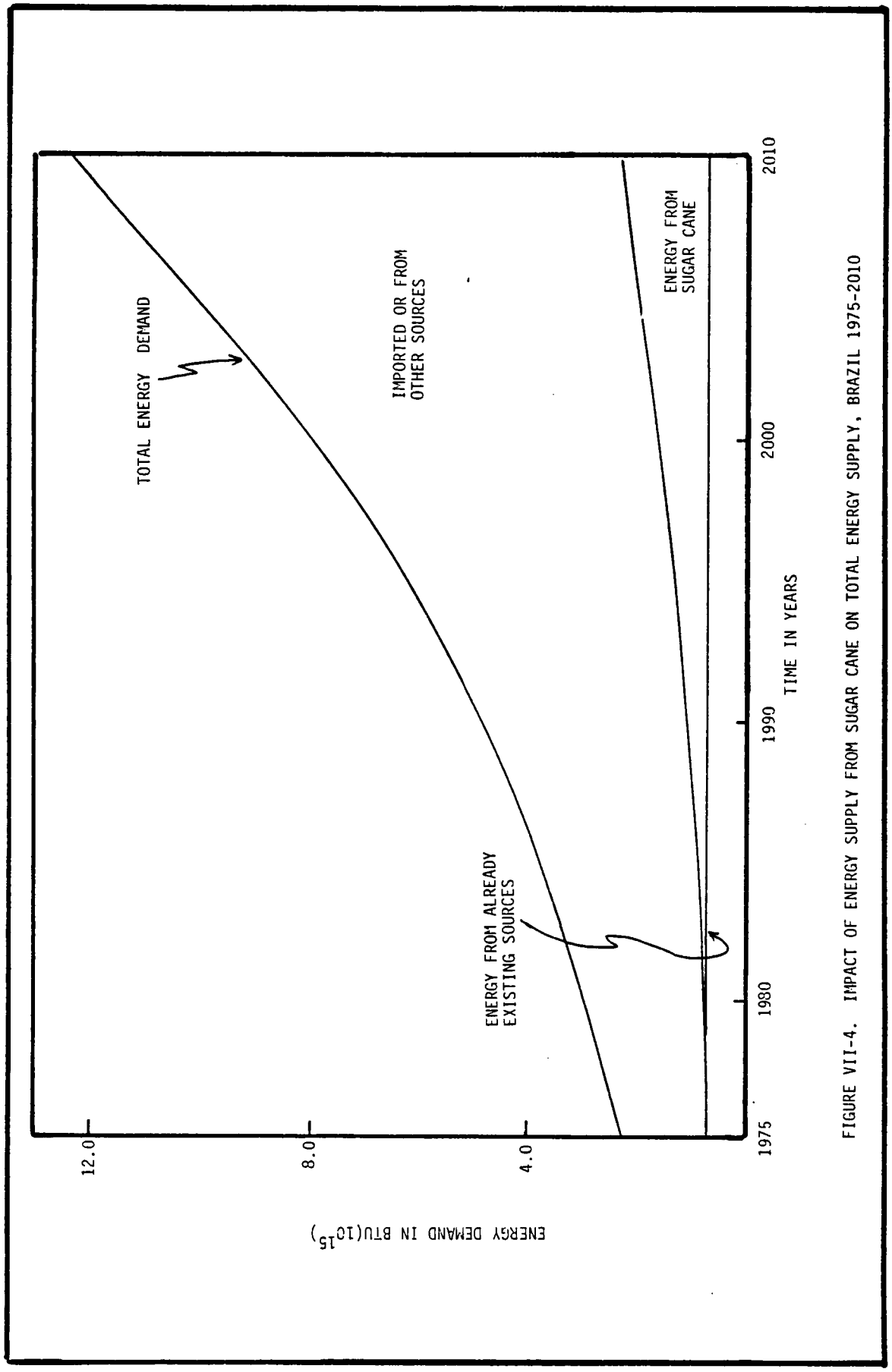


FIGURE VII-4. IMPACT OF ENERGY SUPPLY FROM SUGAR CANE ON TOTAL ENERGY SUPPLY, BRAZIL 1975-2010

TABLE VII-4

IMPACT OF ENERGY FROM SUGAR CANE ON TOTAL ENERGY SUPPLY, BRAZIL 1975-2010

Year	Total Energy Demand 10^{15} BTU	Imported[a] Energy If Energy From Sugar Cane Not Used 10^{15} BTU	Supply of Energy From Sugar Cane: Total Energy 10^{15} BTU	Supply of Energy From Sugar Cane: As Percentage of Imported Energy
1975	2.1	1.4	-	-
1980	2.8	2.1	-	-
1990	4.9	4.2	0.44	10.5
2000	8.1	7.4	0.93	12.5
2010	12.5	11.8	1.48	12.5

[a]Assumed that 0.7 X 10^{15} BTU of energy produced at present locally from hydro and other sources would remain unchanged.

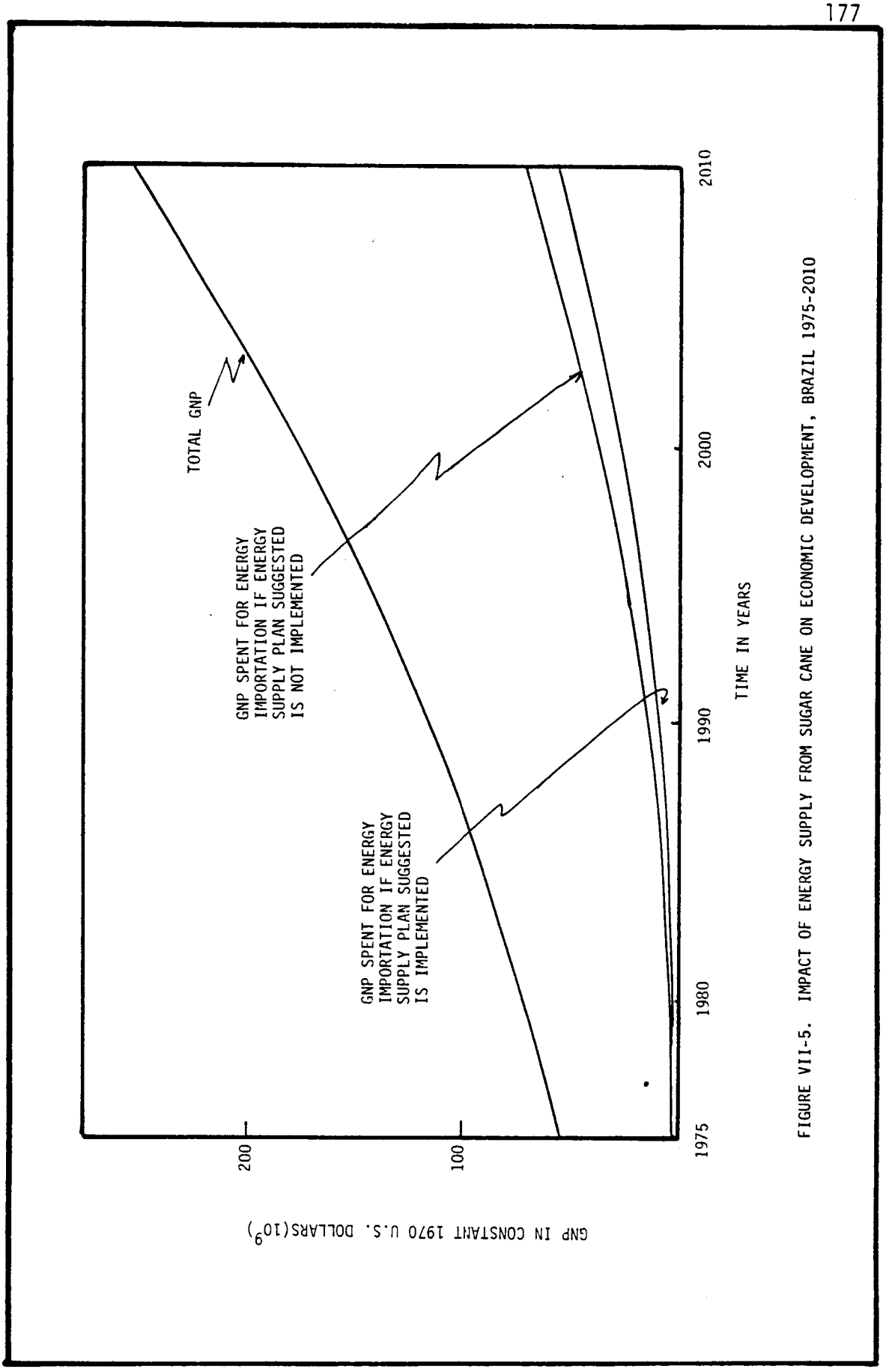


FIGURE VII-5. IMPACT OF ENERGY SUPPLY FROM SUGAR CANE ON ECONOMIC DEVELOPMENT, BRAZIL 1975-2010

TABLE VII-5

IMPACT OF ENERGY FROM SUGAR CANE ON ECONOMIC DEVELOPMENT, BRAZIL 1975-2010

Year	GNP 10^9 $[a]	Average Cost of Imported Energy[b] $[a] Per 10^6 BTU	If Energy From Sugar Cane Not Used: Total Cost of Imported Energy 10^9 $[a]	If Energy From Sugar Cane Not Used: Percentage of GNP Used For Energy Importation	If Energy From Sugar Cane is Used: Percentage of GNP Saving
1975	55.3	1.83	2.56	4.6	-
1980	71.3	2.18	4.57	6.4	-
1990	115.0	3.08	12.90	11.2	10.5
2000	175.2	4.34	32.1	18.3	12.5
2010	250.1	6.12	72.2	28.9	12.5

[a] In terms of constant 1970 U. S. dollars.

[b] Average cost of energy has been computed using 1975 data on total energy imported in forms of oil, coal, etc., and total cost of importation. Moreover, based on historical trend an annual increase of 3.5% of the price of imported energy has been assumed.

systems. The factors and assumptions used for the estimates are included as foot notes to the table.

From the figure it can be concluded that without the biomass-energy system by 2010 approximately 72.2 billion dollars (constant 1970 dollars) of the nation's GNP, i.e., approximately 29% would be spent on energy imports. On the other hand, with the biomass energy system 9 billion dollars (constant 1970 dollars) of the above GNP would be saved representing approximately 12.5% saving on GNP. It must be added that this sugar cane biomass system is one of the several other energy systems that can be developed in Brazil. It also is recognized that the economic analysis is much more involved and complex but beyond the scope of this study.

Brazil already has embarked on a major national commitment to biomass and biomass derived fuels as a national energy policy. For example, all gasoline now sold in Brazil has at least 10% alcohol content, and in some areas as much as 20%. Approximately 15,000 vehicles are now operating on straight alcohol and the officially stated government goal is to have about 250,000 vehicles operating on straight alcohol by 1981.[71,85]

The purpose of the preceding section thus is not to present an argument for a completely new strategy for Brazil, but rather to analyse the potential for expansion of the existing strategy and the potential economic impact over the time frame through 2010 encompassed by the Aggregate Energy Demand Model discussed in earlier chapters.

C. Biomass as an Energy Source in Mauritius

1. Biomass Production.

In Mauritius, in order to sustain the nation's economy which is heavily dependent on the sugar cane industry, roughly 45% (200,000 acres[86] or 323 square miles) of the total land area (460,000 acres or 720 square miles) is devoted to sugar cane plantations for the production of 7 million tons of sugar cane (or 700,000 tons sugar)[87] annually. The rest of the land is utilized[80] as shown in Table VII-6. Because of the size of the country it is almost impossible to expand the sugar cane plantation area any further. Also, due to the strong dependency of the economy on the sugar production diverting the sugar cane produced at present to energy production is out of the question. However, the favorable climatic and soil conditions would permit an increase in yield, and extra sugar cane produced can then be utilized for energy production.

By modification of the agricultural practices as suggested for Brazil, i.e., reduction of space between rows of the sugar cane crop from an average of $4\frac{1}{2}$ to $2\frac{1}{2}$ feet and collection of tops and leaves of the sugar cane, yield can be increased by roughly $2\frac{1}{2}$ fold. Figure VII-6 shows that with the above modifications the total production of sugar cane in Mauritius could be increased from the present 7 to 17 million tons by 2010 without any increase in land area. As mentioned above the extra 10 million tons of sugar cane could be used for energy production and the 7 million tons would still be available to produce the 700,000 tons of sugar which is vital to the Mauritian

TABLE VII-6

LAND UTILIZATION IN MAURITIUS, 1975

	Square Miles	10^3 Acres
Total Area[a]	718	460
Inland water bodies	4	3
Land area[b]	714	457
Arable land and permanent crop[c]	409	262
Forest and woodland[d]	27	17
Permanent meadows and pastures[e]	224	143
Other land	54	35

[a]Total area refers to the total area of the country, including area under inland water bodies.

[b]Land area refers to total area excluding area under inland water bodies, i.e., lakes and rivers.

[c]Arable land refers to land under temporary crops (double cropped areas are counted only once); permanent crops include crop which go beyond 5 years, e.g., tea and coffee.

[d]Forest and woodland refers to land under planted and natural forest and bushes.

[e]Permanent meadows and pastures refers to land used permanently for herbaceous forage crops, either cultivated or growing wild.

[f]Other land refers to unused but potentially productive land, built-on areas, waste land, parks, roads, lanes, etc.

Source: Food and Agricultural Organization (FAO) of the U. N., "Production Yearbook," U. N., Rome, Italy, Vol. 30, 1977.

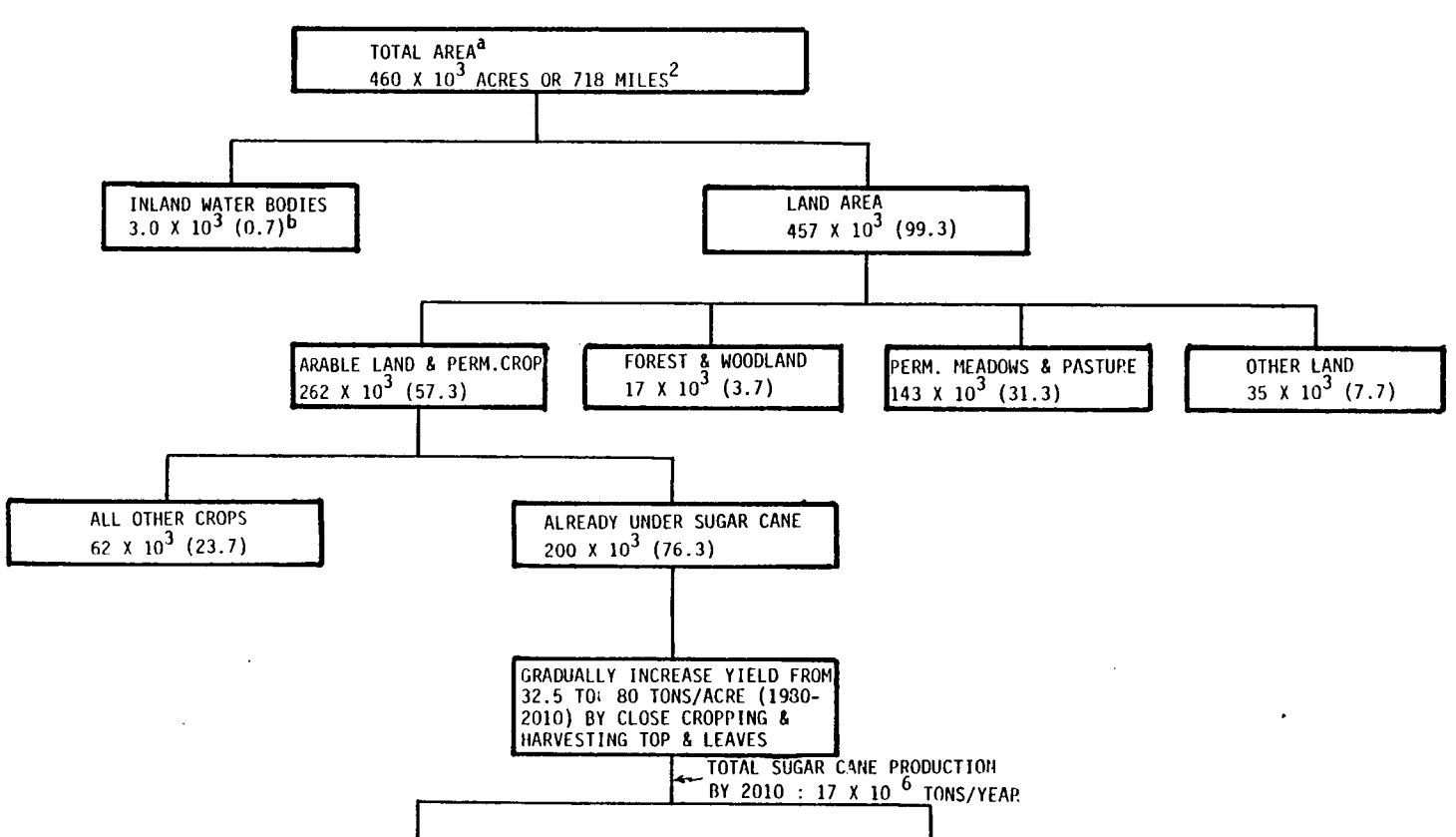


FIGURE VII-6. SUGAR CANE LAND DEVELOPMENT PLAN, MAURITIUS 1975-2010

[a]All areas in acres.

[b]Percentage.

economy. Table VII-7 gives the projected sugar cane production from 1975 through 2010 computed based on the following assumptions:

(i) Area limited to 200,000 acres which already is providing 32-35 tons per acre per year.

(ii) Move to close cropping, i.e., distance between rows reduced from roughly 4 $\frac{1}{2}$ feet to 2 $\frac{1}{2}$ feet.

(iii) Tops and leaves harvested and brought to the factory.

(iv) Both (ii) and (iii) above would increase the yield from the current average of 32-35 tons per acre per year as given in (i) to 80-90 tons. Thus, total production would be increased from 7 to 17 million tons from the already existing 200,000 acres.

(v) Seven million tons used to maintain the present sugar production of 700,000 tons and the extra 10 million tons used for energy and fertilizer production.

(vi) Considering the typical life cycle of 5 years for the sugar cane crop the whole plantation area can be modified within 5 to 6 years. In Mauritius, however, the average recycling period is around 7 years but 10 to 12 years is not unusual. There are two major reasons: first, the soil and climatic conditions do allow the extension of the recycling time without affecting the yield significantly, and second, the financial situation in many instances does not permit shorter recycling time. Thus it has been assumed that the change from traditional cropping to close cropping would take some 20 to 30 years.

TABLE VII-7

PROJECTED SUGAR CANE PRODUCTION FOR SUGAR, ENERGY AND FERTILIZER PRODUCTION, MAURITIUS 1975-2010

Year	Area Under Sugar Cane 10^3 Acres	Production of Sugar Cane[a]		
		Total 10^6 Tons	For Sugar Production 10^6 Tons	For Energy and Fertilizer Production 10^6 Tons
1976[b]	200	6.6	6.6	-
1980	200	7.0	7.0	-
1990	200	10.0	7.0	3.0
2000	200	13.5	7.0	6.5
2010	200	17.0	7.0	10.0

[a]Note that total production of sugar cane increases due to increase in yield by close cropping and harvesting of top and leaves.

[b]Data for 1976 used instead of 1975 because 1975 was a cyclonic year which destroyed a high percentage of the sugar cane crop.

2. Biomass Utilization.

Since the sugar production is more crucial to the Mauritian economy than it is to the Brazilian one, the sugar cane utilization strategy suggested here is similar to only the first system already described for Brazil. As shown in Figure VII-7 the sugar production unit is coupled with the energy and ammonia production unit. The flow chart also includes the overall annual energy and material balance of the whole sugar industry of the island, based on an annual production of 17 million tons of sugar cane (tops and leaves included). It must be noted that 17 million tons of cane is the maximum production that can be achieved by the turn of the century if the development strategies described in the previous subsection are implemented. The assumptions used for the material and energy balance calculation are similar to those already given when the Brazilian systems were being discussed. A few additional ones used here have been listed below:

(i) Total area of land allocated to sugar cane plantations in Mauritius is 200,000 acres.

(ii) Yield of cane would be increased from an average of 32-35 tons per acre to 80-90 tons per acre by close cropping and collection of tops and leaves.

(iii) Average hauling distance is 5 miles.

(iv) Mill capacity increased from 125 tons per hour to 200 tons per hour by use of 4 roller mills instead of 3 roller mills for the 21 factories that exist at present. All factories operating 22 hours a day for 330 days a year.

(v) Molasses, containing 50% fermentable, is produced at a rate of 0.03 tons per ton of sugar cane.

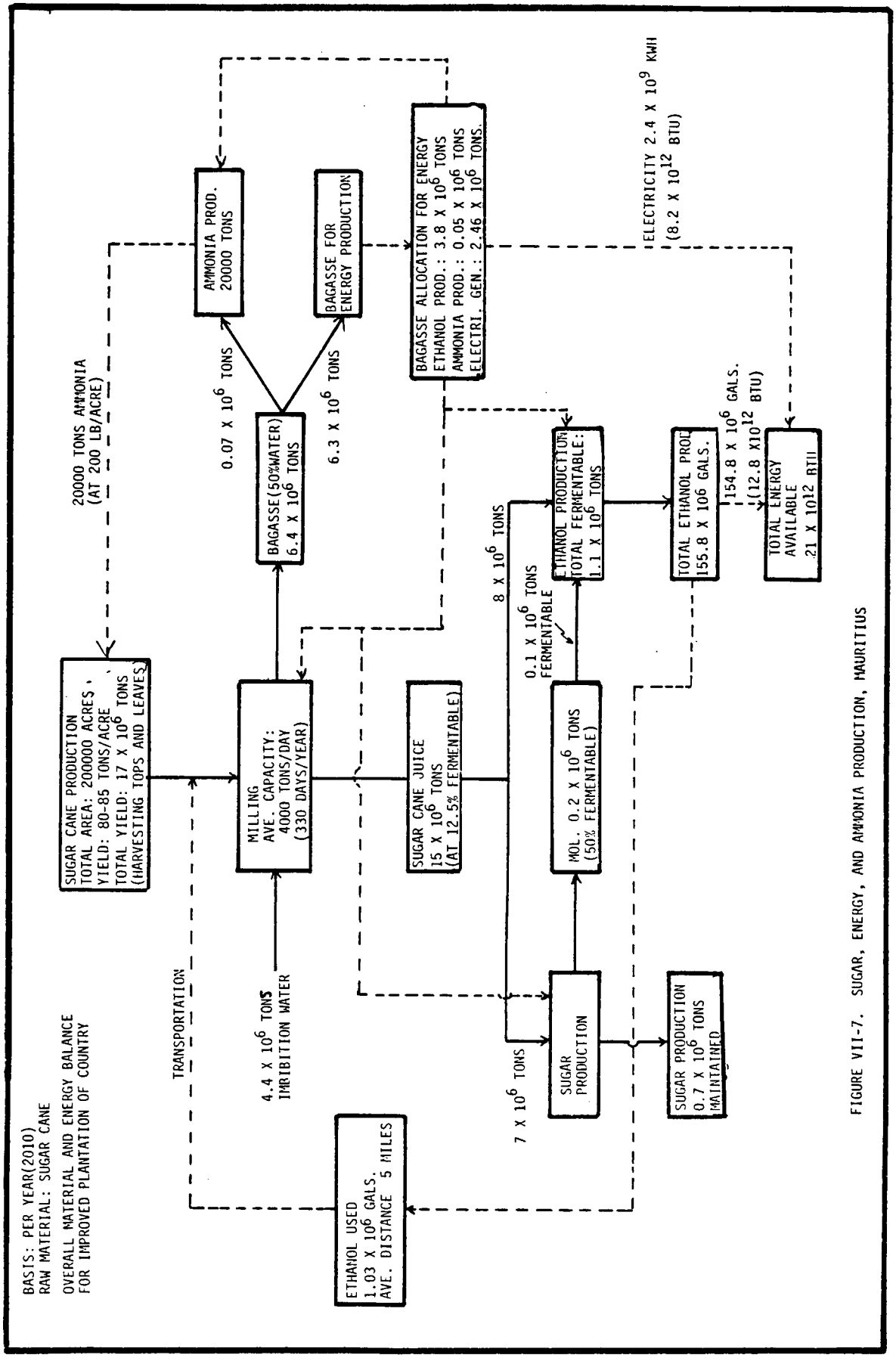


FIGURE VII-7. SUGAR, ENERGY, AND AMMONIA PRODUCTION, MAURITIUS

Table VII-8 summarizes the output of the system from 1975 through 2010. Through the above time frame the annual production of 700,000 tons of sugar, which is vital to the nation's economy, would be sustained by the 7 million tons sugar cane. Molasses, which is a by-product, and any additional sugar cane above that 7 million tons would produce the energy in the form of ethyl alcohol, shown in the table. Bagasse, which is the major by-product, however, would continuously supply enough ammonia to sustain the nitrogen fertilizer requirement of the plantations and enough steam to meet the energy requirement of the process plus some excess electricity.

Though the system appears to be favorable, its bearing on the overall economic development of Mauritius needs to be analyzed before making any strong recommendation. Both of these factors are discussed in the subsection that follows.

3. Overall Impact of Biomass Strategy on Energy Supply and Economic Development.

Estimation of cost of production (current dollars) of ethyl alcohol, ammonia and electricity along the same lines as discussed earlier gives the following:

Ethyl Alcohol	$1.20 to 1.50	per gallon
Electricity	$0.03	per KWH
Ammonia	$247	per ton

The fact that these production costs are slightly lower in Mauritius when compared to the costs in Brazil and U. S. can be explained by the following:

TABLE VII-8

PROJECTED ENERGY AND SUGAR PRODUCTION,
MAURITIUS 1975-2010

Year	Sugar[a] 10^6 Tons	Energy[b] 10^{12} BTU
1976[c]	0.7	0.24
1980	0.7	0.24
1990	0.7	7.5
2000	0.7	17.5
2010	0.7	21.0

[a]Sugar production maintained at 0.7 million tons to sustain nation's economy.

[b]Only excess sugar cane and by-product used for energy and fertilizer production. Total of liquid fuel ethyl alcohol and electricity.

[c]Data for 1976 used instead of 1975 because 1975 was a cyclonic year which destroyed a high percentage of the sugar cane crop.

(i) According to the development plan no new factories would have to be constructed. Instead all extra sugar cane would be handled by improvement of the milling capacity. This in itself reduces the total capital requirement in the milling department which in turn reduces the overall cost per unit of product.

(ii) Since the total production would be increased by improving the productivity of the 200,000 acres already under sugar cane, capital investment would be lower as compared to the case in Brazil, where higher capital investment is required for the development of the new lands.

(iii) The labor being cheaper than in the U. S. partially accounts for the lower cost of production.

However, before making any strong recommendation analyses similar to those carried out in the case of Brazil, that is overall effect of the biomass energy on the total energy demand and economic development is discussed below.

a. Impact on Energy Supply

The results obtained using analyses similar to those carried out for the Brazilian case have been summarized in Figure VII-8 and Table VII-9. As shown on the graph, the top curve represents the most probable energy demand projection as obtained from Chapter III. The other two curves show the energy supply from hydro power which already exists and the supply from the sugar cane industry if the development strategy suggested is implemented. It can be concluded that almost 48% of the total energy demand that would need to be

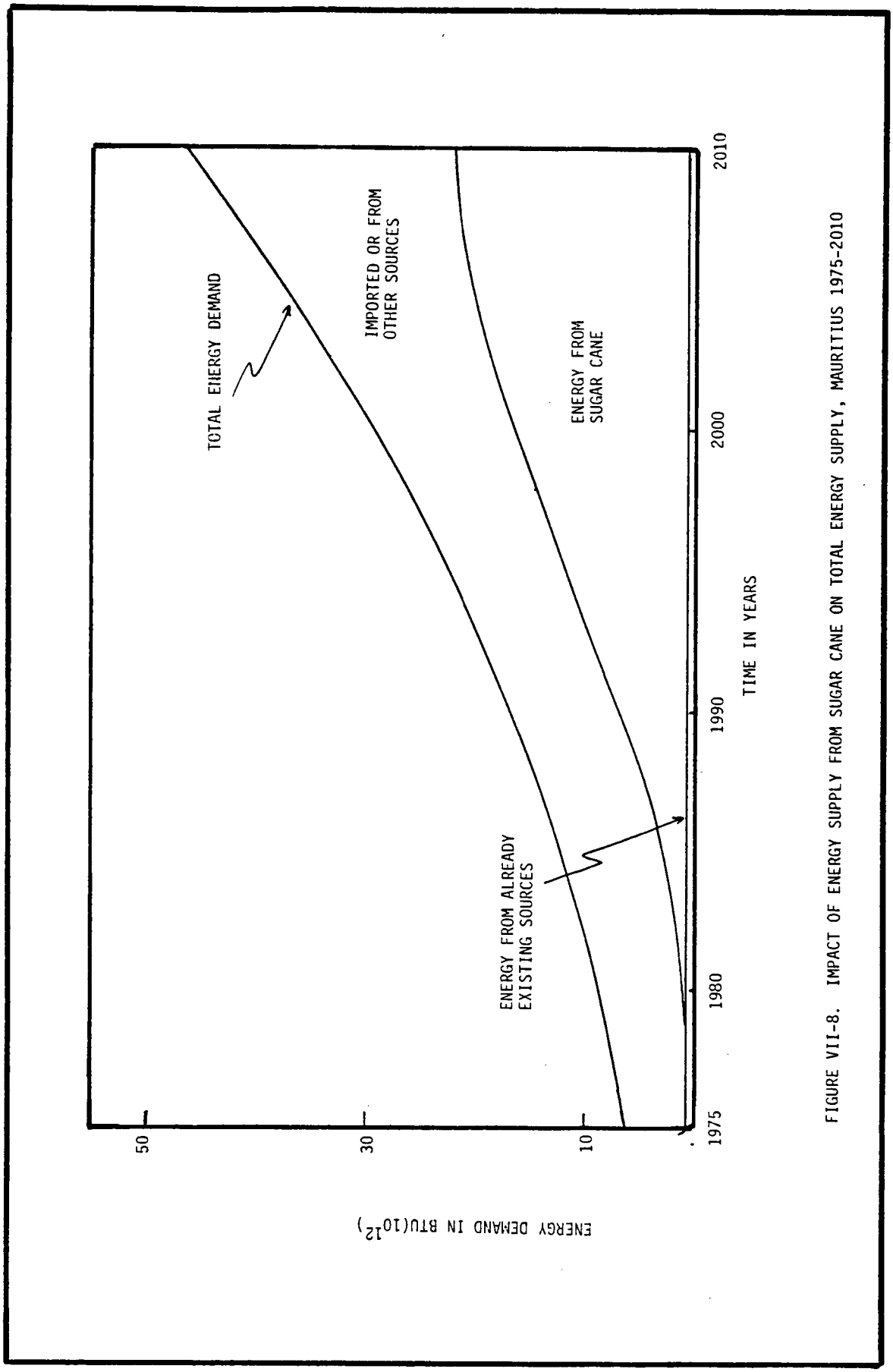


FIGURE VII-8. IMPACT OF ENERGY SUPPLY FROM SUGAR CANE ON TOTAL ENERGY SUPPLY, MAURITIUS 1975-2010

TABLE VII-9

IMPACT OF ENERGY FROM SUGAR CANE ON TOTAL ENERGY SUPPLY, MAURITIUS 1975-2010

Year	Total Energy Demand 10^{12} BTU	Imported Energy[a] If Energy From Sugar Cane Not Used 10^{12} BTU	Supply of Energy From Sugar Cane Total Energy 10^{12} BTU	Supply of Energy From Sugar Cane As Percentage of Imported Energy
1975	6.17	5.82	0.06[b]	4.1
1980	8.95	8.65	0.06	2.8
1990	17.03	16.73	7.5	44.8
2000	29.19	28.89	17.5	60.6
2010	46.09	45.79	21.0	46.0

[a]Assumed that 0.3 X 10^{12} BTU of energy produced at present locally from hydro would remain unchanged. Thermal electricity produced using imported oil has been treated as imported energy.

[b]Sugar factories have been producing electricity from bagasse since mid fifties.

imported could be met by the sugar cane industry by the turn of the century. The effect on the economic development of this biomass energy supply is considered below.

b. Impact on Economic Development

The results of the analysis are summarized in Figure VII-9 and Table VII-10. The calculations have been based on assumptions similar to those used in the case of Brazil, except that the cost of imported energy has been considered separately, because Mauritius imports only refined liquids in order to meet its fossil energy requirements.[88] This is not the case in Brazil or in most other countries. Summarized assumptions and factors considered in the computations are included as footnotes to the table.

Considering the results it can be concluded that there would be a considerable saving in the GNP if the sugar industry becomes a major source of energy. It is very important to reemphasize that the production of 700,000 tons of sugar which accounts for almost 80% of the nation's economy would still be maintained, and energy production would be sustained by any extra cane produced by improvement in yield and by using by-products more efficiently.

D. Biomass as an Energy Source in Nicaragua

1. Biomass Production.

It can be seen from Table VII-11 which summarizes the land utilization in Nicaragua that the opportunity for agricultural expansion does exist.[80] This opportunity becomes more apparent when the high portion of so-called "other land" is considered, which represents fertile land not used for agricultural purposes. Historical data on

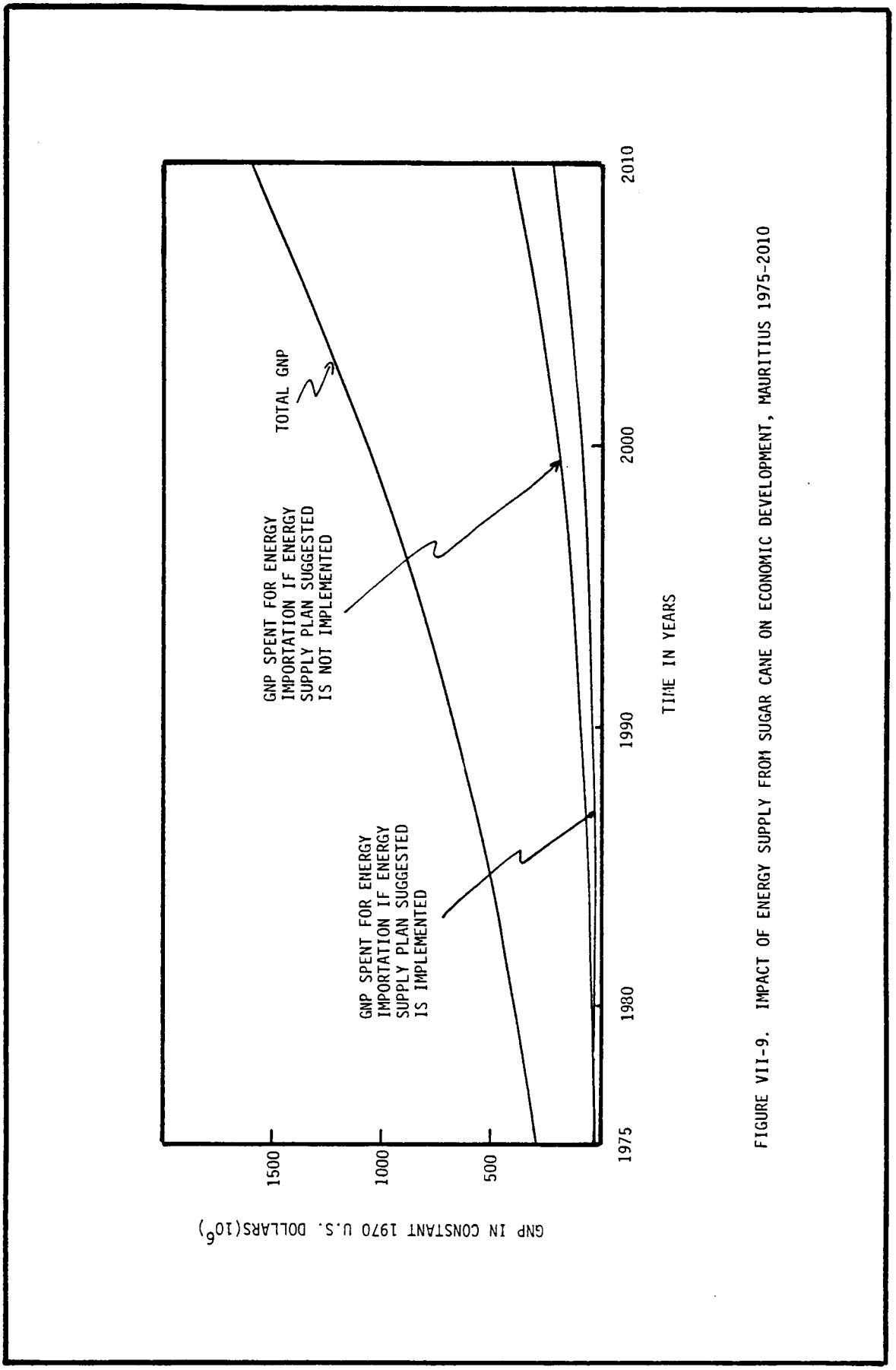


FIGURE VII-9. IMPACT OF ENERGY SUPPLY FROM SUGAR CANE ON ECONOMIC DEVELOPMENT, MAURITIUS 1975-2010

TABLE VII-10

IMPACT OF ENERGY FROM SUGAR CANE ON ECONOMIC DEVELOPMENT, MAURITIUS 1975-2010

Year	GNP 10^6 $[a]	Average Cost of Imported Energy[b] $[a] per 10^6 BTU	If Energy From Sugar Cane Not Used: Total Cost of Imported Energy 10^6 $[a]	If Energy From Sugar Cane Not Used: Percentage of GNP Used For Importation	If Energy From Sugar Cane is Used: Percentage of GNP Saving
1975	272	3.0	17.5	6.4	-
1980	379	3.5	30.3	8.0	-
1990	666	4.7	78.6	11.8	44.8
2000	1054	6.3	182.0	17.3	60.6
2010	1536	8.5	389.2	25.3	48.0

[a] In terms of constant 1970 U. S. dollars.

[b] Since Mauritius imports only refined liquid fuel, the average imported energy in 1975 was approximately $3.0 per 10^6 BTU instead of 1.83 as seen in the case of Brazil. Moreover, based on historical trend an annual increase of 3.0% of the price of imported energy has been assumed.

TABLE VII-11

LAND UTILIZATION IN NICARAGUA, 1975

	Area	
	10^3 Square Miles	10^6 Acres
Total Area[a]	50.2	32.1
Inland water bodies	3.5	2.2
Land area[b]	46.7	29.9
Arable land and permanent crop[c]	3.7	2.4
Forest and woodland[d]	7.1	4.5
Permanent meadows and pastures[e]	23.7	15.2
Other land[f]	12.2	7.8

[a]Total area refers to the total area of the country, including area under inland water bodies.

[b]Land area refers to total area excluding area under inland water bodies, i.e., lakes and rivers.

[c]Arable land refers to land under temporary crops (double cropped areas are counted only once); permanent crops include crop which go beyond 5 years, e.g., tea and coffee.

[d]Forest and woodland refers to land under planted and natural forest and bushes.

[e]Permanent meadows and pastures refers to land used permanently for herbaceous forage crops, either cultivated or growing wild.

[f]Other land refers to unused but potentially productive land, built-on areas, waste land, parks, roads, lanes, etc.

Source: Food and Agricultural Organization (FAO) of the U. N., "Production Yearbook," U. N., Rome, Italy, Vol. 30, 1977.

production reveals that the average annual yield of sugar cane per acre has been in the region of 28 tons and 100,000 acres of sugar cane were grown for production of 212,000 tons of sugar in 1975.[89,90] Based on these factors two systems for the expansion of the sugar cane plantations for both sugar and energy production have been suggested.

The first system deals with the improvement of yield on the already existing 100,000 acres of sugar cane plantation from 28 tons per acre per year to somewhere between 55 to 65 tons by close cropping and harvesting of tops and leaves. This improvement if implemented would finally yield some 6 million tons of sugar cane by the turn of the century, and this can be handled by capacity improvement of the 6 factories that already exist for production of sugar.[90] Only the by-products such as molasses and bagasse would be used for energy and fertilizer production. This is illustrated in detail in the next section.

This second system which is identical to the second system described in the case of Brazil makes use of the sugar cane produced from new plantations. It also considers construction of individual processing units, solely for utilization of sugar cane produced from about 60,000 acres of land for production of energy and fertilizer. It is suggested that 6 such units be constructed during the next 30 years and about 0.36 million acres of new land be put to sugar cane plantation.

Some additional comments relative to the potential for sugar cane in Nicaragua are provided here, based upon information from personal conversations in Nicaragua earlier in 1979, and information obtained from other Nicaraguan work by UTK during 1978 and 1979.[91]

(i) The majority of the Nicaraguan sugar cane production is in a rather limited portion of the country, generally bound by the Pacific coast, to the north of the city of Managua and to the west of the mountainous areas.

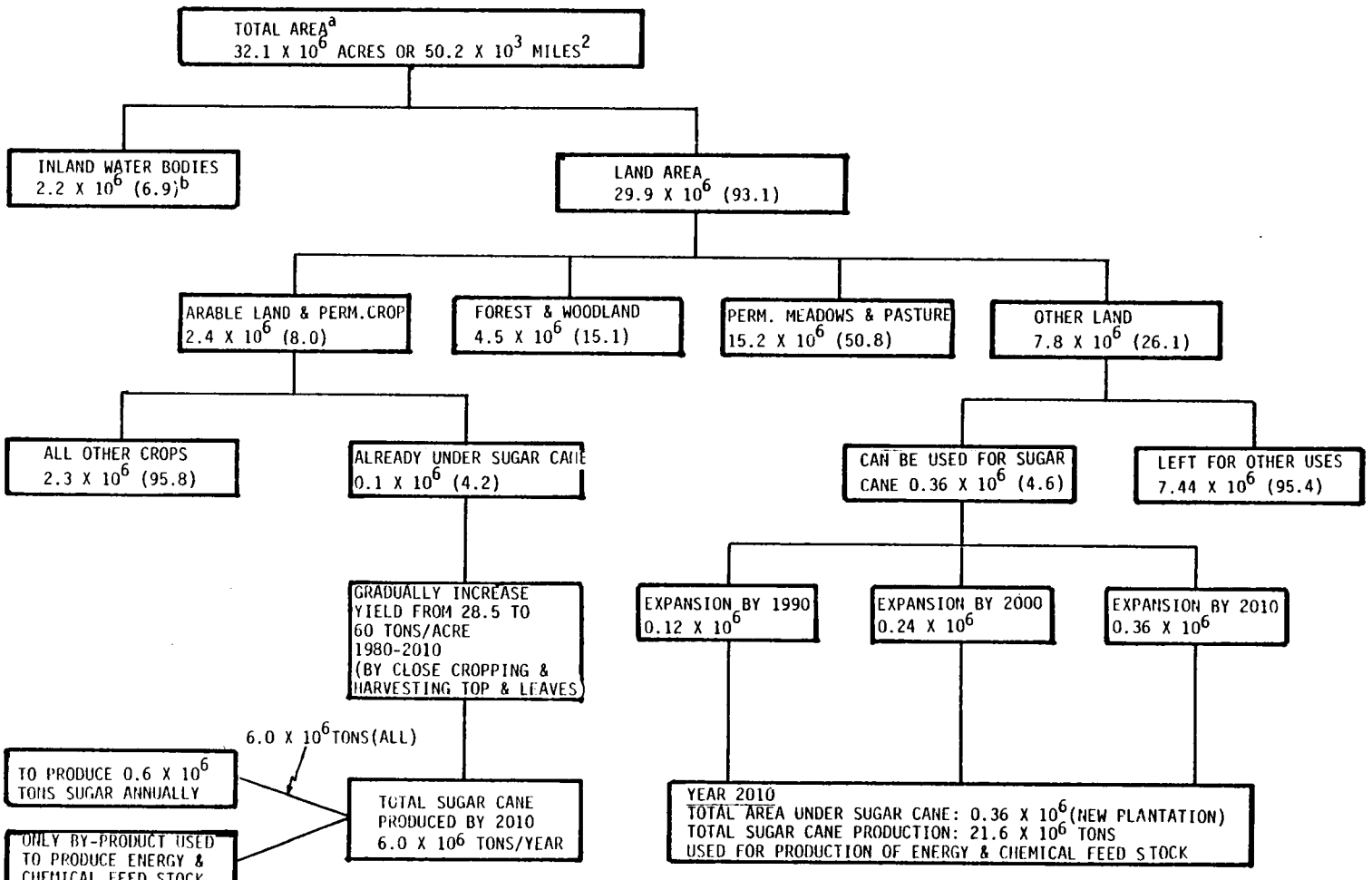
(ii) Because of historical land use practices, this agricultural area already is in need of irrigation.

(iii) The eastern portion of the country, encompassing roughly 80% of the total available land and having a heavier rainfall is not now used very much for agricultural production. Its timber was cut many years ago, and now it is a kind of savannah area of marginal land quality.

(iv) The potential for sugar cane production in the eastern area has not been considered in this dissertation, since that becomes a major study in itself. It's interesting, however, to compare that in Brazil (especially in the northeast) sugar cane is now being produced profitably on lands that 10-15 years ago were not considered suitable for sugar cane.

(v) Alternatively in such marginal areas (and in similar marginal areas of Brazil and other tropical countries) manioca cassava may be introduced in lieu of sugar cane for similar energy strategies. The manioca cassava strategy already is being looked into heavily in Brazil.[72]

Figure VII-10 shows the development plan in further detail. The total sugar cane output, if both systems are implemented in Nicaragua by 2010 is given in Table VII-12. The details associated with utilization of the sugar cane for production of sugar, energy, and ammonia and the material and energy balance, are discussed in the next section.



[a]All areas in acres.

[b]Percentage.

FIGURE VII-10. SUGAR CANE LAND DEVELOPMENT PLAN, NICARAGUA 1975-2010

TABLE VII-12

PROJECTED SUGAR CANE PRODUCTION FOR SUGAR, ENERGY AND FERTILIZER PRODUCTION, NICARAGUA 1975-2010

Year	From Already Existing[a] Sugar Cane Land		From New Plantation		
	Area 10^3 Acres	Used For Raw Sugar Production 10^6 Tons	Area[b] 10^3 Acres	Used For Energy and Fertilizer Production 10^6 Tons	Total Area 10^3 Acres
1975	100	2.4	-	-	-
1980	100	2.4	-	-	-
1990	100	3.0	120	6.6	220
2000	100	4.3	240	13.2	340
2010	100	6.0	360	19.8	460

[a]Note all cane from old plantation goes to sugar production and only by-products used for energy and fertilizer production. Total production of sugar cane increases due to increase in yield by close cropping and harvesting top and leaves.

[b]Area includes land used for road construction, housing and plant site.

2. Biomass Utilization.

Figure VII-11 illustrates how the sugar cane produced from the already existing 100,000 acres of sugar cane plantation would be used for producing sugar. However, the two major by-products of the process, i.e., molasses and bagasse, would be used for ethyl alcohol, fertilizer, and electricity production. From the overall material and energy balance of the system at its maximum operating capacity, which would be achieved by 2010, it can be seen that in addition to the 600,000 tons of sugar, an equivalent of 4.0×10^{12} BTU of energy would be produced annually. This energy would be both in the form of liquids, i.e., ethyl alcohol, and electricity. Moreover, enough ammonia would be produced to meet the nitrogen fertilizer requirements of the plantations. The results of the output of the system are summarized in Table VII-13 and the general effect on the nation's energy demand and economic development have been dealt with in the next subsection.

Sugar cane produced by the implementation of the second system of development, i.e., new land planted with sugar cane solely for production of energy, ethyl alcohol and electricity and enough nitrogen fertilizer ammonia to sustain the plantations, would be handled by an approach similar to that described in the case of Brazil. As already pointed out six such units would have to be built during the next 30 years, i.e., two units every 10 years. The total output of this system also is summarized in Table VII-13 and its effects on economic development and energy demand have been considered in the next subsection.

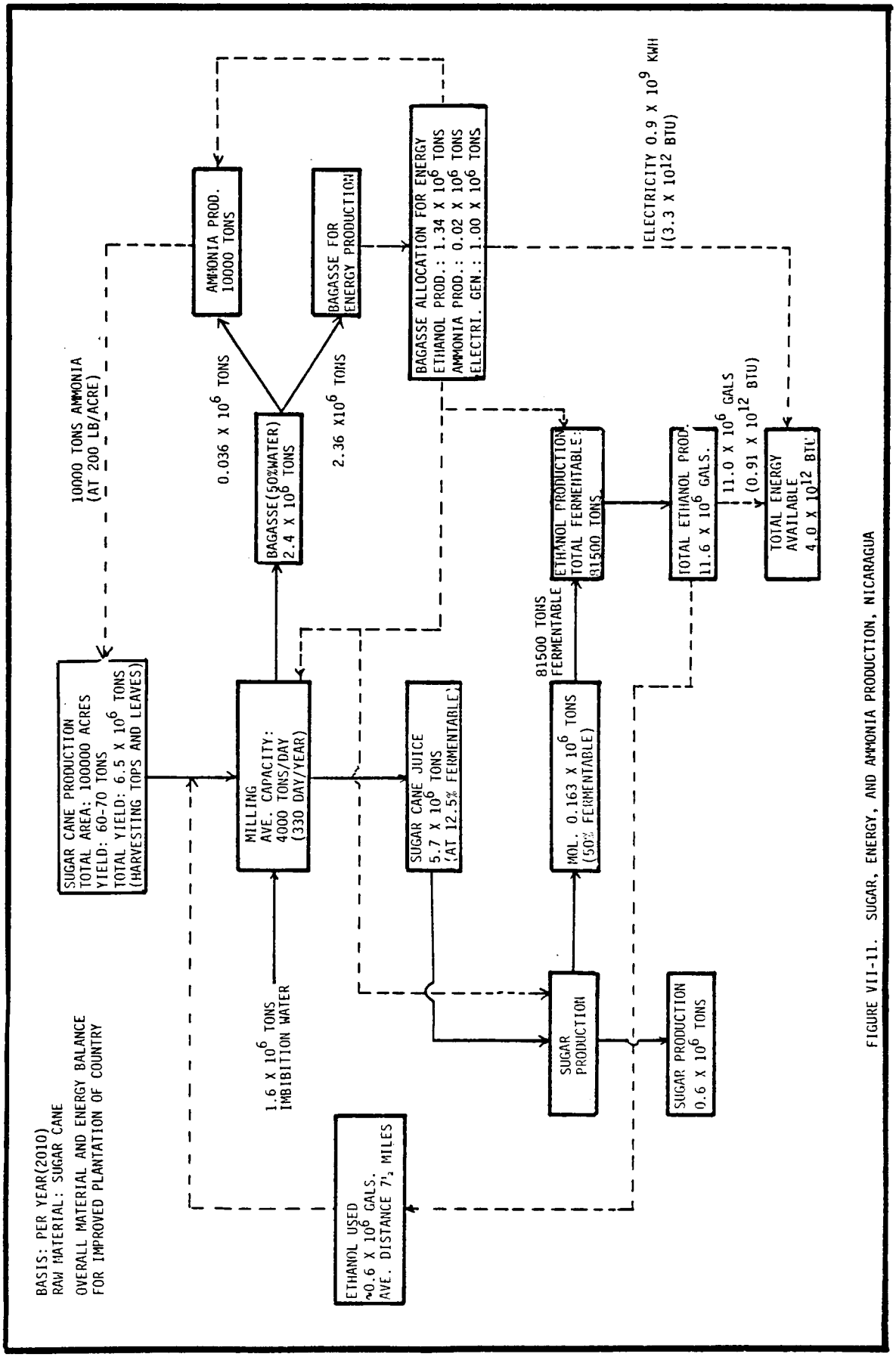


FIGURE VII-11. SUGAR, ENERGY, AND AMMONIA PRODUCTION, NICARAGUA

TABLE VII-13

PROJECTED ENERGY AND SUGAR PRODUCTION OF FIRST AND SECOND SYSTEMS, NICARAGUA 1975-2010

	First System[a]		Second System[b]	Total Energy[c]
Year	Sugar 10^3 Tons	Energy 10^{12} BTU	Energy 10^{12} BTU	10^{12} BTU
1975	212	-	-	-
1980	212	-	-	-
1990	300	1.4	10.4	11.8
2000	425	2.8	20.8	23.8
2010	600	4.1	31.2	35.2

[a]Production of sugar increased to improve nation's economy and by-products only used for energy and fertilizer production.

[b]Sugar cane from new plantation used for energy production only, except enough fertilizer produced to sustain plantation.

[c]Total of liquid fuel ethyl alcohol and electricity.

3. Overall Impact of Biomass Strategy on Energy Supply and Economic Development.

Using economic analyses similar to those already discussed, the cost of production in current dollars of three major products of interest have been estimated and given below.

Ethyl Alcohol	$1.38 - 1.50	per gallon
Electricity	$0.03	per KWH
Ammonia	$ 247	per ton

The figures are very close to those obtained in the case of Brazil, primarily because almost the same strategy of development would be used in both cases.

a. Impact on Energy Supply

Figure VII-12 illustrates the supply and demand of energy in Nicaragua for the time frame 1975-2010. If no energy source is developed during this time frame, Nicaragua would have to depend almost entirely on imported energy. With the development of the sugar cane biomass energy system discussed already, however, almost 14% of the total imported energy could be supplied locally by 2010. Moreover, there are other energy sources, such as geothermal and hydro, as well as other biomass, that could be developed in order to decrease the high dependency on foreign energy.[92] As illustrated in Table VII-14 only the sugar cane biomass energy has been considered in this study. The various assumptions made and factors taken into account in the computations are given as footnotes to the table.

b. Impact on Economic Development

In 1975 Nicaragua spent some 55 million dollars (constant 1970 dollars)[17,19] representing almost 5% of its total GNP, for the

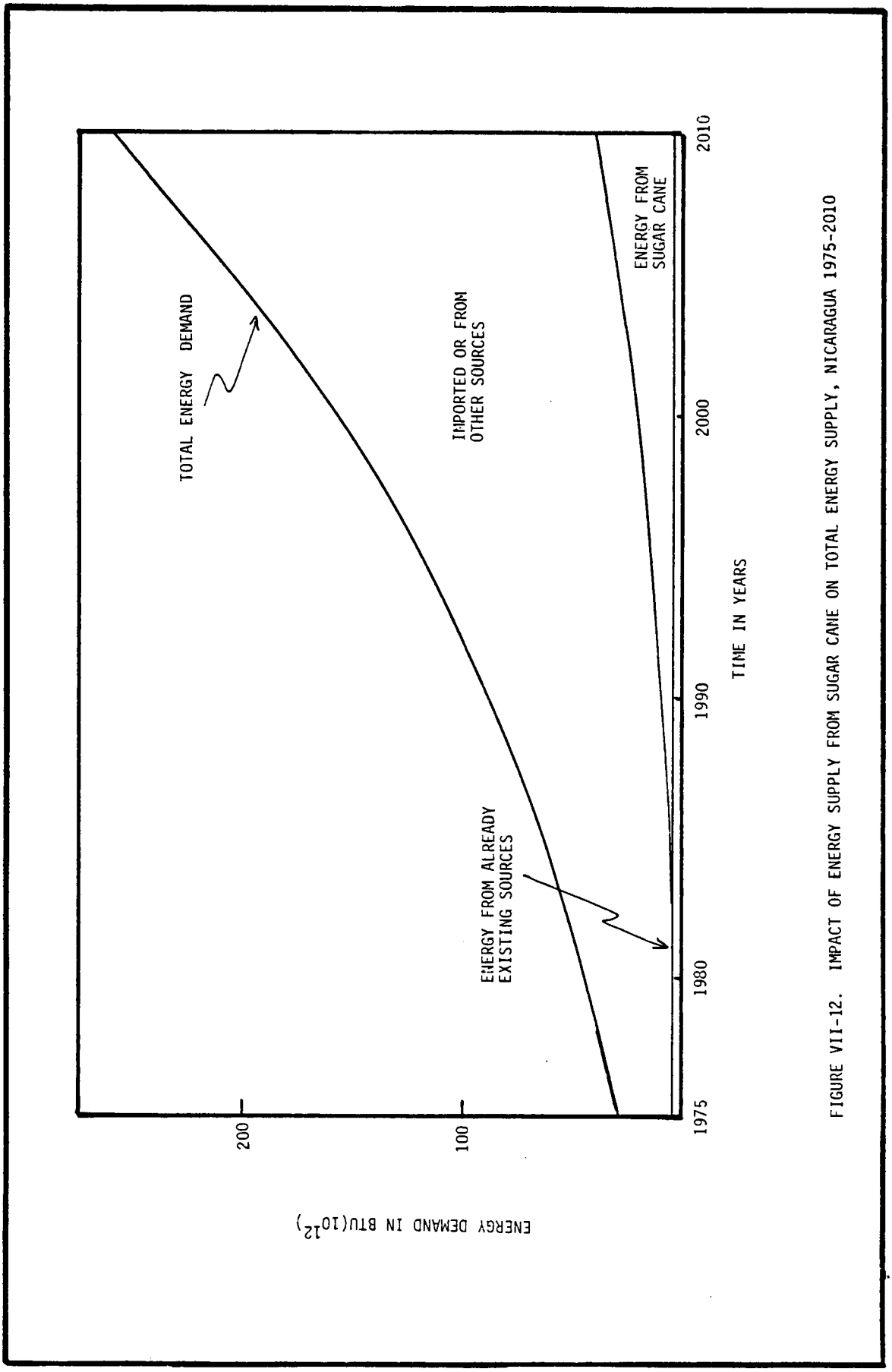


FIGURE VII-12. IMPACT OF ENERGY SUPPLY FROM SUGAR CANE ON TOTAL ENERGY SUPPLY, NICARAGUA 1975-2010

TABLE VII-14

IMPACT OF ENERGY FROM SUGAR CANE ON TOTAL ENERGY SUPPLY, NICARAGUA 1975-2010

Year	Total Energy Demand 10^{12} BTU	Imported[a] Energy If Energy From Sugar Cane Not Used 10^{12} BTU	Supply of Energy From Sugar Cane: Total Energy 10^{12} BTU	Supply of Energy From Sugar Cane: As Percentage of Imported Energy
1975	31.2	29.6	-	-
1980	43.1	42.3	-	-
1990	85.5	83.9	11.8	14.1
2000	155.7	154.1	23.8	15.4
2010	262.5	260.9	35.0	13.5

[a]Assumed that 1.6×10^{12} BTU of energy produced at present locally from hydro and other sources would remain unchanged.

importation of energy. World oil price increases, coupled with the rapidly growing energy demand in Nicaragua will increase the balance of payment problem. Thus economic development increasingly will be handicapped. Nevertheless, with the implementation of the sugar cane biomass system the magnitude of the problem can be reduced. Figure VII-13 and Table VII-15 illustrates the overall impact of the sugar cane biomass strategy on the total GNP of Nicaragua.

E. General Comments

From the analysis carried out in this chapter it can be concluded that sugar cane in addition to sugar as a product has great potential for supplying energy in the form of ethyl alcohol and electricity, and nitrogen fertilizer in the form of liquid ammonia. For the conditions prevailing in Brazil, Mauritius, and Nicaragua the cost of production would be:

Ethyl Alcohol	$1.00 to 1.75	per gallon
Electricity	$0.03	per KWH
Ammonia	$250	per ton

These costs are quite competitive because the LDCs rely almost entirely on imports for their fossil energy supply.

Of the several advantages of the sugar cane biomass systems already pointed out in the text, two major ones need to be mentioned here. The first advantage is that the system can be shifted from production of sugar as the major product to production of ethyl alcohol from its by-product molasses or the production of ethyl alcohol as a major product from the sugar cane juice, depending upon the market situation for the products. The second advantage is that after the

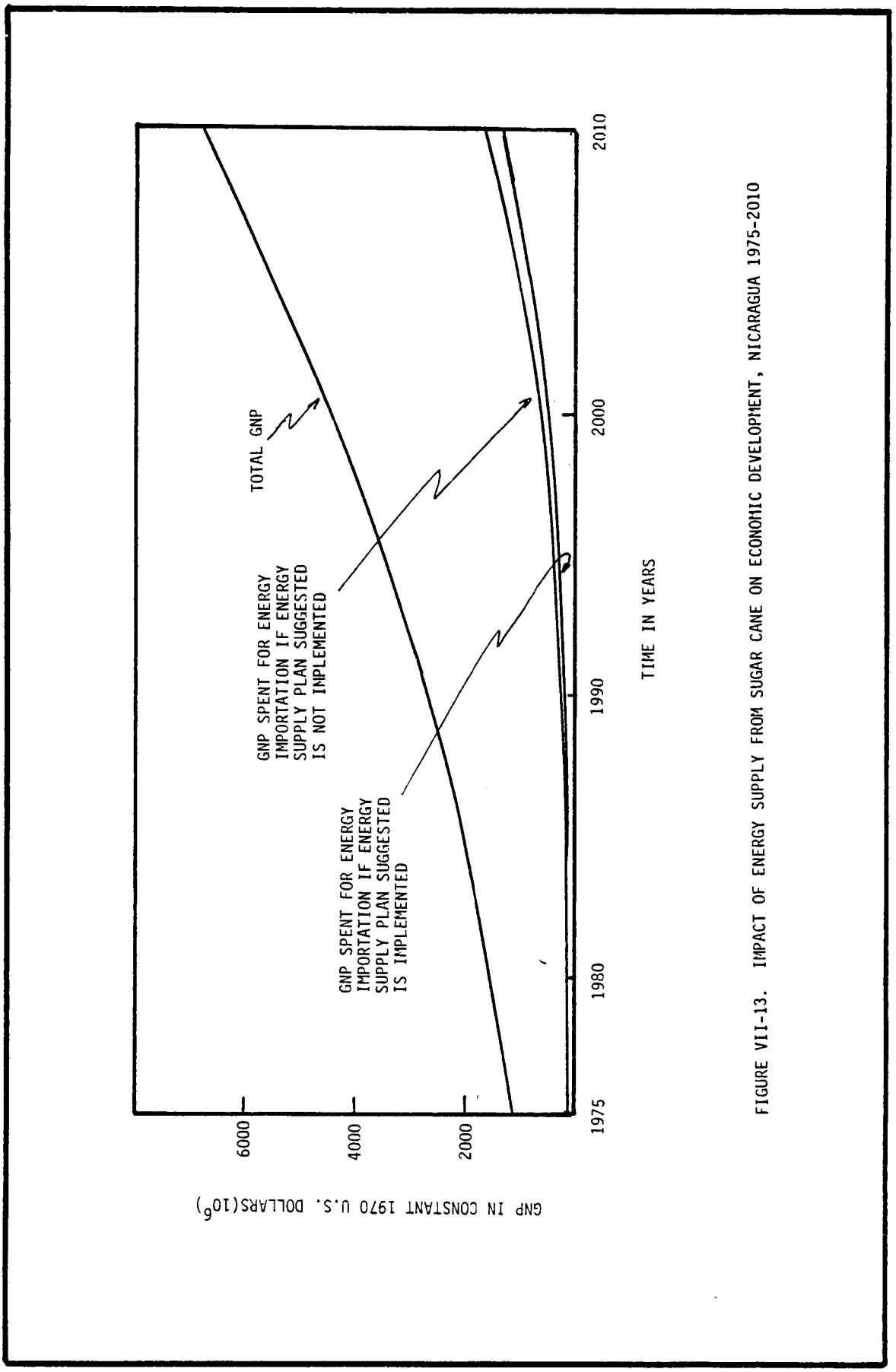


FIGURE VII-13. IMPACT OF ENERGY SUPPLY FROM SUGAR CANE ON ECONOMIC DEVELOPMENT, NICARAGUA 1975-2010

TABLE VII-15

IMPACT OF ENERGY FROM SUGAR CANE ON ECONOMIC DEVELOPMENT, NICARAGUA 1975-2010

Year	GNP 10^6 $[a]	Average Cost of Imported Energy[b] $[a] per 10^6 BTU	If Energy From Sugar Cane Not Used: Total Cost of Imported Energy 10^6 $[a]	If Energy From Sugar Cane Not Used: Percentage of GNP Used	If Energy From Sugar Cane is Used: Percentage of GNP Saving
1975	1077	1.83	54.0	5.0	-
1980	1452	2.18	93.2	6.4	-
1990	2588	3.08	258.4	10.0	14.1
2000	4294	4.34	668.8	15.6	15.4
2010	6568	6.12	1596.7	24.3	13.5

[a] In terms of constant 1970 U. S. dollars.

[b] Average cost of energy has been computed using 1975 data on total energy imported in forms of oil, coal, etc., and total cost of importation. Moreover, based on historical trend an annual increase of 3.5% of the price of imported energy has been assumed.

production of enough nitrogen fertilizer to sustain the plantations from the by-product bagasse, there would still be excess bagasse left for energy production.

A flexible production system of this type would, however, require that excess capacity be designed into the various process units in order to have the stated flexibility. Such excess capacity would increase capital costs and thus increase the various cost estimates provided earlier in this dissertation.

The results also show that if the development plans suggested are fully implemented by the year 2010, the sugar industry would supply at least 15 to 20% of the total energy demand for each of the 3 LDCs considered here. Though these above percentages may not seem too high, the fact that sugar cane is only one of the whole range of biomass materials that can be developed, especially in Brazil and Nicaragua, must not be ignored. At the same time development of other means of solar energy utilization, i.e., direct heating, wind and hydro power, and others which would supply energy over and above that of the sugar industry still need to be considered. The fact that energy from sugar cane is a renewable form of energy is an asset in itself.

The analyses also show that the supply of energy from the sugar industry will have a significant impact on the economic development of the LDCs, largely by reducing expenditures for imported fuels. A saving of at least 10 to 15% on the total GNP which otherwise would be spent for importation of fossil fuels can be achieved by implementation of the above sugar cane biomass plan. Furthermore, the production of sugar, which is a very important cash crop, would still be maintained

as part of the nation's basic economy, as it has been in the past. However, more detailed economic studies must be undertaken before implementation of such plans.

In summary the combination of technical and economic analyses presented in this dissertation suggest that sugar cane as a biomass energy and chemical feedstock has sufficient potential in each of the three countries considered to justify further attention. When coupled with opportunities to expand the use of other forms of biomass, plus expansion of energy sources such as geothermal, hydro, wind, and direct solar energy, there appears to be a realistic potential for reducing the nations' balance of payments problems related to imported energy, with consequent reinforcement of future economic development.

SUMMARY AND RECOMMENDATIONS

A. Summary

This dissertation has examined the relationship between economic growth and energy demand on a long range basis through the year 2010 for the less developed countries (LDCs), with Brazil, Mauritius, and Nicaragua used as specific examples. The U. S. and West Germany have been used as comparative examples from the industrialized nation group.

A system analysis model has been developed to relate economic growth and aggregate energy demand in the LDCs, and the results have been included here. Since sectoral data are scarce and unreliable in many LDCs, the model presented in this dissertation has been developed on an aggregate basis, using population dynamics, labor force, labor productivity, and the efficiency of energy utilization for economic output as the parameters. The model has been tested against the results of sectoral models developed for the U. S.

The potential for biomass as a renewable supply source for energy in the LDCs (and perhaps eventually in industrialized nations) has been examined. The biomass strategies treated in this dissertation focus primarily upon sugar cane, with some additional treatment of corn. The primary focus is upon ethyl alcohol, ammonia, and electricity, with lesser emphasis upon methyl alcohol and ethylene.

The analyses show that the present cost of production (in current U. S. dollars) of these major products in the three LDCs would be approximately as follows.

Ethyl Alcohol	1.00 - 1.75	$ per gallon
Electricity	0.02 - 0.03	$ per KWH
Ammonia	250	$ per short ton

Considering that the three LDCs are net importers of fossil fuel, the price of which has more than doubled during 1979, the above costs are already competitive with the cost of fossil fuel. The analyses also suggest that an intensive biomass strategy could supply by the year 2010 12.5% (Brazil), 46.0% (Mauritius) and 13.5% (Nicaragua) of the total energy demand which also means similar percentages of savings of the total GNP required for importation of energy in each of those three countries; using intermediate figures from the aggregate demand model as the total energy demand and total GNP figures.

Allowing for inherent uncertainties, as would be true in any long range demand analysis, the potential for biomass still is sufficiently large to justify a significant effort in each of the three countries analyzed, and probably in many other LDCs as well. Because of inplace differences in the economic structures and the amounts of available arable land, the potential for biomass strategies in the industrialized nations is less clear.

B. Recommendations

As mentioned above, the scarcity and unreliability of historical data have precluded the development of a Sectoral Energy Demand Model which, compared to the Aggregate Energy Demand Model, is a more powerful tool in understanding the relationships between economic development and energy demand. It is true that this problem of historical sectoral data cannot be remedied in a retroactive sense. Nevertheless, other approaches

can be taken to make best use of data that presently exist. One of the approaches, based on number of automobiles, types of fossil fuel used for generation of electricity, types of fossil fuel being imported, etc., and other more concrete assumptions for breaking down the aggregate energy consumption by fuel types and consuming sectors, has already been initiated at the Center for International Research and Development in connection with the Brazilian data base study. Eventually this kind of approach would enable us to project future energy demand by fuel types and consuming sectors, which would be an improvement over the aggregate model.

Thus, it is recommended that similar studies be undertaken for the other LDCs in order to have a better idea of the types of energy sources that need more attention. It must be emphasized, however, that none of these models, whether sectoral or aggregate, or any other more sophisticated model, is prophetic in nature, which is very often a misunderstood concept. Rather these models give a better understanding of the relationships between economic development and energy demand which is very important in future planning and development.

As for the question of the use of biomass for energy and chemical feedstock production, collaborative research efforts are certainly well justified in each of the three LDCs, as well as in other LDCs. Sugar cane is only one of the wide range of other biomass materials which need further investigation. Any large scale biomass strategy must of course include serious attention to related problems of land use, water resources, ecology and environment, and competition with production of food, in addition to the obvious technical and economic considerations. There are other direct and indirect uses of solar energy

attractive to the LDCs and developed nations which need careful attention in the future.

In this study, the problem of energy and economic development has been approached from a chemical engineer's point of view and efforts have been made to look into the economic aspects of the problem. Certainly it is not solely the job of engineers or economists to solve this problem which threatens our present and future generations. Rather it is an interdisciplinary problem, which has to be approached by scientists, mathematicians, and social and political scientists, whose collective efforts would help to answer the innumerable questions, a few have been included here. Why is it that the polls in the U. S. constantly show that more than half of the population do not believe that there is an energy crisis? What are the factors that would make people aware of the depletion of this valuable resource and other resources as well, which would convince them to conserve? What kind of policies can be adopted in order to make people realize, especially in the LDCs, that population growth rate must be substantially reduced? What are the driving forces necessary to convince every individual in any nation to collaborate in order to build a strong economy? What can be done in order to build a world that is ecologically sustainable and socially just?

Many of the above questions can be answered if world history is studied. Certainly the study of world history would help to understand the driving forces and policies which have contributed to the growth of the industrialized nations. Obviously this type of study goes beyond engineering economics and requires interdisciplinary collaboration.

The present study must be considered as one step towards several others that need to be taken in order to find solutions to the energy problem of the LDCs as well as the developed nations.

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APPENDICES

APPENDIX A

APPENDIX A

AGGREGATE ENERGY DEMAND MODEL
BASE DATA AND RESULTS

LDC/CIRD - 1, which is a computer simulation of the Aggregate Energy Demand Model developed during this study, has been included in this appendix. Tables A-1 to A-6 include the base data (1950-1975) for the U. S., West Germany, Brazil, Mauritius, Nicaragua, and Venezuela. Each of these tables is followed by the computer printouts generated by the above model. These computer printouts include the various parametric projections discussed in Chapters I to III of the text.

Finally, Table A-7 shows the Consumer Price Index (CPI with 1970 = 100) used in this study.

LDC/CIRD - 1
AGGREGATE ENERGY DEMAND MODEL

```
C
C       NAME:LDC/CIRD-I : COTJB1.FOR
C
C       THIS PROGRAM PROJECTS ENERGY DEMAND AND ECONOMIC
C       DEVELOPMENT.
C
C
C
C       IYEAR=YEAR
C       BRH,BRM,BRL=BIRTH RATES: HIGH,MEDIUM,LOW
C       DRH,DRM,DRL=DEATH RATES: HIGH,MEDIUM,LOW
C       PGRH,PGRM,PGRL=POPULATION GROWTH RATES: HIGH,MEDIUM,LOW
C       POPH,POPM,POPL=POPULATION: HIGH,MEDIUM,LOW
C       GPOPH,GPOPM,GPOPL=POPULATION GROWTH RATES: HIGH,MEDIUM,LOW
C       WORKFH,WORKFM,WORKFL=WORK FORCE: HIGH,MEDIUM,LOW
C       WRKFAC=WORK FORCE AS A PERCENTAGE OF POPULATION
C       PRODH,PRODL=PRODUCTIVITY: HIGH,LOW
C       GPRODH,GPRODL=PRODUCTIVITY GROWTH RATES: HIGH,LOW
C
C
C
        DIMENSION IYEAR(100),
       1BRH(100),BRM(100),BRL(100),
       1DRH(100),DRM(100),DRL(100),
       1PGRH(100),PGRM(100),PGRL(100),
       1POPH(100),POPM(100),POPL(100),
       1GPOPH(100),GPOPM(100),GPOPL(100),
       1WORKFH(100),WORKFM(100),WORKFL(100),
       1WRKFAC(100),
       1PRODH(100),PRODL(100),
       1GPRODH(100),GPRODL(100)
C
C
C       GNPHH,GNPHM,GNPHL=GNP: HIGH,MEDIUM,LOW AND ASSUMING HIGH
C               PRODUCTIVITY
C       GNPLH,GNPLM,GNPLL=GNP: HIGH,MEDIUM,LOW AND ASSUMING LOW
C               PRODUCTIVITY
C       GGNPHH,GGNPHM,GGNPHL=GNP GROWTH RATES: HIGH,MEDIUM,LOW AND ASSUMING HIGH
C               PRODUCTIVITY
C       GGNPLH,GGNPLM,GGNPLL=GNP GROWTH RATES: HIGH,MEDIUM,LOW AND ASSUMING LOW
C               PRODUCTIVITY
C       GCAPHH,GCAPHM,GCAPHL=GNP/CAPITA: HIGH,MEDIUM,LOW AND ASSUMING HIGH
C               PRODUCTIVITY
C       GCAPLH,GCAPLM,GCAPLL=GNP/CAPITA: HIGH,MEDIUM,LOW AND ASSUMING LOW
C               PRODUCTIVITY
C       GGCPHH,GGCPHM,GGCPHL=GNP/CAPITA GROWTH RATES:HIGH,MEDIUM,LOW AND
C               ASSUMING HIGH PRODUCTIVITY
C       GGCPLH,GGCPLM,GGCPLL=GNP/CAPITA GROWTH RATES:HIGH,MEDIUM,LOW AND
C               ASSUMING LOW PRODUCTIVITY
C
C
C
        DIMENSION GNPHH(100),GNPHM(100),GNPHL(100),
       1GNPLH(100),GNPLM(100),GNPLL(100),
       1GGNPHH(100),GGNPHM(100),GGNPHL(100),
       1GGNPLH(100),GGNPLM(100),GGNPLL(100),
       1GCAPHH(100),GCAPHM(100),GCAPHL(100),
       1GCAPLH(100),GCAPLM(100),GCAPLL(100),
       1GGCPHH(100),GGCPHM(100),GGCPHL(100),
       1GGCPLH(100),GGCPLM(100),GGCPLL(100)
C
C
C
C       EGNPRH,EGNPRL=ENERGY/GNP RATIO: HIGH,LOW
```

```
C        GEGPRH,GEGPRL=ENERGY/GNP RATIO GROWTH RATES: HIGH,LOW
C        EDHHRH,EDHMRH,EDHLRH=ENERGY DEMAND: HIGH,MEDIUM,LOW
C                             ASSUMING HIGH RATIO AND HIGH
C                             PRODUTIVITY
C        EDLHRH,EDLMRH,EDLLRH=ENERGY DEMAND: HIGH,MEDIUM,LOW
C                             ASSUMING HIGH RATIO AND LOW
C                             PRODUCTIVITY
C        EDHHRL,EDHMRL,EDHLRL=ENERGY DEMAND: HIGH,MEDIUM,LOW
C                             ASSUMING LOW RATIO AND HIGH
C                             PRODUCTIVITY
C        EDLHRL,EDLMRL,EDLLRL=ENERGY DEMAND: HIGH,MEDIUM,LOW
C                             ASSUMING LOW RATIO AND LOW
C                             PRODUCTIVITY
C        GEDHHH,GEDHMH,GEDHLH=ENERGY DEMAND GROWTH RATES:
C                             HIGH,MEDIUM,LOW ASSUMING HIGH
C                             RATIO AND HIGH PRODUCTIVITY
C        GEDLHH,GEDLMH,GEDLLH=ENERGY DEMAND GROWTH RATES:
C                             HIGH,MEDIUM,LOW ASSUMING HIGH
C                             RATIO AND LOW PRODUCTIVITY
C        GEDHHL,GEDHML,GEDHLL=ENERGY DEMAND GROWTH RATES:
C                             HIGH,MEDIUM,LOW ASSUMING LOW
C                             RATIO AND HIGH PRODUCTIVITY
C        GEDLHL,GEDLML,GEDLLL=ENERGY DEMAND GROWTH RATES:
C                             HIGH,MEDIUM,LOW ASSUMING LOW
C                             RATIO AND LOW PRODUCTIVITY
C        ECPHHH,ECPHMH,ECPHLH=ENERGY DEMAND/CAPITA: HIGH,
C                             MEDIUM,LOW ASSUMING HIGH RATIO
C                             AND HIGH PRODUCTIVITY
C        ECPLHH,ECPLMH,ECPLLH=ENERGY DEMAND/CAPITA: HIGH,
C                             MEDIUM,LOW ASSUMING HIGH RATIO
C                             AND LOW PRODUCTIVITY
C        ECPHHL,ECPHML,ECPHLL=ENERGY DEMAND/CAPITA: HIGH,
C                             MEDIUM,LOW ASSUMING LOW RATIO
C                             AND HIGH PRODUCTIVITY
C        ECPLHL,ECPLML,ECPLLL=ENERGY DEMAND/CAPITA: HIGH,
C                             MEDIUM,LOW ASSUMING LOW RATIO
C                             AND LOW PRODUCTIVITY
C        GEKHHH,GEKHMH,GEKHLH=ENERGY DEMAND/CAPITA GROWTH RATES:
C                             HIGH,MEDIUM,LOW ASSUMING HIGH RATIO
C                             AND HIGH PRODUCTIVITY
C        GEKLHH,GEKLMH,GEKLLH=ENERGY DEMAND/CAPITA GROWTH RATES:
C                             HIGH,MEDIUM,LOW ASSUMING HIGH RATIO
C                             AND LOW PRODUCTIVITY
C        GEKHHL,GEKHML,GEKHLL=ENERGY DEMAND/CAPITA GROWTH RATES:
C                             HIGH,MEDIUM,LOW ASSUMING LOW RATIO
C                             AND HIGH PRODUCTIVITY
C        GEKLHL,GEKLML,GEKLLL=ENERGY DEMAND/CAPITA GROWTH RATES:
C                             HIGH,MEDIUM,LOW ASSUMING LOW RATIO
C                             AND LOW PRODUCTIVITY
C
C
C
         DIMENSION EGNPRH(100),EGNPRL(100),
        1GEGPRH(100),GEGPRL(100),
        1EDHHRH(100),EDHMRH(100),EDHLRH(100),
        1EDLHRH(100),EDLMRH(100),EDLLRH(100),
        1EDHHRL(100),EDHMRL(100),EDHLRL(100),
        1EDLHRL(100),EDLMRL(100),EDLLRL(100),
        1GEDHHH(100),GEDHMH(100),GEDHLH(100),
        1GEDLHH(100),GEDLMH(100),GEDLLH(100),
        1GEDHHL(100),GEDHML(100),GEDHLL(100),
        1GEDLHL(100),GEDLML(100),GEDLLL(100),
        1ECPHHH(100),ECPHMH(100),ECPHLH(100),
        1ECPLHH(100),ECPLMH(100),ECPLLH(100),
        1ECPHHL(100),ECPHML(100),ECPHLL(100),
        1ECPLHL(100),ECPLML(100),ECPLLL(100),
        1GEKHHH(100),GEKHMH(100),GEKHLH(100),
        1GEKLHH(100),GEKLMH(100),GEKLLH(100),
        1GEKHHL(100),GEKHML(100),GEKHLL(100),
```

```
     1GEKLHL(100),GEKLML(100),GEKLLL(100)
C
C
C
C    READ BASE YEAR:1975,POPULATION,GNP/CAPITA(CONSTANT 1970
C    U.S DOLLAR),PRODUCTIVITY(1970 U.S $/EMPLOYEE),ENERGY:GNP
C    RATIO(BTU/1970 U.S $),WORK FORCE(AS PERCENTAGE OF POPULA-
C    TION),BIRTH AND DEATH RATES PER 1000.
C
C
     READ(41,1000)IYEARB,POP,GNPPC,PRODIN,EGNPR,WFA,BR,DR,WORLD,USA,WG
1000 FORMAT(I,4E,6F)
     IYEAR(1)=IYEARB
C
C
C    A.POPULATION PROJECTION.
C
C    A.1.HIGH LEVEL POPULATION GROWTH RATE.
C
C
     DO100I=2,8
100  IYEAR(I)=IYEARB+(5*(I-1))
     BRH(1)=BR
     DRH(1)=DR
     BRM(1)=BR
     DRM(1)=DR
     BRL(1)=BR
     DRL(1)=DR
     IF(BRH(1).LE.10.000)GOTO 10
     DO101I=2,21
     BRH(I)=(BR*2.*(EXP(0.02292*5.*(I-1))))/
     1(1.+EXP(0.04584*5.*(I-1)))
     NHB=I
101  IF(BRH(I).LE.10.000)GOTO 11
11   DO102I=NHB,21
102  BRH(I)=10.0
     GOTO 12
10   DO103I=2,21
103  BRH(I)=BR
12   IF(DRH(1).LE.10.000)GOTO 13
     DO104I=2,21
     DRH(I)=DR*EXP(-0.025*5.*(I-1))
     NHD=I
104  IF(DRH(I).LE.10.000)GOTO 14
14   DO105I=NHD,21
105  DRH(I)=10.0
     GOTO 15
13   DO106I=2,21
106  DRH(I)=DR
15   IF(DRH(I).LT.10.000)GOTO 16
16   DO107I=NHB,21
     GPH=((DRH(21)/BRH(21))**((1./((21-NHB)*5.))))
107  BRH(I)=(BRH(NHB)*((GPH)**(5.*(I-NHB))))
     DO108I=1,21
108  PGRH(I)=((BRH(I)-DRH(I))/10.)
C
C
C    A.2.MEDIUM LEVEL POPULATION GROWTH RATE.
C
C
     IF(BRM(1).LE.10.000)GOTO 17
     DO109I=2,15
     BRM(I)=(BR*2.*(EXP(0.0325*5.*(I-1))))/
     1(1.+EXP(0.0650*5.*(I-1)))
     MMB=I
109  IF(BRM(I).LE.10.000)GOTO 18
18   DO110I=MMB,15
110  BRM(I)=10.
     GOTO 19
```

```
17      DO111I=2,15
111     BRM(I)=BR
19      IF(DRM(1).LE.10.000)GOTO 20
        DO112I=2,15
        DRM(I)=DR*EXP(-0.031*5.*(I-1))
        MMD=I
112     IF(DRM(I).LE.10.000)GOTO 21
21      DO113I=MMD,15
113     DRM(I)=10.0
        GOTO 22
20      DO114I=2,15
114     DRM(I)=DR
22      IF(DRM(I).LT.10.000)GOTO 23
23      DO115I=MMB,15
        GPM=((DRM(15)/BRM(15))**((1./((15-MMB)*5.))))
115     BRM(I)=(BRM(MMB)*((GPM)**(5.*(I-MMB))))
        DO116I=1,15
116     PGRM(I)=((BRM(I)-DRM(I))/10.)
C
C
C       A.3.LOW LEVEL POPULATION GROWTH RATE.
C
C
        IF(BRL(1).LE.10.000)GOTO 24
        DO117I=2,9
        BRL(I)=(BR*2.*(EXP(0.0573*5.*(I-1))))/
        1(1.+EXP(0.1146*5.*(I-1)))
        LLB=I
117     IF(BRL(I).LE.10.000)GOTO 25
25      DO118I=LLB,9
118     BRL(I)=10.0
        GOTO 26
24      DO119I=2,9
119     BRL(I)=BR
26      IF(DRL(1).LE.10.000)GOTO 27
        DO120I=2,9
        DRL(I)=DR*EXP(-0.04175*5.*(I-1))
        LLD=I
120     IF(DRL(I).LE.10.000)GOTO 28
28      DO121I=LLD,9
121     DRL(I)=10.0
        GOTO 29
27      DO122I=2,9
122     DRL(I)=DR
29      IF(DRL(I).LT.10.000)GOTO 30
30      DO123I=LLB,9
        GPL=((DRL(9)/BRL(9))**((1./((9-LLB)*5.))))
123     BRL(I)=(BRL(LLB)*((GPL)**(5.*(I-LLB))))
        DO124I=1,9
124     PGRL(I)=((BRL(I)-DRL(I))/10.)
C
C
C       A.4.POPULATION CALCULATIONS.
C           3 LEVELS : HIGH,MEDIUM,LOW.
C
C
        POPH(1)=POP
        POPM(1)=POP
        POPL(1)=POP
        IF(USA.EQ.1.0)GOTO 31
        DO125I=2,8
        POPH(I)=POPH(I-1)*((1.+(PGRH(I)/100.))**5.)
        POPM(I)=POPM(I-1)*((1.+(PGRM(I)/100.))**5.)
125     POPL(I)=POPL(I-1)*((1.+(PGRL(I)/100.))**5.)
        GOTO 32
31      DO126I=2,8
        POPH(I)=POPH(I-1)*((1.+((0.3+PGRH(I))/100.))**5.)
        POPM(I)=POPM(I-1)*((1.+((0.3+PGRM(I))/100.))**5.)
126     POPL(I)=POPL(I-1)*((1.+((0.3+PGRL(I))/100.))**5.)
```

```
      GOTO 32
C
C
C     B.PRODUCTIVITY PROJECTIONS.
C       2 LEVELS : HIGH AND LOW.
C
C
32    IF(WORLD.EQ.1.0)GOTO 41
      PRH=(((0.3750E4/PRODIN)**0.02857)-1.)
      PRL=(((0.2750E4/PRODIN)**0.02857)-1.)
      GOTO 42
41    PRH=0.017
      PRL=0.010
      GOTO 42
42    PRODH(1)=PRODIN
      PRODL(1)=PRODIN
      DO200I=2,8
      PRODH(I)=(1.+PRH)**(5.*(I-1))*PRODIN
200   PRODL(I)=(1.+PRL)**(5.*(I-1))*PRODIN
C
C
C     C.WORK FORCE PROJECTIONS.
C       3 LEVELS : HIGH,MEDIUM AND LOW.
C
C
      WFAS=((0.40-WFA)/7.)
      WRKFAC(1)=WFA
      DO300I=2,8
300   WRKFAC(I)=(WFA+WFAS*(I-1))
      DO301I=1,8
      WORKFH(I)=WRKFAC(I)*POPH(I)
      WORKFM(I)=WRKFAC(I)*POPM(I)
301   WORKFL(I)=WRKFAC(I)*POPL(I)
C
C
C     D.GROSS NATIONAL PRODUCT PROJECTIONS.(CONSTANT 1970 U.S $)
C       6 LEVELS : REFER TO MODEL'S FLOW CHART.
C
C
      DO400I=1,8
      GNPHH(I)=PRODH(I)*WORKFH(I)
      GNPHM(I)=PRODH(I)*WORKFM(I)
      GNPHL(I)=PRODH(I)*WORKFL(I)
      GNPLH(I)=PRODL(I)*WORKFH(I)
      GNPLM(I)=PRODL(I)*WORKFM(I)
400   GNPLL(I)=PRODL(I)*WORKFL(I)
C
C
C     E.TOTAL ENERGY DEMAND PROJECTIONS (BTU)-1975-2010.
C
C     E.1.ENERGY TO GNP RATIO PROJECTIONS.(BTU/CONSTANT 1970 US. $)
C         2 LEVELS: (1).HIGH LEVEL BASED ON U.S.DEVELOPMENT PATTERN.
C                   (2).LOW LEVEL BASED ON W.GERMANY DEVELOPMENT PATTERN
C
C
      RRH=(((0.5000E5/EGNPR)**0.02857)-1.)
      RRL=(((0.3000E5/EGNPR)**0.02857)-1.)
      EGNPRI=EGNPR
      EGNPRH(1)=EGNPR
      EGNPRL(1)=EGNPR
      DO500I=2,8
      EGNPRH(I)=(1.+RRH)**(5.*(I-1))*EGNPRI
500   EGNPRL(I)=(1.+RRL)**(5.*(I-1))*EGNPRI
C
C
C     E.2.TOTAL ENERGY DEMAND CALCULATIONS.
C         12 LEVELS - REFER TO MODEL'S FLOW CHART.
C
C
```

```
      DO501I=1,8
      EDHHRH(I)=GNPHH(I)*EGNPRH(I)
      EDHMRH(I)=GNPHM(I)*EGNPRH(I)
      EDHLRH(I)=GNPHL(I)*EGNPRH(I)
      EDLHRH(I)=GNPLH(I)*EGNPRH(I)
      EDLMRH(I)=GNPLM(I)*EGNPRH(I)
      EDLLRH(I)=GNPLL(I)*EGNPRH(I)
      EDHHRL(I)=GNPHH(I)*EGNPRL(I)
      EDHMRL(I)=GNPHM(I)*EGNPRL(I)
      EDHLRL(I)=GNPHL(I)*EGNPRL(I)
      EDLHRL(I)=GNPLH(I)*EGNPRL(I)
      EDLMRL(I)=GNPLM(I)*EGNPRL(I)
501   EDLLRL(I)=GNPLL(I)*EGNPRL(I)
C
C
C     F.AVERAGE ANNUAL GROWTH RATES CALCULATIONS.
C
C     F.1.POPULATION GROWTH RATES.
C
      DO600I=1,7
      GPOPH(I)=((POPH(I+1)/POPH(I))**0.2-1.)*100.
      GPOPM(I)=((POPM(I+1)/POPM(I))**0.2-1.)*100.
      GPOPL(I)=((POPL(I+1)/POPL(I))**0.2-1.)*100.
C
C     F.2.PRODUCTIVITY GROWTH RATES.
C
      GPRODH(I)=((PRODH(I+1)/PRODH(I))**0.2-1.)*100.
      GPRODL(I)=((PRODL(I+1)/PRODL(I))**0.2-1.)*100.
C
C     F.3.GNP GROWTH RATES.
C
      GGNPHH(I)=((GNPHH(I+1)/GNPHH(I))**0.2-1.)*100.
      GGNPHM(I)=((GNPHM(I+1)/GNPHM(I))**0.2-1.)*100.
      GGNPHL(I)=((GNPHL(I+1)/GNPHL(I))**0.2-1.)*100.
      GGNPLH(I)=((GNPLH(I+1)/GNPLH(I))**0.2-1.)*100.
      GGNPLM(I)=((GNPLM(I+1)/GNPLM(I))**0.2-1.)*100.
      GGNPLL(I)=((GNPLL(I+1)/GNPLL(I))**0.2-1.)*100.
C
C     F.4.ENERGY-GNP RATIO GROWTH RATES.
C
      GEGPRH(I)=((EGNPRH(I+1)/EGNPRH(I))**0.2-1.)*100.
      GEGPRL(I)=((EGNPRL(I+1)/EGNPRL(I))**0.2-1.)*100.
C
C     F.4.ENERGY DEMAND GROWTH RATES.
C
      GEDHHH(I)=((EDHHRH(I+1)/EDHHRH(I))**0.2-1.)*100.
      GEDHMH(I)=((EDHMRH(I+1)/EDHMRH(I))**0.2-1.)*100.
      GEDHLH(I)=((EDHLRH(I+1)/EDHLRH(I))**0.2-1.)*100.
      GEDLHH(I)=((EDLHRH(I+1)/EDLHRH(I))**0.2-1.)*100.
      GEDLMH(I)=((EDLMRH(I+1)/EDLMRH(I))**0.2-1.)*100.
      GEDLLH(I)=((EDLLRH(I+1)/EDLLRH(I))**0.2-1.)*100.
      GEDHHL(I)=((EDHHRL(I+1)/EDHHRL(I))**0.2-1.)*100.
      GEDHML(I)=((EDHMRL(I+1)/EDHMRL(I))**0.2-1.)*100.
      GEDHLL(I)=((EDHLRL(I+1)/EDHLRL(I))**0.2-1.)*100.
      GEDLHL(I)=((EDLHRL(I+1)/EDLHRL(I))**0.2-1.)*100.
      GEDLML(I)=((EDLMRL(I+1)/EDLMRL(I))**0.2-1.)*100.
600   GEDLLL(I)=((EDLLRL(I+1)/EDLLRL(I))**0.2-1.)*100.
C
C
C     G.WRITE STATEMENTS-TABLES 1 TO 3.
```

```
C
C       G.1.TABLE 1.A.:POPULATION,WORK FORCE AND PRODUCTIVITY.
C
C
        WRITE(24,7000)
7000    FORMAT(////////////,28X,'ECONOMIC DEVELOPMENT AND ENERGY
       1DEMAND PROJECTIONS:                1975-2010',///)
        WRITE(24,7010)
7010    FORMAT(13X,'1. ECONOMIC DEVELOPMENT',/)
        WRITE(24,7020)
7020    FORMAT(12X,'1A. POPULATION,WORKFORCE AND PRODUCTIVITY',/)
        WRITE(24,7030)
7030    FORMAT(6X,'YEAR',19X,'POPULATION',33X,'WORK
       1FORCE',25X,'PRODUCTIVITY')
        WRITE(24,7040)
7040    FORMAT(100X,'[1970 U.S $/YEAR/EMPLOYEE]',/)
        WRITE(24,7050)
7050    FORMAT(19X,'HIGH',8X,'MEDIUM',9X,'LOW',13X,'HIGH',8X,'ME
       1DIUM',9X,'LOW',13X,'HIGH',8X,'LOW',/)
        DO700I=1,8
700     WRITE(24,7060)(IYEAR(I),POPH(I),POPM(I),POPL(I),WORKFH(I),
       1WORKFM(I),WORKFL(I),PRODH(I),PRODL(I))
7060    FORMAT(5X,I5,5X,3(E12.5,1X),4X,3(E12.5,1X),4X,2(E11.4,1X))
C
C
C       G.2.TABLE 1.B.: TOTAL GROSS NATIONAL PRODUCT.
C
C
        WRITE(24,7070)
7070    FORMAT(/////,12X,'1B. ANNUAL GROSS NATIONAL PRODUCT (CO
       1NSTANT 1970 U.S DOLLARS)',/)
        WRITE(24,7080)
7080    FORMAT(6X,'YEAR',11X,'ASSUMING HIGH PRODUCTIVITY',18X,'A
       1SSUMING LOW PRODUCTIVITY',/)
        WRITE(24,7090)
7090    FORMAT(19X,'HIGH',8X,'MEDIUM',9X,'LOW',13X,'HIGH',8X,'M
       1EDIUM',9X,'LOW',/)
        DO701I=1,8
701     WRITE(24,7100)(IYEAR(I),GNPHH(I),GNPHM(I),GNPHL(I),
       1GNPLH(I),GNPLM(I),GNPLL(I))
7100    FORMAT(5X,I5,5X,3(E12.5,1X),4X,3(E12.5,1X))
C
C
C       G.3.TABLE 2.:TOTAL ENERGY DEMAND.
C
C            TABLE 2.A.:ENERGY DEMAND ASSUMING HIGH ENERY/GNP RATIO.
C
C
        WRITE(24,7110)
7110    FORMAT(1H1,////////////,12X,' 2. ANNUAL ENERGY DEMAND IN BTU',/)
        IF(WORLD.EQ.3.0)GOTO 91
        IF(WG.EQ.1.0)GOTO 81
        IF(USA.EQ.1.0)GOTO 68
68      WRITE(24,7111)
7111    FORMAT(/,16X,'NOTE THAT IN THE CASE OF U.S. ONLY HIG
       1H E/GNP RATIO HAS BEEN USED TO COMPUTE ENERGY DEMAND',/)
91      WRITE(24,7120)
7120    FORMAT(12X,'2A. ASSUMING HIGH ENERGY/G
       1NP RATIO',/)
        WRITE(24,7130)
7130    FORMAT(6X,'YEAR',4X,'HIGH ENERGY/GNP',10X,'ASSUMING H
       1IGH PRODUCTIVITY',16X,'ASSUMING LOW PRODUCTIVITY')
        WRITE(24,7140)
7140    FORMAT(18X,'RATIO')
        WRITE(24,7141)
7141    FORMAT(12X,'BTU/CONSTANT 1970 $')
        WRITE(24,7150)
7150    FORMAT(38X,'HIGH',7X,'MEDIUM',8X,'LOW',14X,'HIGH',7X,'M
       1EDIUM',8X,'LOW',/)
```

```
      DO702I=1,8
702   WRITE(24,7160)(IYEAR(I),EGNPRH(I),EDHHRH(I),EDHMRH(I),
     1EDHLRH(I),EDLHRH(I),EDLMRH(I),EDLLRH(I))
7160  FORMAT(5X,I5,E16.4,8X,3(E11.4,1X),6X,3(E11.4,1X))
      IF(WORLD.EQ.3.0)GOTO 92
      IF(USA.EQ.1.0)GOTO 71
C
C
C          TABLE.2.B: ENERGY DEMAND ASSUMING LOW ENERGY/GNP RATIO.
C
C
81    WRITE(24,7161)
7161  FORMAT(/,16X,'NOTE THAT IN THE CASE OF WEST GERM
     1ANY LOW E/GNP RATIO HAS BEEN USED TO COMPUTE ENERGY DEMAND',/)
92    WRITE(24,7170)
7170  FORMAT(/////,12X,'2B. ASSUMING LOW ENERGY/G
     1NP RATIO',/)
      WRITE(24,7180)
7180  FORMAT(6X,'YEAR',4X,'LOW ENERGY/GNP',11X,'ASSUMING HIG
     1H PRODUCTIVITY',16X,'ASSUMING LOW PRODUCTIVITY')
      WRITE(24,7190)
7190  FORMAT(18X,'RATIO')
      WRITE(24,7191)
7191  FORMAT(12X,'BTU/CONSTANT 1970 $')
      WRITE(24,7200)
7200  FORMAT(38X,'HIGH',7X,'MEDIUM',8X,'LOW',14X,'HIGH',7X,'M
     1EDIUM',8X,'LOW',/)
      DO703I=1,8
703   WRITE(24,7210)(IYEAR(I),EGNPRL(I),EDHHRL(I),EDHMRL(I),
     1EDHLRL(I),EDLHRL(I),EDLMRL(I),EDLLRL(I))
7210  FORMAT(5X,I5,E16.4,8X,3(E11.4,1X),6X,3(E11.4,1X))
C
C
C     G.4.TABLE.3.: AVERAGE ANNUAL GROWTH RATES.
C
C          TABLE.3.A.: POPULATION AND PRODUCTIVITY GROWTH RATES.
C
C
71    WRITE(24,7220)
7220  FORMAT(1H1,////////////,12X,' 3. AVERAGE ANNUAL GROWTH RATES',/)
      WRITE(24,7230)
7230  FORMAT(12X,'3A. POPULATION AND PRODUCTIVITY',/)
      WRITE(24,7240)
7240  FORMAT(6X,' PERIOD',19X,'POPULATION',16X,'PRODUCTIVIT
     1Y',/)
      WRITE(24,7250)
7250  FORMAT(28X,'H',7X,'M',7X,'L',14X,'H',7X,'L'/)
      DO704I=1,7
704   WRITE(24,7260)(IYEAR(I),IYEAR(I+1),GPOPH(I),GPOPM(I),
     1GPOPL(I),GPRODH(I),GPRODL(I))
7260  FORMAT(5X,I5,'-',I4,11X,3(F5.2,3X),7X,2(F5.2,3X))
C
C
C          TABLE.3.B.:GROSS NATIONAL PRODUCT GROWTH RATES.
C
C
      WRITE(24,7270)
7270  FORMAT(//,12X,'3B. GROSS NATIONAL PRODUCT',/)
      WRITE(24,7280)
7280  FORMAT(6X,' PERIOD',11X,'ASSUMING HIGH PRODUC
     1TIVITY',6X,'ASSUMING LOW PRODUCTIVITY',/)
      WRITE(24,7290)
7290  FORMAT(28X,'H',7X,'M',7X,'L',14X,'H',7X,'M',7X,'L',/)
      DO705I=1,7
705   WRITE(24,7300)(IYEAR(I),IYEAR(I+1),GGNPHH(I),GGNPHM(I),
     1GGNPHL(I),GGNPLH(I),GGNPLM(I),GGNPLL(I))
7300  FORMAT(5X,I5,'-',I4,11X,3(F5.2,3X),7X,3(F5.2,3X))
C
C
```

```
C           TABLE.3.C.:ENERGY DEMAND  GROWTH RATES.
C
C           TABLE.3.C.I.:ASSUMING HIGH ENERGY/GNP RATIO.
C
C
      WRITE(24,7309)
7309  FORMAT(1H1,////////////,12X,' 3. GROWTH RATES (CONTINUED)',/)
      WRITE(24,7310)
7310  FORMAT(/,12X,'3C. ENERGY DEMAND',1X)
      IF(WG.EQ.1.0)GOTO 82
      WRITE(24,7320)
7320  FORMAT(/,11X,'(I). ASSUMING HIGH ENERGY/GNP RATIO',/)
      WRITE(24,7330)
7330  FORMAT(6X,' PERIOD',14X,'HIGH',8X,'ASSUMING HIG
     1H PRODUCTIVITY',6X,'ASSUMING LOW PRODUTIVITY')
      WRITE(24,7340)
7340  FORMAT(27X,'RATIO')
      WRITE(24,7350)
7350  FORMAT(43X,'H',7X,'M',7X,'L',14X,'H',7X,'M',7X,'L',/)
      DO706I=1,7
706   WRITE(24,7360)(IYEAR(I),IYEAR(I+1),GEGPRH(I),GEDHHH(I),
     1GEDHMH(I),GEDHLH(I),GEDLHH(I),GEDLMH(I),GEDLLH(I))
7360  FORMAT(5X,I5,'-',I4,11X,F5.2,10X,3(F5.2,3X),7X,3(F5.2,3X))
      IF(USA.EQ.1.0)GOTO 72
C
C
C           TABLE.3.C.II:ASSUMING LOW ENERGY/GNP RATIO.
C
C
82    WRITE(24,7370)
7370  FORMAT(//,10X,'(II). ASSUMING LOW ENERGY/GNP RATIO',/)
      WRITE(24,7380)
7380  FORMAT(6X,' PERIOD',14X,'LOW',9X,'ASSUMING HIGH PROD
     1UCTIVITY',6X,'ASSUMING LOW PRODUCTIVITY')
      WRITE(24,7390)
7390  FORMAT(27X,'RATIO')
      WRITE(24,7400)
7400  FORMAT(43X,'H',7X,'M',7X,'L',14X,'H',7X,'M',7X,'L',/)
      DO707I=1,7
707   WRITE(24,7410)(IYEAR(I),IYEAR(I+1),GEGPRL(I),GEDHHL(I),
     1GEDHML(I),GEDHLL(I),GEDLHL(I),GEDLML(I),GEDLLL(I))
7410  FORMAT(5X,I5,'-',I4,11X,F5.2,10X,3(F5.2,3X),7X,3(F5.2,3X))
C
C
C     H.PER CAPITA GNP AND ENERGY DEMAND CALCULATIONS.
C
C     H.1.GNP PER CAPITA.
C
C
72    DO800I=1,8
      GCAPHH(I)=GNPHH(I)/POPH(I)
      GCAPHM(I)=GNPHM(I)/POPM(I)
      GCAPHL(I)=GNPHL(I)/POPL(I)
      GCAPLH(I)=GNPLH(I)/POPH(I)
      GCAPLM(I)=GNPLM(I)/POPM(I)
      GCAPLL(I)=GNPLL(I)/POPL(I)
C
C
C     H.2.ENERGY DEMAND PER CAPITA.
C
C
      ECPHHH(I)=EDHHRH(I)/POPH(I)
      ECPHMH(I)=EDHMRH(I)/POPM(I)
      ECPHLH(I)=EDHLRH(I)/POPL(I)
      ECPLHH(I)=EDLHRH(I)/POPH(I)
      ECPLMH(I)=EDLMRH(I)/POPM(I)
      ECPLLH(I)=EDLLRH(I)/POPL(I)
      ECPHHL(I)=EDHHRL(I)/POPH(I)
      ECPHML(I)=EDHMRL(I)/POPM(I)
```

```
      ECPHLL(I)=EDHLRL(I)/POPL(I)
      ECPLHL(I)=EDLHRL(I)/POPH(I)
      ECPLML(I)=EDLMRL(I)/POPM(I)
800   ECPLLL(I)=EDLLRL(I)/POPL(I)
      DO801I=1,7
C
CC
CC    H.3.PER CAPITA GNP AND ENERGY DEMAND GROWTH RATES CALCULATIONS.
CCC
CCC       PER CAPITA GNP GROWTH RATES.
CC
C
      GGCPHH(I)=((GCAPHH(I+1)/GCAPHH(I))**0.2-1.)*100.
      GGCPHM(I)=((GCAPHM(I+1)/GCAPHM(I))**0.2-1.)*100.
      GGCPHL(I)=((GCAPHL(I+1)/GCAPHL(I))**0.2-1.)*100.
      GGCPLH(I)=((GCAPLH(I+1)/GCAPLH(I))**0.2-1.)*100.
      GGCPLM(I)=((GCAPLM(I+1)/GCAPLM(I))**0.2-1.)*100.
      GGCPLL(I)=((GCAPLL(I+1)/GCAPLL(I))**0.2-1.)*100.
C
CC
CCC       PER CAPITA ENERGY DEMAND GROWTH RATES.
CC
C
      GEKHHH(I)=((ECPHHH(I+1)/ECPHHH(I))**0.2-1.)*100.
      GEKHMH(I)=((ECPHMH(I+1)/ECPHMH(I))**0.2-1.)*100.
      GEKHLH(I)=((ECPHLH(I+1)/ECPHLH(I))**0.2-1.)*100.
      GEKLHH(I)=((ECPLHH(I+1)/ECPLHH(I))**0.2-1.)*100.
      GEKLMH(I)=((ECPLMH(I+1)/ECPLMH(I))**0.2-1.)*100.
      GEKLLH(I)=((ECPLLH(I+1)/ECPLLH(I))**0.2-1.)*100.
      GEKHHL(I)=((ECPHHL(I+1)/ECPHHL(I))**0.2-1.)*100.
      GEKHML(I)=((ECPHML(I+1)/ECPHML(I))**0.2-1.)*100.
      GEKHLL(I)=((ECPHLL(I+1)/ECPHLL(I))**0.2-1.)*100.
      GEKLHL(I)=((ECPLHL(I+1)/ECPLHL(I))**0.2-1.)*100.
      GEKLML(I)=((ECPLML(I+1)/ECPLML(I))**0.2-1.)*100.
801   GEKLLL(I)=((ECPLLL(I+1)/ECPLLL(I))**0.2-1.)*100.
C
CC
CC    I.WRITE STATEMENTS TABLE 4 AND 5.
C
C     I.1.TABLE.4.:GNP AND ENERGY DEMAND PER CAPITA.
C         TABLE.4.A.GNP/CAPITA.
CC
C
      WRITE(24,9000)
9000  FORMAT(1H1,////////////,12X,' 4. GROSS NATIONAL PRODUCT AND ENERG
     1Y DEMAND PER CAPITA',/)
      WRITE(24,9010)
9010  FORMAT(12X,'4A. GNP PER CAPITA',/)
      WRITE(24,9020)
9020  FORMAT(6X,'YEAR',10X,'ASSUMING HIGH PRODUCTIVITY',15X,'A
     1SSUMING LOW PRODUCTIVITY',/)
      DO900I=1,8
900   WRITE(24,9030)(IYEAR(I),GCAPHM(I),
     1GCAPLM(I))
9030  FORMAT(5X,I5,16X,E11.4,29X,E11.4)
C
C
C     I.2.TABLE.4.B.:ENERGY DEMAND PER CAPITA
C
C         TABLE.4.B.I.:ASSUMING HIGH ENERGY/GNP RATIO.
C
C
      WRITE(24,9040)
9040  FORMAT(///,12X,'4B. ENERGY DEMAND PER CAPITA',/)
      IF(WG.EQ.1.0)GOTO 83
      WRITE(24,9050)
9050  FORMAT(11X,'(I). ASSUMING HIGH ENERGY/GNP RATIO',/)
      WRITE(24,9060)
9060  FORMAT(6X,'YEAR',10X,'ASSUMING HIGH PRODUCTIVITY',15X,'A
```

```
     1SSUMING LOW PRODUCTIVITY',/)
     DO901I=1,8
901  WRITE(24,9070)(IYEAR(I),ECPHMH(I),
     1ECPLMH(I))
9070 FORMAT(5X,I5,16X,E11.4,29X,E11.4)
     IF(USA.EQ.1.0)GOTO 73
C
C
C        TABLE.4.B.II:ASSUMING LOW ENERGY GNP RATIO.
C
C
83   WRITE(24,9080)
9080 FORMAT(//,10X,'(II). ASSUMING LOW ENERGY/GNP RATIO',/)
     WRITE(24,9090)
9090 FORMAT(6X,'YEAR',10X,'ASSUMING HIGH PRODUCTIVITY'15X,'A
     1SSUMING LOW PRODUCTIVITY',/)
     DO902I=1,8
902  WRITE(24,9100)(IYEAR(I),ECPHML(I),ECPLML(I))
9100 FORMAT(5X,I5,16X,E11.4,29X,E11.4)
C
C
C    I.3.TABLE.5.:AVERAGE ANNUAL GROWTH RATES OF GNP/CAPITA
C        AND ENERGY DEMAND /CAPITA.
C
C        TABLE.5.A.:GNP/CAPITA GROWTH RATES.
C
C
73   WRITE(24,9110)
9110 FORMAT(1H1,////////////,12X,' 5. AVERAGE ANNUAL GROWTH RATE OF G
     1NP/CAP.AND ENERGY DEMAND/CAP',/)
     WRITE(24,9120)
9120 FORMAT(12X,'5A. GROSS NATIONAL PRODUCT/CAPITA',/)
     WRITE(24,9130)
9130 FORMAT(6X,' PERIOD',11X,'ASSUMING HIGH PRODUC
     1TIVITY',8X,'ASSUMING LOW PRODUCTIVITY',/)
     DO903I=1,7
903  WRITE(24,9140)(IYEAR(I),IYEAR(I+1),
     1GGCPHM(I),GGCPLM(I))
9140 FORMAT(5X,I5,'-',I4,19X,F5.2,28X,F5.2)
C
C
C        TABLE.5.B.ENERGY DEMAND/CAPITA GROWTH RATES.
C
C        TABLE.5.B.I.:ASSUMING HIGH ENERGY/GNP RATIO.
C
C
     WRITE(24,9150)
9150 FORMAT(///,12X,'5B. ENERGY DEMAND/CAPTIA',/)
     IF(WG.EQ.1.0)GOTO 84
     WRITE(24,9160)
9160 FORMAT(11X,'(I). ASSUMING HIGH ENERGY/GNP RATIO',/)
     WRITE(24,9170)
9170 FORMAT(6X,' PERIOD',11X,'ASSUMING HIGH PRODUCTIVITY',8X,'A
     1SSUMING LOW PRODUCTIVITY',/)
     DO904I=1,7
904  WRITE(24,9180)(IYEAR(I),IYEAR(I+1),
     1GEKHMH(I),GEKLMH(I))
9180 FORMAT(5X,I5,'-',I4,19X,F5.2,28X,F5.2)
     IF(USA.EQ.1.0)GOTO 74
C
C
C        TABLE.5.B.II.:ASSUMING LOW ENERGY/GNP RATIO.
C
C
84     WRITE(24,9190)
9190 FORMAT(//,10X,'(II). ASSUMING LOW ENERGY/GNP RATIO',/)
     WRITE(24,9200)
9200 FORMAT(6X,' PERIOD',11X,'ASSUMING HIGH PRODUCTIVITY',8X,'A
     1SSUMING LOW PRODUCTIVITY',/)
```

```
      DO905I=1,7
905   WRITE(24,9210)(IYEAR(I),IYEAR(I+1),
     1GEKHML(I),GEKLML(I))
9210  FORMAT(5X,I5,'-',I4,19X,F5.2,28X,F5.2)
74    WRITE(24,9220)
9220  FORMAT(1H1)
      DO906I=1,21
906   WRITE(24,9230)(BRH(I),DRH(I),PGRH(I))
9230  FORMAT(1X,(3(F5.1)))
      DO907I=1,15
907   WRITE(24,9240)(BRM(I),DRM(I),PGRM(I))
      DO908I=1,9
908   WRITE(24,9250)(BRL(I),DRL(I),PGRL(I))
9240  FORMAT(1X,3F5.1)
9250  FORMAT(1X,3F5.1)
      STOP
      END
```

TABLE A-1

ENERGY CONSUMPTION AND ECONOMIC DEVELOPMENT DATA[a] - UNITED STATES[b] 1950-1975

Year	Population (10^3)	Labor Force		Annual Energy Consumption in BTU		Annual GNP in Constant 1970 U.S. Dollars		Energy GNP Ratio in BTU per Constant 1970 U.S. Dollars (10^3)	Productivity in Constant 1970 U.S. Dollars per Year per Employee (10^3)
		Total (10^3)	Percentage of Population	Total (10^{15})	Per Capita (10^6)	Total (10^9)	Per Capita		
1950	152,271	57863	38.0	33.9	222.6	480.7	3169	70.5	8.31
1955	165,932	63193	38.1	39.7	239.3	592.6	3585	67.0	9.38
1960	180,671	65778	36.4	44.5	246.3	660.0	3652	67.4	10.03
1965	194,303	71088	36.6	53.3	274.3	835.9	4304	63.8	11.76
1970	204,879	78627	38.4	67.1	327.5	974.1	4756	68.9	12.39
1975	213,925	84783	39.6	70.6	330.5	1103.0	5156	64.0	12.87

[a]These historical data have been used to produce the various projections shown in the computer printouts that follow.

[b]Note that for the energy demand projections for the U. S. only the high energy/GNP ratio has been used.

ECONOMIC DEVELOPMENT AND ENERGY DEMAND PROJECTIONS: UNITED STATES 1975-2010

1. ECONOMIC DEVELOPMENT

1A. POPULATION, WORKFORCE AND PRODUCTIVITY

YEAR	POPULATION			WORKFORCE			PRODUCTIVITY 1970 U.S $/YEAR/EMPLOYEE	
	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW	HIGH	LOW
1975	0.21393E+09	0.21393E+09	0.21393E+09	0.85572E+08	0.85572E+08	0.85572E+08	0.1287E+05	0.1287E+05
1980	0.22450E+09	0.22438E+09	0.22391E+09	0.89801E+08	0.89754E+08	0.89562E+08	0.1400E+05	0.1353E+05
1985	0.23524E+09	0.23464E+09	0.23238E+09	0.94094E+08	0.93857E+08	0.92954E+08	0.1523E+05	0.1422E+05
1990	0.24588E+09	0.24424E+09	0.23853E+09	0.98350E+08	0.97696E+08	0.95411E+08	0.1657E+05	0.1494E+05
1995	0.25617E+09	0.25277E+09	0.24285E+09	0.10247E+09	0.10111E+09	0.97141E+08	0.1803E+05	0.1570E+05
2000	0.26587E+09	0.25995E+09	0.24707E+09	0.10635E+09	0.10398E+09	0.98827E+08	0.1962E+05	0.1650E+05
2005	0.27476E+09	0.26558E+09	0.25116E+09	0.10991E+09	0.10623E+09	0.10047E+09	0.2134E+05	0.1735E+05
2010	0.28268E+09	0.27040E+09	0.25514E+09	0.11307E+09	0.10816E+09	0.10206E+09	0.2322E+05	0.1823E+05

1B. ANNUAL GROSS NATIONAL PRODUCT (CONSTANT 1970 U.S DOLLARS)

YEAR	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
1975	0.11013E+13	0.11013E+13	0.11013E+13	0.11013E+13	0.11013E+13	0.11013E+13
1980	0.12574E+13	0.12567E+13	0.12540E+13	0.12147E+13	0.12141E+13	0.12115E+13
1985	0.14333E+13	0.14297E+13	0.14160E+13	0.13377E+13	0.13343E+13	0.13215E+13
1990	0.16299E+13	0.16191E+13	0.15812E+13	0.14695E+13	0.14597E+13	0.14256E+13
1995	0.18475E+13	0.18230E+13	0.17515E+13	0.16091E+13	0.15878E+13	0.15255E+13
2000	0.20861E+13	0.20396E+13	0.19385E+13	0.17553E+13	0.17161E+13	0.16311E+13
2005	0.23454E+13	0.22671E+13	0.21440E+13	0.19065E+13	0.18428E+13	0.17428E+13
2010	0.26252E+13	0.25111E+13	0.23695E+13	0.20615E+13	0.19719E+13	0.18607E+13

2. ANNUAL ENERGY DEMAND IN BTU

NOTE THAT IN THE CASE OF U.S. ONLY HIGH E/GNP RATIO HAS BEEN USED TO COMPUTE ENERGY DEMAND

2A. ASSUMING HIGH ENERGY/GNP RATIC

YEAR	HIGH ENERGY/GNP RATIO BTU/CONSTANT 1970 $	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
		HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
1975	0.6400E+05	0.7048E+17	0.7048E+17	0.7048E+17	0.7048E+17	0.7048E+17	0.7048E+17
1980	0.6178E+05	0.7768E+17	0.7764E+17	0.7748E+17	0.7505E+17	0.7501E+17	0.7485E+17
1985	0.5964E+05	0.8549E+17	0.8527E+17	0.8445E+17	0.7978E+17	0.7958E+17	0.7882E+17
1990	0.5758E+05	0.9384E+17	0.9322E+17	0.9104E+17	0.8461E+17	0.8404E+17	0.8208E+17
1995	0.5558E+05	0.1027E+18	0.1013E+18	0.9735E+17	0.8944E+17	0.8825E+17	0.8479E+17
2000	0.5365E+05	0.1119E+18	0.1094E+18	0.1040E+18	0.9418E+17	0.9208E+17	0.8752E+17
2005	0.5180E+05	0.1215E+18	0.1174E+18	0.1110E+18	0.9875E+17	0.9545E+17	0.9027E+17
2010	0.5000E+05	0.1313E+18	0.1256E+18	0.1185E+18	0.1031E+18	0.9860E+17	0.9303E+17

3. AVERAGE ANNUAL GROWTH RATES

3A. POPULATION AND PRODUCTIVITY

PERIOD	POPULATION			PRODUCTIVITY	
	H	M	L	H	L
1975-1980	0.97	0.96	0.92	1.70	1.00
1980-1985	0.94	0.90	0.75	1.70	1.00
1985-1990	0.89	0.80	0.52	1.70	1.00
1990-1995	0.82	0.69	0.36	1.70	1.00
1995-2000	0.75	0.56	0.34	1.70	1.00
2000-2005	0.66	0.43	0.33	1.70	1.00
2005-2010	0.57	0.36	0.31	1.70	1.00

3B. GROSS NATIONAL PRODUCT

PERIOD	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
	H	M	L	H	M	L
1975-1980	2.69	2.68	2.63	1.98	1.97	1.92
1980-1985	2.65	2.61	2.46	1.95	1.91	1.75
1985-1990	2.60	2.52	2.23	1.90	1.81	1.53
1990-1995	2.54	2.40	2.07	1.83	1.70	1.36
1995-2000	2.46	2.27	2.05	1.75	1.57	1.35
2000-2005	2.37	2.14	2.04	1.67	1.43	1.33
2005-2010	2.28	2.07	2.02	1.58	1.36	1.32

3. GROWTH RATES (CONTINUED)

3C. ENERGY DEMAND

(I). ASSUMING HIGH ENERGY/GNP RATIO

PERIOD	HIGH RATIO	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUTIVITY		
		H	M	L	H	M	L
1975-1980	-0.70	1.96	1.95	1.91	1.26	1.25	1.21
1980-1985	-0.70	1.93	1.89	1.74	1.23	1.19	1.04
1985-1990	-0.70	1.88	1.80	1.51	1.18	1.10	0.81
1990-1995	-0.70	1.82	1.68	1.35	1.12	0.98	0.65
1995-2000	-0.70	1.74	1.55	1.33	1.04	0.85	0.64
2000-2005	-0.70	1.65	1.42	1.32	0.95	0.72	0.62
2005-2010	-0.70	1.56	1.35	1.30	0.86	0.65	0.61

4. GROSS NATIONAL PRODUCT AND ENERGY DEMAND PER CAPITA

4A. GNP PER CAPITA

YEAR	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975	0.5148E+04	0.5148E+04
1980	0.5601E+04	0.5411E+04
1985	0.6093E+04	0.5687E+04
1990	0.6629E+04	0.5977E+04
1995	0.7212E+04	0.6282E+04
2000	0.7846E+04	0.6602E+04
2005	0.8536E+04	0.6939E+04
2010	0.9287E+04	0.7293E+04

4B. ENERGY DEMAND PER CAPITA

(I). ASSUMING HIGH ENERGY/GNP RATIO

YEAR	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975	0.3295E+09	0.3295E+09
1980	0.3460E+09	0.3343E+09
1985	0.3634E+09	0.3392E+09
1990	0.3817E+09	0.3441E+09
1995	0.4008E+09	0.3491E+09
2000	0.4210E+09	0.3542E+09
2005	0.4421E+09	0.3594E+09
2010	0.4644E+09	0.3646E+09

5. AVERAGE ANNUAL GROWTH RATE OF GNP/CAP.AND ENERGY DEMAND/CAP

5A. GROSS NATIONAL PRODUCT/CAPITA

PERIOD	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975-1980	1.70	1.00
1980-1985	1.70	1.00
1985-1990	1.70	1.00
1990-1995	1.70	1.00
1995-2000	1.70	1.00
2000-2005	1.70	1.00
2005-2010	1.70	1.00

5B. ENERGY DEMAND/CAPTIA

(I). ASSUMING HIGH ENERGY/GNP RATIO

PERIOD	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975-1980	0.99	0.29
1980-1985	0.99	0.29
1985-1990	0.99	0.29
1990-1995	0.99	0.29
1995-2000	0.99	0.29
2000-2005	0.99	0.29
2005-2010	0.99	0.29

TABLE A-2

ENERGY CONSUMPTION AND ECONOMIC DEVELOPMENT DATA[a] -
WEST GERMANY[b] 1950-1975

Year	Population (10^3)	Labor Force		Annual Energy Consumption in BTU		Annual GNP in Constant 1970 U.S. Dollars		Energy GNP Ratio in BTU per Constant 1970 U.S. Dollars (10^3)	Productivity in Constant 1970 U.S. Dollars per Year per Employee (10^3)
		Total (10^3)	Percentage of Population	Total (10^{15})	Per Capita (10^6)	Total (10^9)	Per Capita		
1950	49,989	-	-	3.45	69.0	33.5	670	103.0	-
1955	52,382	-	-	4.94	94.3	60.2	1149	82.0	-
1960	55,433	25924	46.8	5.69	102.7	93.1	1679	61.1	3.58
1965	59,012	26418	44.8	7.18	122.3	130.1	2205	55.1	4.94
1970	60,700	26169	43.1	9.13	150.4	187.9	3096	48.6	7.11
1975	61,682	24798	40.2	9.18	148.5	287.5	4661	31.9	11.76

[a]These historical data have been used to produce the various projections shown in the computer printouts that follow.

[b]Note that for the energy demand projections for West Germany only the low energy/GNP ratio has been used.

ECONOMIC DEVELOPMENT AND ENERGY DEMAND PROJECTIONS: WEST GERMANY 1975-2010

1. ECONOMIC DEVELOPMENT

1A. POPULATION, WORKFORCE AND PRODUCTIVITY

YEAR	POPULATION			WORKFORCE			PRODUCTIVITY 1970 U.S $/YEAR/EMPLOYEE	
	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW	HIGH	LOW
1975	0.61682E+08	0.61682E+08	0.61682E+08	0.24673E+08	0.24673E+08	0.24673E+08	0.1176E+05	0.1176E+05
1980	0.62066E+08	0.62140E+08	0.62153E+08	0.24827E+08	0.24856E+08	0.24861E+08	0.1279E+05	0.1236E+05
1985	0.62593E+08	0.62574E+08	0.62237E+08	0.25037E+08	0.25030E+08	0.24895E+08	0.1392E+05	0.1299E+05
1990	0.63009E+08	0.62794E+08	0.62237E+08	0.25203E+08	0.25118E+08	0.24895E+08	0.1514E+05	0.1365E+05
1995	0.63274E+08	0.62794E+08	0.62237E+08	0.25310E+08	0.25118E+08	0.24895E+08	0.1648E+05	0.1435E+05
2000	0.63359E+08	0.62794E+08	0.62237E+08	0.25344E+08	0.25118E+08	0.24895E+08	0.1792E+05	0.1508E+05
2005	0.63359E+08	0.62794E+08	0.62237E+08	0.25344E+08	0.25118E+08	0.24895E+08	0.1950E+05	0.1585E+05
2010	0.63359E+08	0.62794E+08	0.62237E+08	0.25344E+08	0.25118E+08	0.24895E+08	0.2121E+05	0.1666E+05

1B. ANNUAL GROSS NATIONAL PRODUCT (CONSTANT 1970 U.S DOLLARS)

YEAR	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
1975	0.29015E+12	0.29015E+12	0.29015E+12	0.29015E+12	0.29015E+12	0.29015E+12
1980	0.31764E+12	0.31801E+12	0.31808E+12	0.30685E+12	0.30722E+12	0.30728E+12
1985	0.34850E+12	0.34839E+12	0.34652E+12	0.32524E+12	0.32514E+12	0.32339E+12
1990	0.38166E+12	0.38037E+12	0.37699E+12	0.34410E+12	0.34293E+12	0.33989E+12
1995	0.41698E+12	0.41381E+12	0.41014E+12	0.36318E+12	0.36042E+12	0.35722E+12
2000	0.45425E+12	0.45021E+12	0.44621E+12	0.38222E+12	0.37881E+12	0.37545E+12
2005	0.49420E+12	0.48980E+12	0.48545E+12	0.40171E+12	0.39813E+12	0.39460E+12
2010	0.53766E+12	0.53287E+12	0.52814E+12	0.42220E+12	0.41844E+12	0.41473E+12

2. ANNUAL ENERGY DEMAND IN BTU

NOTE THAT IN THE CASE OF WEST GERMANY LOW E/GNP RATIO HAS BEEN USED TO COMPUTE ENERGY DEMAND

2B. ASSUMING LOW ENERGY/GNP RATIO

YEAR	LOW ENERGY/GNP RATIO BTU/CONSTANT 1970 $	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
		HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
1975	0.3200E+05	0.9285E+16	0.9285E+16	0.9285E+16	0.9285E+16	0.9285E+16	0.9285E+16
1980	0.3171E+05	0.1007E+17	0.1008E+17	0.1009E+17	0.9729E+16	0.9741E+16	0.9743E+16
1985	0.3142E+05	0.1095E+17	0.1094E+17	0.1089E+17	0.1022E+17	0.1021E+17	0.1016E+17
1990	0.3113E+05	0.1188E+17	0.1184E+17	0.1173E+17	0.1071E+17	0.1067E+17	0.1058E+17
1995	0.3084E+05	0.1286E+17	0.1276E+17	0.1265E+17	0.1120E+17	0.1112E+17	0.1102E+17
2000	0.3056E+05	0.1388E+17	0.1376E+17	0.1364E+17	0.1168E+17	0.1158E+17	0.1147E+17
2005	0.3028E+05	0.1496E+17	0.1483E+17	0.1470E+17	0.1216E+17	0.1205E+17	0.1195E+17
2010	0.3000E+05	0.1613E+17	0.1599E+17	0.1584E+17	0.1267E+17	0.1255E+17	0.1244E+17

3. AVERAGE ANNUAL GROWTH RATES

3A. POPULATION AND PRODUCTIVITY

PERIOD	POPULATION			PRODUCTIVITY	
	H	M	L	H	L
1975-1980	0.12	0.15	0.15	1.70	1.00
1980-1985	0.17	0.14	0.03	1.70	1.00
1985-1990	0.13	0.07	0.00	1.70	1.00
1990-1995	0.08	0.00	0.00	1.70	1.00
1995-2000	0.03	0.00	0.00	1.70	1.00
2000-2005	0.00	0.00	0.00	1.70	1.00
2005-2010	0.00	0.00	0.00	1.70	1.00

3B. GROSS NATIONAL PRODUCT

PERIOD	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
	H	M	L	H	M	L
1975-1980	1.83	1.85	1.85	1.13	1.15	1.15
1980-1985	1.87	1.84	1.73	1.17	1.14	1.03
1985-1990	1.83	1.77	1.70	1.13	1.07	1.00
1990-1995	1.79	1.70	1.70	1.08	1.00	1.00
1995-2000	1.73	1.70	1.70	1.03	1.00	1.00
2000-2005	1.70	1.70	1.70	1.00	1.00	1.00
2005-2010	1.70	1.70	1.70	1.00	1.00	1.00

3. GROWTH RATES (CONTINUED)

3C. ENERGY DEMAND

(II). ASSUMING LOW ENERGY/GNP RATIO

PERIOD	LOW RATIO	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
		H	M	L	H	M	L
1975-1980	-0.18	1.64	1.66	1.67	0.94	0.96	0.97
1980-1985	-0.18	1.68	1.65	1.54	0.98	0.95	0.84
1985-1990	-0.18	1.65	1.58	1.51	0.95	0.88	0.81
1990-1995	-0.18	1.60	1.51	1.51	0.90	0.81	0.81
1995-2000	-0.18	1.54	1.51	1.51	0.84	0.81	0.81
2000-2005	-0.18	1.51	1.51	1.51	0.81	0.81	0.81
2005-2010	-0.18	1.51	1.51	1.51	0.81	0.81	0.81

4. GROSS NATIONAL PRODUCT AND ENERGY DEMAND PER CAPITA

4A. GNP PER CAPITA

YEAR	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975	0.4704E+04	0.4704E+04
1980	0.5118E+04	0.4944E+04
1985	0.5568E+04	0.5196E+04
1990	0.6057E+04	0.5461E+04
1995	0.6590E+04	0.5740E+04
2000	0.7170E+04	0.6033E+04
2005	0.7800E+04	0.6340E+04
2010	0.8486E+04	0.6664E+04

4B. ENERGY DEMAND PER CAPITA

(II). ASSUMING LOW ENERGY/GNP RATIO

YEAR	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975	0.1505E+09	0.1505E+09
1980	0.1623E+09	0.1568E+09
1985	0.1749E+09	0.1632E+09
1990	0.1885E+09	0.1700E+09
1995	0.2032E+09	0.1770E+09
2000	0.2191E+09	0.1843E+09
2005	0.2362E+09	0.1920E+09
2010	0.2546E+09	0.1999E+09

5. AVERAGE ANNUAL GROWTH RATE OF GNP/CAP.AND ENERGY DEMAND/CAP

5A. GROSS NATIONAL PRODUCT/CAPITA

PERIOD	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975-1980	1.70	1.00
1980-1985	1.70	1.00
1985-1990	1.70	1.00
1990-1995	1.70	1.00
1995-2000	1.70	1.00
2000-2005	1.70	1.00
2005-2010	1.70	1.00

5B. ENERGY DEMAND/CAPTIA

(I). ASSUMING LOW ENERGY/GNP RATIO

PERIOD	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975-1980	1.51	0.81
1980-1985	1.51	0.81
1985-1990	1.51	0.81
1990-1995	1.51	0.81
1995-2000	1.51	0.81
2000-2005	1.51	0.81
2005-2010	1.51	0.81

TABLE A-3

ENERGY CONSUMPTION AND ECONOMIC DEVELOPMENT DATA[a] -
BRAZIL 1950-1975

Year	Population (10^3)	Labor Force		Annual Energy Consumption in BTU		Annual GNP in Constant 1970 U.S. Dollars		Energy GNP Ratio in BTU per Constant 1970 U.S. Dollars (10^3)	Productivity in Constant 1970 U.S. Dollars per Year per Employee (10^3)
		Total (10^3)	Percentage of Population	Total (10^{15})	Per Capita (10^6)	Total (10^9)	Per Capita		
1950	52,901	17117	32.4	0.32	5.5	10.0	189	29.0	.580
1955	61,864	-	-	0.47	7.6	13.9	225	34.0	-
1960	71,539	22651	31.7	0.65	9.2	19.3	270	34.0	0.850
1965	82,541	26240	31.8	0.83	10.2	24.1	292	35.0	0.920
1970	95,204	29557	31.0	1.24	13.2	34.6	363	36.0	1.170
1975	109,730	32400	29.5	2.10	19.1	55.3	504	38.0	1.706

[a]These historical data have been used to produce the various projections shown in the computer printouts that follow.

ECONOMIC DEVELOPMENT AND ENERGY DEMAND PROJECTIONS: BRAZIL 1975-2010

1. ECONOMIC DEVELOPMENT

1A. POPULATION, WORKFORCE AND PRODUCTIVITY

YEAR	POPULATION			WORKFORCE			PRODUCTIVITY 1970 U.S $/YEAR/EMPLOYEE	
	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW	HIGH	LOW
1975	0.10973E+09	0.10973E+09	0.10973E+09	0.32370E+08	0.32370E+08	0.32370E+08	0.1706E+04	0.1706E+04
1980	0.12601E+09	0.12586E+09	0.12526E+09	0.39064E+08	0.39018E+08	0.38831E+08	0.1909E+04	0.1826E+04
1985	0.14421E+09	0.14339E+09	0.14031E+09	0.46868E+08	0.46603E+08	0.45599E+08	0.2137E+04	0.1955E+04
1990	0.16413E+09	0.16168E+09	0.15327E+09	0.55803E+08	0.54970E+08	0.52113E+08	0.2391E+04	0.2093E+04
1995	0.18544E+09	0.17994E+09	0.16320E+09	0.65830E+08	0.63880E+08	0.57935E+08	0.2676E+04	0.2241E+04
2000	0.20771E+09	0.19742E+09	0.16979E+09	0.76853E+08	0.73045E+08	0.62824E+08	0.2994E+04	0.2399E+04
2005	0.23043E+09	0.21341E+09	0.17329E+09	0.88716E+08	0.82164E+08	0.66717E+08	0.3351E+04	0.2569E+04
2010	0.25305E+09	0.22739E+09	0.17433E+09	0.10122E+09	0.90957E+08	0.69733E+08	0.3750E+04	0.2750E+04

1B. ANNUAL GROSS NATIONAL PRODUCT (CONSTANT 1970 U.S DOLLARS)

YEAR	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
1975	0.55224E+11	0.55224E+11	0.55224E+11	0.55224E+11	0.55224E+11	0.55224E+11
1980	0.74579E+11	0.74491E+11	0.74134E+11	0.71347E+11	0.71263E+11	0.70921E+11
1985	0.10013E+12	0.99568E+11	0.97423E+11	0.91643E+11	0.91125E+11	0.89161E+11
1990	0.13342E+12	0.13143E+12	0.12460E+12	0.11682E+12	0.11507E+12	0.10909E+12
1995	0.17614E+12	0.17092E+12	0.15501E+12	0.14753E+12	0.14316E+12	0.12984E+12
2000	0.23012E+12	0.21872E+12	0.18811E+12	0.18439E+12	0.17526E+12	0.15073E+12
2005	0.29727E+12	0.27532E+12	0.22356E+12	0.22788E+12	0.21105E+12	0.17137E+12
2010	0.37955E+12	0.34108E+12	0.26149E+12	0.27834E+12	0.25013E+12	0.19176E+12

2. ANNUAL ENERGY DEMAND IN BTU

2A. ASSUMING HIGH ENERGY/GNP RATIO

YEAR	HIGH ENERGY/GNP RATIO BTU/CONSTANT 1970 $	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
		HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
1975	0.3800E+05	0.2099E+16	0.2099E+16	0.2099E+16	0.2099E+16	0.2099E+16	0.2099E+16
1980	0.3952E+05	0.2947E+16	0.2944E+16	0.2930E+16	0.2820E+16	0.2816E+16	0.2803E+16
1985	0.4110E+05	0.4115E+16	0.4092E+16	0.4004E+16	0.3766E+16	0.3745E+16	0.3664E+16
1990	0.4274E+05	0.5703E+16	0.5618E+16	0.5326E+16	0.4993E+16	0.4918E+16	0.4663E+16
1995	0.4445E+05	0.7830E+16	0.7598E+16	0.6891E+16	0.6558E+16	0.6364E+16	0.5771E+16
2000	0.4623E+05	0.1064E+17	0.1011E+17	0.8696E+16	0.8524E+16	0.8102E+16	0.6968E+16
2005	0.4808E+05	0.1429E+17	0.1324E+17	0.1075E+17	0.1096E+17	0.1015E+17	0.8239E+16
2010	0.5000E+05	0.1898E+17	0.1705E+17	0.1307E+17	0.1392E+17	0.1251E+17	0.9588E+16

2B. ASSUMING LOW ENERGY/GNP RATIO

YEAR	LOW ENERGY/GNP RATIO BTU/CONSTANT 1970 $	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
		HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
1975	0.3800E+05	0.2099E+16	0.2099E+16	0.2099E+16	0.2099E+16	0.2099E+16	0.2099E+16
1980	0.3674E+05	0.2740E+16	0.2737E+16	0.2724E+16	0.2621E+16	0.2618E+16	0.2606E+16
1985	0.3552E+05	0.3557E+16	0.3536E+16	0.3460E+16	0.3255E+16	0.3237E+16	0.3167E+16
1990	0.3434E+05	0.4582E+16	0.4513E+16	0.4279E+16	0.4011E+16	0.3951E+16	0.3746E+16
1995	0.3320E+05	0.5848E+16	0.5674E+16	0.5146E+16	0.4898E+16	0.4753E+16	0.4310E+16
2000	0.3210E+05	0.7386E+16	0.7020E+16	0.6038E+16	0.5918E+16	0.5625E+16	0.4838E+16
2005	0.3103E+05	0.9225E+16	0.8543E+16	0.6937E+16	0.7071E+16	0.6549E+16	0.5318E+16
2010	0.3000E+05	0.1139E+17	0.1023E+17	0.7845E+16	0.8350E+16	0.7504E+16	0.5753E+16

3. AVERAGE ANNUAL GROWTH RATES

3A. POPULATION AND PRODUCTIVITY

PERIOD	POPULATION			PRODUCTIVITY	
	H	M	L	H	L
1975-1980	2.81	2.78	2.68	2.28	1.37
1980-1985	2.73	2.64	2.29	2.28	1.37
1985-1990	2.62	2.43	1.78	2.28	1.37
1990-1995	2.47	2.16	1.26	2.28	1.37
1995-2000	2.29	1.87	0.80	2.28	1.37
2000-2005	2.10	1.57	0.41	2.28	1.37
2005-2010	1.89	1.28	0.12	2.28	1.37

3B. GROSS NATIONAL PRODUCT

PERIOD	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
	H	M	L	H	M	L
1975-1980	6.19	6.17	6.07	5.26	5.23	5.13
1980-1985	6.07	5.97	5.62	5.13	5.04	4.68
1985-1990	5.91	5.71	5.04	4.97	4.78	4.12
1990-1995	5.71	5.40	4.46	4.78	4.47	3.54
1995-2000	5.49	5.06	3.95	4.56	4.13	3.03
2000-2005	5.25	4.71	3.51	4.33	3.79	2.60
2005-2010	5.01	4.38	3.18	4.08	3.46	2.27

3. GROWTH RATES (CONTINUED)

3C. ENERGY DEMAND

(I). ASSUMING HIGH ENERGY/GNP RATIO

PERIOD	HIGH RATIO	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUTIVITY		
		H	M	L	H	M	L
1975-1980	0.79	7.03	7.00	6.90	6.09	6.06	5.96
1980-1985	0.79	6.91	6.81	6.45	5.96	5.87	5.51
1985-1990	0.79	6.74	6.54	5.87	5.80	5.60	4.94
1990-1995	0.79	6.54	6.22	5.29	5.60	5.29	4.36
1995-2000	0.79	6.32	5.88	4.76	5.38	4.95	3.84
2000-2005	0.79	6.08	5.53	4.33	5.15	4.60	3.41
2005-2010	0.79	5.83	5.20	4.00	4.90	4.27	3.08

(II). ASSUMING LOW ENERGY/GNP RATIO

PERIOD	LOW RATIO	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
		H	M	L	H	M	L
1975-1980	-0.67	5.48	5.45	5.35	4.55	4.52	4.42
1980-1985	-0.67	5.36	5.26	4.90	4.43	4.33	3.98
1985-1990	-0.67	5.19	5.00	4.34	4.27	4.07	3.42
1990-1995	-0.67	5.00	4.69	3.76	4.07	3.76	2.85
1995-2000	-0.67	4.78	4.35	3.25	3.86	3.43	2.34
2000-2005	-0.67	4.55	4.01	2.82	3.62	3.09	1.91
2005-2010	-0.67	4.30	3.67	2.49	3.38	2.76	1.59

4. GROSS NATIONAL PRODUCT AND ENERGY DEMAND PER CAPITA

4A. GNP PER CAPITA

YEAR	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975	0.5033E+03	0.5033E+03
1980	0.5918E+03	0.5662E+03
1985	0.6944E+03	0.6355E+03
1990	0.8129E+03	0.7117E+03
1995	0.9499E+03	0.7956E+03
2000	0.1108E+04	0.8877E+03
2005	0.1290E+04	0.9889E+03
2010	0.1500E+04	0.1100E+04

4B. ENERGY DEMAND PER CAPITA

(I). ASSUMING HIGH ENERGY/GNP RATIO

YEAR	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975	0.1912E+08	0.1912E+08
1980	0.2339E+08	0.2238E+08
1985	0.2854E+08	0.2612E+08
1990	0.3475E+08	0.3042E+08
1995	0.4222E+08	0.3537E+08
2000	0.5122E+08	0.4104E+08
2005	0.6202E+08	0.4754E+08
2010	0.7500E+08	0.5500E+08

(II). ASSUMING LOW ENERGY/GNP RATIO

YEAR	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975	0.1912E+08	0.1912E+08
1980	0.2174E+08	0.2080E+08
1985	0.2466E+08	0.2257E+08
1990	0.2791E+08	0.2444E+08
1995	0.3153E+08	0.2641E+08
2000	0.3556E+08	0.2849E+08
2005	0.4003E+08	0.3069E+08
2010	0.4500E+08	0.3300E+08

5. AVERAGE ANNUAL GROWTH RATE OF GNP/CAP.AND ENERGY DEMAND/CAP

5A. GROSS NATIONAL PRODUCT/CAPITA

PERIOD	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975-1980	3.30	2.38
1980-1985	3.25	2.34
1985-1990	3.20	2.29
1990-1995	3.16	2.25
1995-2000	3.13	2.22
2000-2005	3.09	2.18
2005-2010	3.06	2.15

5B. ENERGY DEMAND/CAPTIA

(I). ASSUMING HIGH ENERGY/GNP RATIO

PERIOD	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975-1980	4.11	3.19
1980-1985	4.06	3.14
1985-1990	4.02	3.10
1990-1995	3.97	3.06
1995-2000	3.94	3.02
2000-2005	3.90	2.99
2005-2010	3.87	2.96

(II). ASSUMING LOW ENERGY/GNP RATIO

PERIOD	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975-1980	2.60	1.69
1980-1985	2.55	1.65
1985-1990	2.51	1.60
1990-1995	2.47	1.56
1995-2000	2.43	1.53
2000-2005	2.40	1.49
2005-2010	2.37	1.46

TABLE A-4

ENERGY CONSUMPTION AND ECONOMIC DEVELOPMENT DATA[a] -
MAURITIUS 1950-1975

Year	Population (10^3)	Labor Force		Annual Energy Consumption in BTU		Annual GNP in Constant 1970 U.S. Dollars		Energy GNP Ratio in BTU per Constant 1970 U.S. Dollars (10^3)	Productivity in Constant 1970 U.S. Dollars per Year per Employee (10^3)
		Total (10^3)	Percentage of Population	Total (10^{15})	Per Capita (10^6)	Total (10^9)	Per Capita		
1950	479	-	-	0.0021	4.4	0.136	284	15.6	-
1955	570	-	-	0.0014	2.5	0.162	284	8.9	-
1960	662	-	-	0.0020	3.0	0.166	251	12.0	-
1965	761	-	-	0.0036	4.7	0.224	294	15.9	-
1970	824	112.6	13.6	0.0042	5.1	0.190	231	22.3	1.68
1975	899	151.8	17.2	0.0066	7.5	0.271	302	22.7	1.89

[a]These historical data have been used to produce the various projections shown in the computer printouts that follow.

ECONOMIC DEVELOPMENT AND ENERGY DEMAND PROJECTIONS: MAURITIUS 1975-2010

1. ECONOMIC DEVELOPMENT

1A. POPULATION, WORKFORCE AND PRODUCTIVITY

YEAR	POPULATION			WORKFORCE			PRODUCTIVITY 1970 U.S $/YEAR/EMPLOYEE	
	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW	HIGH	LOW
1975	0.89900E+06	0.89900E+06	0.89900E+06	0.15463E+06	0.15463E+06	0.15463E+06	0.1890E+04	0.1890E+04
1980	0.97922E+06	0.97846E+06	0.97537E+06	0.20032E+06	0.20017E+06	0.19953E+06	0.2084E+04	0.1994E+04
1985	0.10642E+07	0.10602E+07	0.10451E+07	0.25236E+06	0.25142E+06	0.24784E+06	0.2299E+04	0.2104E+04
1990	0.11523E+07	0.11409E+07	0.11015E+07	0.31079E+06	0.30772E+06	0.29710E+06	0.2535E+04	0.2220E+04
1995	0.12417E+07	0.12174E+07	0.11416E+07	0.37535E+06	0.36799E+06	0.34510E+06	0.2796E+04	0.2342E+04
2000	0.13305E+07	0.12867E+07	0.11654E+07	0.44553E+06	0.43087E+06	0.39025E+06	0.3083E+04	0.2471E+04
2005	0.14166E+07	0.13469E+07	0.11842E+07	0.52051E+06	0.49489E+06	0.43510E+06	0.3400E+04	0.2607E+04
2010	0.14983E+07	0.13966E+07	0.11928E+07	0.59930E+06	0.55864E+06	0.47711E+06	0.3750E+04	0.2750E+04

1B. ANNUAL GROSS NATIONAL PRODUCT (CONSTANT 1970 U.S DOLLARS)

YEAR	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
1975	0.29225E+09	0.29225E+09	0.29225E+09	0.29225E+09	0.29225E+09	0.29225E+09
1980	0.41754E+09	0.41721E+09	0.41589E+09	0.39944E+09	0.39913E+09	0.39787E+09
1985	0.58009E+09	0.57793E+09	0.56970E+09	0.53090E+09	0.52892E+09	0.52139E+09
1990	0.78786E+09	0.78009E+09	0.75317E+09	0.68980E+09	0.68300E+09	0.65943E+09
1995	0.10494E+10	0.10288E+10	0.96480E+09	0.87896E+09	0.86172E+09	0.80811E+09
2000	0.13736E+10	0.13285E+10	0.12032E+10	0.11007E+10	0.10645E+10	0.96412E+09
2005	0.17698E+10	0.16827E+10	0.14794E+10	0.13567E+10	0.12899E+10	0.11341E+10
2010	0.22473E+10	0.20948E+10	0.17891E+10	0.16481E+10	0.15362E+10	0.13120E+10

2. ANNUAL ENERGY DEMAND IN BTU

2A. ASSUMING HIGH ENERGY/GNP RATIO

YEAR	HIGH ENERGY/GNP RATIO ETU/CONSTANT 1970 $	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
		HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
1975	0.2270E+05	0.6634E+13	0.6634E+13	0.6634E+13	0.6634E+13	0.6634E+13	0.6634E+13
1980	0.2541E+05	0.1061E+14	0.1060E+14	0.1057E+14	0.1015E+14	0.1014E+14	0.1011E+14
1985	0.2844E+05	0.1650E+14	0.1644E+14	0.1621E+14	0.1510E+14	0.1505E+14	0.1483E+14
1990	0.3184E+05	0.2509E+14	0.2484E+14	0.2398E+14	0.2196E+14	0.2175E+14	0.2100E+14
1995	0.3564E+05	0.3740E+14	0.3667E+14	0.3439E+14	0.3133E+14	0.3072E+14	0.2880E+14
2000	0.3990E+05	0.5481E+14	0.5301E+14	0.4801E+14	0.4392E+14	0.4247E+14	0.3847E+14
2005	0.4466E+05	0.7905E+14	0.7516E+14	0.6608E+14	0.6060E+14	0.5761E+14	0.5065E+14
2010	0.5000E+05	0.1124E+15	0.1047E+15	0.8945E+14	0.8240E+14	0.7681E+14	0.6560E+14

2B. ASSUMING LOW ENERGY/GNP RATIO

YEAR	LOW ENERGY/GNP RATIO ETU/CONSTANT 1970 $	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
		HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
1975	0.2270E+05	0.6634E+13	0.6634E+13	0.6634E+13	0.6634E+13	0.6634E+13	0.6634E+13
1980	0.2362E+05	0.9863E+13	0.9856E+13	0.9824E+13	0.9436E+13	0.9428E+13	0.9399E+13
1985	0.2458E+05	0.1426E+14	0.1421E+14	0.1400E+14	0.1305E+14	0.1300E+14	0.1282E+14
1990	0.2558E+05	0.2015E+14	0.1996E+14	0.1927E+14	0.1765E+14	0.1747E+14	0.1687E+14
1995	0.2662E+05	0.2794E+14	0.2739E+14	0.2568E+14	0.2340E+14	0.2294E+14	0.2151E+14
2000	0.2770E+05	0.3805E+14	0.3680E+14	0.3333E+14	0.3049E+14	0.2949E+14	0.2671E+14
2005	0.2883E+05	0.5102E+14	0.4851E+14	0.4265E+14	0.3911E+14	0.3719E+14	0.3269E+14
2010	0.3000E+05	0.6742E+14	0.6284E+14	0.5367E+14	0.4944E+14	0.4609E+14	0.3936E+14

3. AVERAGE ANNUAL GROWTH RATES

3A. POPULATION AND PRODUCTIVITY

PERIOD	POPULATION			PRODUCTIVITY	
	H	M	L	H	L
1975-1980	1.72	1.71	1.64	1.98	1.08
1980-1985	1.68	1.62	1.39	1.98	1.08
1985-1990	1.60	1.48	1.06	1.98	1.08
1990-1995	1.51	1.31	0.72	1.98	1.08
1995-2000	1.39	1.11	0.41	1.98	1.08
2000-2005	1.26	0.92	0.32	1.98	1.08
2005-2010	1.13	0.73	0.14	1.98	1.08

3B. GROSS NATIONAL PRODUCT

PERIOD	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
	H	M	L	H	M	L
1975-1980	7.40	7.38	7.31	6.45	6.43	6.36
1980-1985	6.80	6.73	6.50	5.86	5.79	5.56
1985-1990	6.31	6.18	5.74	5.38	5.25	4.81
1990-1995	5.90	5.69	5.08	4.97	4.76	4.15
1995-2000	5.53	5.25	4.52	4.60	4.32	3.59
2000-2005	5.20	4.84	4.22	4.27	3.92	3.30
2005-2010	4.89	4.48	3.87	3.97	3.56	2.96

3. GROWTH RATES (CONTINUED)

3C. ENERGY DEMAND

(I). ASSUMING HIGH ENERGY/GNP RATIO

PERIOD	HIGH RATIO	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUTIVITY		
		H	M	L	H	M	L
1975-1980	2.28	9.85	9.83	9.76	8.88	8.86	8.79
1980-1985	2.28	9.23	9.17	8.93	8.27	8.21	7.96
1985-1990	2.28	8.74	8.61	8.16	7.78	7.65	7.20
1990-1995	2.28	8.32	8.10	7.47	7.36	7.15	6.53
1995-2000	2.28	7.94	7.65	6.90	6.99	6.70	5.96
2000-2005	2.28	7.60	7.23	6.60	6.65	6.29	5.66
2005-2010	2.28	7.29	6.86	6.24	6.34	5.92	5.31

(II). ASSUMING LOW ENERGY/GNP RATIO

PERIOD	LOW RATIO	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
		H	M	L	H	M	L
1975-1980	0.80	8.26	8.24	8.17	7.30	7.28	7.22
1980-1985	0.80	7.65	7.59	7.35	6.70	6.64	6.40
1985-1990	0.80	7.16	7.03	6.59	6.22	6.09	5.65
1990-1995	0.80	6.75	6.54	5.92	5.81	5.60	4.98
1995-2000	0.80	6.38	6.09	5.35	5.44	5.15	4.42
2000-2005	0.80	6.04	5.68	5.05	5.11	4.75	4.13
2005-2010	0.80	5.73	5.31	4.70	4.80	4.38	3.78

4. GROSS NATIONAL PRODUCT AND ENERGY DEMAND PER CAPITA

4A. GNP PER CAPITA

YEAR	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975	0.3251E+03	0.3251E+03
1980	0.4264E+03	0.4079E+03
1985	0.5451E+03	0.4989E+03
1990	0.6837E+03	0.5986E+03
1995	0.8451E+03	0.7079E+03
2000	0.1032E+04	0.8273E+03
2005	0.1249E+04	0.9577E+03
2010	0.1500E+04	0.1100E+04

4B. ENERGY DEMAND PER CAPITA

(I). ASSUMING HIGH ENERGY/GNP RATIO

YEAR	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975	0.7379E+07	0.7379E+07
1980	0.1084E+08	0.1037E+08
1985	0.1551E+08	0.1419E+08
1990	0.2177E+08	0.1906E+08
1995	0.3012E+08	0.2523E+08
2000	0.4119E+08	0.3301E+08
2005	0.5580E+08	0.4278E+08
2010	0.7499E+08	0.5500E+08

(II). ASSUMING LOW ENERGY/GNP RATIO

YEAR	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975	0.7379E+07	0.7379E+07
1980	0.1007E+08	0.9636E+07
1985	0.1340E+08	0.1226E+08
1990	0.1749E+08	0.1531E+08
1995	0.2250E+08	0.1884E+08
2000	0.2860E+08	0.2292E+08
2005	0.3602E+08	0.2761E+08
2010	0.4500E+08	0.3300E+08

5. AVERAGE ANNUAL GROWTH RATE OF GNP/CAP.AND ENERGY DEMAND/CAP

5A. GROSS NATIONAL PRODUCT/CAPITA

PERIOD	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975-1980	5.58	4.64
1980-1985	5.04	4.11
1985-1990	4.64	3.71
1990-1995	4.33	3.41
1995-2000	4.09	3.17
2000-2005	3.89	2.97
2005-2010	3.72	2.81

5B. ENERGY DEMAND/CAPTIA

(I). ASSUMING HIGH ENERGY/GNP RATIO

PERIOD	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975-1980	7.98	7.03
1980-1985	7.43	6.48
1985-1990	7.02	6.08
1990-1995	6.71	5.77
1995-2000	6.46	5.52
2000-2005	6.26	5.32
2005-2010	6.09	5.15

(II). ASSUMING LOW ENERGY/GNP RATIO

PERIOD	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975-1980	6.42	5.48
1980-1985	5.88	4.94
1985-1990	5.47	4.54
1990-1995	5.16	4.24
1995-2000	4.92	3.99
2000-2005	4.72	3.79
2005-2010	4.55	3.63

TABLE A-5

ENERGY CONSUMPTION AND ECONOMIC DEVELOPMENT DATA[a] -
NICARAGUA 1950-1975

Year	Population (10^3)	Labor Force		Annual Energy Consumption in BTU		Annual GNP in Constant 1970 U.S. Dollars		Energy GNP Ratio in BTU per Constant 1970 U.S. Dollars (10^3)	Productivity in Constant 1970 U.S. Dollars per Year per Employee (10^3)
		Total (10^3)	Percentage of Population	Total (10^{15})	Per Capita (10^6)	Total (10^9)	Per Capita		
1950	1109	330.0	29.8	0.0025	2.3	0.264	249	9.0	0.80
1955	1278	-	-	0.0053	4.2	0.382	312	13.0	-
1960	1472	-	-	0.0083	4.8	0.439	311	15.0	-
1965	1701	491.1	28.9	0.0113	6.8	0.667	413	16.0	1.38
1970	1970	548.4	27.8	0.0190	11.6	0.818	436	27.0	1.49
1975	2318	654.6	28.2	0.0287	13.3	1.079	465	29.0	1.61

[a]These historical data have been used to produce the various projections shown in the computer printouts that follow.

ECONOMIC DEVELCPMENT AND ENERGY DEMAND PROJECTIONS: NICARAGUA 1975-2010

1. ECONOMIC DEVELOPMENT

1A. POPULATICN,WORKFORCE AND PRODLCTIVITY

YEAR	POPULATION			WORKFORCE			PRODUCTIVITY 1970 U.S $/YEAR/EMPLOYEE	
	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW	HIGH	LOW
1975	0.22300E+07	0.22300E+07	0.22300E+07	0.62886E+06	0.62886E+06	0.62886E+06	0.1610E+04	0.1610E+04
1980	0.26577E+07	0.26583E+07	0.26498E+07	0.79428E+06	0.79447E+06	0.79193E+06	0.1817E+04	0.1738E+04
1985	0.31754E+07	0.31674E+07	0.30918E+07	0.10025E+07	0.99999E+06	0.97611E+06	0.2050E+04	0.1876E+04
1990	0.37820E+07	0.37271E+07	0.34926E+07	0.12578E+07	0.12395E+07	0.11615E+07	0.2313E+04	0.2025E+04
1995	0.44622E+07	0.43129E+07	0.38164E+07	0.15592E+07	0.15071E+07	0.13336E+07	0.2610E+04	0.2186E+04
2000	0.52064E+07	0.48991E+07	0.40473E+07	0.19070E+07	0.17945E+07	0.14825E+07	0.2945E+04	0.2360E+04
2005	0.59996E+07	0.54595E+07	0.41863E+07	0.22987E+07	0.20918E+07	0.16039E+07	0.3323E+04	0.2547E+04
2010	0.68232E+07	0.59714E+07	0.42446E+07	0.27293E+07	0.23886E+07	0.16978E+07	0.3750E+04	0.2750E+04

1B. ANNUAL GROSS NATIONAL PRODUCT (CONSTANT 1970 U.S DOLLARS)

YEAR	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
1975	0.10125E+10	0.10125E+10	0.10125E+10	0.10125E+10	0.10125E+10	0.10125E+10
1980	0.14430E+10	0.14433E+10	0.14387E+10	0.13804E+10	0.13807E+10	0.13763E+10
1985	0.20551E+10	0.20499E+10	0.20009E+10	0.18808E+10	0.18761E+10	0.18313E+10
1990	0.29093E+10	0.28671E+10	0.26867E+10	0.25472E+10	0.25103E+10	0.23523E+10
1995	0.40697E+10	0.39335E+10	0.34806E+10	0.34087E+10	0.32947E+10	0.29154E+10
2000	0.56164E+10	0.52849E+10	0.43660E+10	0.45004E+10	0.42348E+10	0.34985E+10
2005	0.76391E+10	0.69514E+10	0.53302E+10	0.58559E+10	0.53287E+10	0.40860E+10
2010	0.10234E+11	0.89567E+10	0.63666E+10	0.75054E+10	0.65683E+10	0.46689E+10

2. ANNUAL ENERGY DEMAND IN BTU

2A. ASSUMING HIGH ENERGY/GNP RATIO

YEAR	HIGH ENERGY/GNP RATIO BTU/CONSTANT 1970 $	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
		HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
1975	0.2900E+05	0.2936E+14	0.2936E+14	0.2936E+14	0.2936E+14	0.2936E+14	0.2936E+14
1980	0.3135E+05	0.4523E+14	0.4524E+14	0.4510E+14	0.4327E+14	0.4328E+14	0.4314E+14
1985	0.3388E+05	0.6963E+14	0.6946E+14	0.6780E+14	0.6373E+14	0.6357E+14	0.6205E+14
1990	0.3663E+05	0.1066E+15	0.1050E+15	0.9840E+14	0.9329E+14	0.9194E+14	0.8616E+14
1995	0.3959E+05	0.1611E+15	0.1557E+15	0.1378E+15	0.1349E+15	0.1304E+15	0.1154E+15
2000	0.4279E+05	0.2403E+15	0.2262E+15	0.1868E+15	0.1926E+15	0.1812E+15	0.1497E+15
2005	0.4626E+05	0.3534E+15	0.3215E+15	0.2466E+15	0.2709E+15	0.2465E+15	0.1890E+15
2010	0.5000E+05	0.5117E+15	0.4478E+15	0.3183E+15	0.3753E+15	0.3284E+15	0.2334E+15

2B. ASSUMING LOW ENERGY/GNP RATIO

YEAR	LOW ENERGY/GNP RATIO BTU/CONSTANT 1970 $	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
		HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
1975	0.2900E+05	0.2936E+14	0.2936E+14	0.2936E+14	0.2936E+14	0.2936E+14	0.2936E+14
1980	0.2914E+05	0.4205E+14	0.4206E+14	0.4192E+14	0.4023E+14	0.4024E+14	0.4011E+14
1985	0.2928E+05	0.6018E+14	0.6003E+14	0.5859E+14	0.5507E+14	0.5494E+14	0.5362E+14
1990	0.2942E+05	0.8561E+14	0.8436E+14	0.7906E+14	0.7495E+14	0.7386E+14	0.6922E+14
1995	0.2957E+05	0.1203E+15	0.1163E+15	0.1029E+15	0.1008E+15	0.9741E+14	0.8620E+14
2000	0.2971E+05	0.1669E+15	0.1570E+15	0.1297E+15	0.1337E+15	0.1258E+15	0.1039E+15
2005	0.2986E+05	0.2281E+15	0.2075E+15	0.1591E+15	0.1748E+15	0.1591E+15	0.1220E+15
2010	0.3000E+05	0.3070E+15	0.2687E+15	0.1910E+15	0.2252E+15	0.1970E+15	0.1401E+15

3. AVERAGE ANNUAL GROWTH RATES

3A. POPULATION AND PRODUCTIVITY

PERIOD	POPULATION			PRODUCTIVITY	
	H	M	L	H	L
1975-1980	3.57	3.58	3.51	2.45	1.54
1980-1985	3.62	3.57	3.13	2.45	1.54
1985-1990	3.56	3.31	2.47	2.45	1.54
1990-1995	3.36	2.96	1.79	2.45	1.54
1995-2000	3.13	2.58	1.18	2.45	1.54
2000-2005	2.88	2.19	0.68	2.45	1.54
2005-2010	2.61	1.81	0.28	2.45	1.54

3B. GROSS NATIONAL PRODUCT

PERIOD	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
	H	M	L	H	M	L
1975-1980	7.34	7.35	7.28	6.40	6.40	6.33
1980-1985	7.33	7.27	6.82	6.38	6.32	5.88
1985-1990	7.20	6.94	6.07	6.25	6.00	5.14
1990-1995	6.94	6.53	5.31	6.00	5.59	4.39
1995-2000	6.65	6.08	4.64	5.71	5.15	3.71
2000-2005	6.34	5.63	4.07	5.41	4.70	3.15
2005-2010	6.02	5.20	3.62	5.09	4.27	2.70

3. GROWTH RATES (CONTINUED)

3C. ENERGY DEMAND

(II). ASSUMING HIGH ENERGY/GNP RATIC

PERIOD	HIGH RATIO	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUTIVITY		
		H	M	L	H	M	L
1975-1980	1.57	9.03	9.03	8.96	8.07	8.07	8.00
1980-1985	1.57	9.01	8.95	8.50	8.05	7.99	7.54
1985-1990	1.57	8.88	8.62	7.74	7.92	7.66	6.78
1990-1995	1.57	8.62	8.20	6.97	7.66	7.25	6.02
1995-2000	1.57	8.33	7.75	6.28	7.37	6.80	5.34
2000-2005	1.57	8.01	7.29	5.70	7.06	6.35	4.77
2005-2010	1.57	7.69	6.85	5.24	6.74	5.91	4.31

(III). ASSUMING LOW ENERGY/GNP RATIO

PERIOD	LOW RATIO	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
		H	M	L	H	M	L
1975-1980	0.10	7.45	7.45	7.38	6.50	6.50	6.44
1980-1985	0.10	7.43	7.37	6.92	6.48	6.43	5.98
1985-1990	0.10	7.30	7.04	6.17	6.36	6.10	5.24
1990-1995	0.10	7.05	6.63	5.42	6.10	5.69	4.49
1995-2000	0.10	6.76	6.19	4.74	5.82	5.25	3.81
2000-2005	0.10	6.45	5.74	4.17	5.51	4.80	3.25
2005-2010	0.10	6.13	5.30	3.72	5.19	4.37	2.80

4. GROSS NATIONAL PRODUCT AND ENERGY DEMAND PER CAPITA

4A. GNP PER CAPITA

YEAR	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975	0.4540E+03	0.4540E+03
1980	0.5429E+03	0.5194E+03
1985	0.6472E+03	0.5923E+03
1990	0.7693E+03	0.6735E+03
1995	0.9120E+03	0.7639E+03
2000	0.1079E+04	0.8644E+03
2005	0.1273E+04	0.9760E+03
2010	0.1500E+04	0.1100E+04

4B. ENERGY DEMAND PER CAPITA

(I). ASSUMING HIGH ENERGY/GNP RATIO

YEAR	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975	0.1317E+08	0.1317E+08
1980	0.1702E+08	0.1628E+08
1985	0.2193E+08	0.2007E+08
1990	0.2817E+08	0.2467E+08
1995	0.3611E+08	0.3024E+08
2000	0.4616E+08	0.3699E+08
2005	0.5890E+08	0.4515E+08
2010	0.7499E+08	0.5500E+08

(II). ASSUMING LOW ENERGY/GNP RATIO

YEAR	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975	0.1317E+08	0.1317E+08
1980	0.1582E+08	0.1514E+08
1985	0.1895E+08	0.1734E+08
1990	0.2264E+08	0.1982E+08
1995	0.2697E+08	0.2259E+08
2000	0.3205E+08	0.2568E+08
2005	0.3801E+08	0.2914E+08
2010	0.4500E+08	0.3300E+08

5. AVERAGE ANNUAL GROWTH RATE OF GNP/CAP.AND ENERGY DEMAND/CAP

5A. GROSS NATIONAL PRODUCT/CAPITA

PERIOD	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975-1980	3.64	2.73
1980-1985	3.58	2.66
1985-1990	3.52	2.60
1990-1995	3.46	2.55
1995-2000	3.41	2.50
2000-2005	3.37	2.46
2005-2010	3.33	2.42

5B. ENERGY DEMAND/CAPTIA

(I). ASSUMING HIGH ENERGY/GNP RATIO

PERIOD	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975-1980	5.27	4.34
1980-1985	5.20	4.27
1985-1990	5.14	4.21
1990-1995	5.09	4.16
1995-2000	5.04	4.11
2000-2005	4.99	4.07
2005-2010	4.95	4.03

(II). ASSUMING LOW ENERGY/GNP RATIO

PERIOD	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975-1980	3.74	2.83
1980-1985	3.68	2.76
1985-1990	3.62	2.70
1990-1995	3.56	2.65
1995-2000	3.52	2.60
2000-2005	3.47	2.56
2005-2010	3.43	2.52

TABLE A-6

ENERGY CONSUMPTION AND ECONOMIC DEVELOPMENT DATA[a] -
VENEZUELA 1950-1975

Year	Population (10^3)	Labor Force		Annual Energy Consumption in BTU		Annual GNP in Constant 1970 U.S. Dollars		Energy GNP Ratio in BTU per Constant 1970 U.S. Dollars (10^3)	Productivity in Constant 1970 U.S. Dollars per Year per Employee (10^3)
		Total (10^3)	Percentage of Population	Total (10^{15})	Per Capita (10^6)	Total (10^9)	Per Capita		
1950	5145	1706	33.2	0.133	25.03	2.4	485	55.42	1.411
1955	6073	2058	33.9	0.254	39.67	3.7	608	68.61	1.843
1960	7635	2293	30.0	0.364	47.06	5.3	823	68.53	2.276
1965	9105	2729	30.0	0.506	58.08	7.7	882	65.76	2.693
1970	10559	2992	28.3	0.662	64.02	9.6	942	69.11	3.102
1975	12213	3712	30.4	0.879	73.31	11.8	992	74.67	3.172

[a]These historical data have been used to produce the various projections shown in the computer printouts that follow.

ECONOMIC DEVELOPMENT AND ENERGY DEMAND PROJECTIONS: VENEZUELA 1975-2010

1. ECONOMIC DEVELOPMENT

1A. POPULATION, WORKFORCE AND PRODUCTIVITY

YEAR	POPULATION			WORKFORCE			PRODUCTIVITY 1970 U.S $/YEAR/EMPLOYEE	
	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW	HIGH	LOW
1975	0.12213E+08	0.12213E+08	0.12213E+08	0.37128E+07	0.37128E+07	0.37128E+07	0.3172E+04	0.3172E+04
1980	0.14080E+08	0.14064E+08	0.13999E+08	0.44735E+07	0.44684E+07	0.44476E+07	0.3249E+04	0.3108E+04
1985	0.16179E+08	0.16090E+08	0.15752E+08	0.53621E+07	0.53326E+07	0.52208E+07	0.3327E+04	0.3045E+04
1990	0.18490E+08	0.18222E+08	0.17300E+08	0.63817E+07	0.62890E+07	0.59711E+07	0.3408E+04	0.2984E+04
1995	0.20982E+08	0.20378E+08	0.18532E+08	0.75296E+07	0.73127E+07	0.66502E+07	0.3490E+04	0.2924E+04
2000	0.23611E+08	0.22473E+08	0.19410E+08	0.87968E+07	0.83728E+07	0.72316E+07	0.3575E+04	0.2865E+04
2005	0.26322E+08	0.24430E+08	0.19954E+08	0.10168E+08	0.94370E+07	0.77078E+07	0.3661E+04	0.2807E+04
2010	0.29055E+08	0.26188E+08	0.20255E+08	0.11622E+08	0.10475E+08	0.81019E+07	0.3750E+04	0.2750E+04

1B. ANNUAL GROSS NATIONAL PRODUCT (CONSTANT 1970 U.S DOLLARS)

YEAR	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
1975	0.11777E+11	0.11777E+11	0.11777E+11	0.11777E+11	0.11777E+11	0.11777E+11
1980	0.14533E+11	0.14517E+11	0.14449E+11	0.13904E+11	0.13888E+11	0.13823E+11
1985	0.17842E+11	0.17744E+11	0.17372E+11	0.16329E+11	0.16239E+11	0.15899E+11
1990	0.21748E+11	0.21432E+11	0.20349E+11	0.19041E+11	0.18765E+11	0.17816E+11
1995	0.26281E+11	0.25524E+11	0.23212E+11	0.22013E+11	0.21379E+11	0.19442E+11
2000	0.31447E+11	0.29931E+11	0.25852E+11	0.25199E+11	0.23984E+11	0.20715E+11
2005	0.37228E+11	0.34552E+11	0.28221E+11	0.28538E+11	0.26487E+11	0.21633E+11
2010	0.43582E+11	0.39281E+11	0.30382E+11	0.31961E+11	0.28807E+11	0.22280E+11

2. ANNUAL ENERGY DEMAND IN BTU

2A. ASSUMING HIGH ENERGY/GNP RATIC

YEAR	HIGH ENERGY/GNP RATIO BTU/CONSTANT 1970 $	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
		HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
1975	0.7467E+05	0.8794E+15	0.8794E+15	0.8794E+15	0.8794E+15	0.8794E+15	0.8794E+15
1980	0.7051E+05	0.1025E+16	0.1024E+16	0.1019E+16	0.9804E+15	0.9792E+15	0.9747E+15
1985	0.6659E+05	0.1188E+16	0.1181E+16	0.1157E+16	0.1087E+16	0.1081E+16	0.1059E+16
1990	0.6288E+05	0.1367E+16	0.1348E+16	0.1280E+16	0.1197E+16	0.1180E+16	0.1120E+16
1995	0.5938E+05	0.1561E+16	0.1516E+16	0.1378E+16	0.1307E+16	0.1269E+16	0.1154E+16
2000	0.5607E+05	0.1763E+16	0.1678E+16	0.1450E+16	0.1413E+16	0.1345E+16	0.1162E+16
2005	0.5295E+05	0.1971E+16	0.1830E+16	0.1494E+16	0.1511E+16	0.1402E+16	0.1145E+16
2010	0.5000E+05	0.2179E+16	0.1964E+16	0.1519E+16	0.1598E+16	0.1440E+16	0.1114E+16

2B. ASSUMING LOW ENERGY/GNP RATIO

YEAR	LOW ENERGY/GNP RATIO BTU/CONSTANT 1970 $	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
		HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
1975	0.7467E+05	0.8794E+15	0.8794E+15	0.8794E+15	0.8794E+15	0.8794E+15	0.8794E+15
1980	0.6555E+05	0.9527E+15	0.9516E+15	0.9471E+15	0.9114E+15	0.9103E+15	0.9061E+15
1985	0.5754E+05	0.1027E+16	0.1021E+16	0.9996E+15	0.9396E+15	0.9345E+15	0.9149E+15
1990	0.5052E+05	0.1099E+16	0.1083E+16	0.1028E+16	0.9619E+15	0.9479E+15	0.9000E+15
1995	0.4435E+05	0.1165E+16	0.1132E+16	0.1029E+16	0.9762E+15	0.9481E+15	0.8622E+15
2000	0.3893E+05	0.1224E+16	0.1165E+16	0.1006E+16	0.9810E+15	0.9337E+15	0.8064E+15
2005	0.3418E+05	0.1272E+16	0.1181E+16	0.9645E+15	0.9753E+15	0.9052E+15	0.7393E+15
2010	0.3000E+05	0.1308E+16	0.1178E+16	0.9115E+15	0.9589E+15	0.8642E+15	0.6684E+15

3. AVERAGE ANNUAL GROWTH RATES

3A. POPULATION AND PRODUCTIVITY

PERIOD	POPULATION			PRODUCTIVITY	
	H	M	L	H	L
1975-1980	2.89	2.86	2.77	0.48	-0.41
1980-1985	2.82	2.73	2.39	0.48	-0.41
1985-1990	2.71	2.52	1.89	0.48	-0.41
1990-1995	2.56	2.26	1.38	0.48	-0.41
1995-2000	2.39	1.98	0.93	0.48	-0.41
2000-2005	2.20	1.68	0.55	0.48	-0.41
2005-2010	2.00	1.40	0.30	0.48	-0.41

3B. GROSS NATIONAL PRODUCT

PERIOD	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
	H	M	L	H	M	L
1975-1980	4.30	4.27	4.17	3.38	3.35	3.26
1980-1985	4.19	4.10	3.75	3.27	3.18	2.84
1985-1990	4.04	3.85	3.21	3.12	2.93	2.30
1990-1995	3.86	3.56	2.67	2.94	2.64	1.76
1995-2000	3.65	3.24	2.18	2.74	2.33	1.28
2000-2005	3.43	2.91	1.77	2.52	2.01	0.87
2005-2010	3.20	2.60	1.49	2.29	1.69	0.59

3. GROWTH RATES (CONTINUED)

3C. ENERGY DEMAND

(I). ASSUMING HIGH ENERGY/GNP RATIC

PERIOD	HIGH RATIO	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUTIVITY		
		H	M	L	H	M	L
1975-1980	-1.14	3.11	3.08	2.99	2.20	2.17	2.08
1980-1985	-1.14	3.00	2.91	2.57	2.09	2.00	1.67
1985-1990	-1.14	2.85	2.67	2.04	1.95	1.76	1.14
1990-1995	-1.14	2.68	2.38	1.50	1.77	1.47	0.60
1995-2000	-1.14	2.47	2.06	1.01	1.57	1.16	0.12
2000-2005	-1.14	2.25	1.74	0.61	1.35	0.84	-0.28
2005-2010	-1.14	2.03	1.43	0.33	1.13	0.53	-0.55

(II). ASSUMING LOW ENERGY/GNP RATIO

PERIOD	LOW RATIO	ASSUMING HIGH PRODUCTIVITY			ASSUMING LOW PRODUCTIVITY		
		H	M	L	H	M	L
1975-1980	-2.57	1.61	1.59	1.50	0.72	0.69	0.60
1980-1985	-2.57	1.51	1.42	1.08	0.61	0.52	0.19
1985-1990	-2.57	1.36	1.18	0.56	0.47	0.29	-0.33
1990-1995	-2.57	1.19	0.89	0.03	0.30	0.00	-0.86
1995-2000	-2.57	0.99	0.58	-0.45	0.10	-0.31	-1.33
2000-2005	-2.57	0.77	0.27	-0.85	-0.12	-0.62	-1.72
2005-2010	-2.57	0.55	-0.04	-1.12	-0.34	-0.92	-2.00

4. GROSS NATIONAL PRODUCT AND ENERGY DEMAND PER CAPITA

4A. GNP PER CAPITA

YEAR	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975	0.9643E+03	0.9643E+03
1980	0.1032E+04	0.9874E+03
1985	0.1103E+04	0.1009E+04
1990	0.1176E+04	0.1030E+04
1995	0.1253E+04	0.1049E+04
2000	0.1332E+04	0.1067E+04
2005	0.1414E+04	0.1084E+04
2010	0.1500E+04	0.1100E+04

4B. ENERGY DEMAND PER CAPITA

(I). ASSUMING HIGH ENERGY/GNP RATIO

YEAR	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975	0.7200E+08	0.7200E+08
1980	0.7278E+08	0.6963E+08
1985	0.7343E+08	0.6720E+08
1990	0.7396E+08	0.6475E+08
1995	0.7437E+08	0.6229E+08
2000	0.7468E+08	0.5984E+08
2005	0.7489E+08	0.5741E+08
2010	0.7500E+08	0.5500E+08

(II). ASSUMING LOW ENERGY/GNP RATIO

YEAR	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975	0.7200E+08	0.7200E+08
1980	0.6766E+08	0.6473E+08
1985	0.6346E+08	0.5808E+08
1990	0.5942E+08	0.5202E+08
1995	0.5555E+08	0.4652E+08
2000	0.5185E+08	0.4155E+08
2005	0.4834E+08	0.3705E+08
2010	0.4500E+08	0.3300E+08

5. AVERAGE ANNUAL GROWTH RATE OF GNP/CAP.AND ENERGY DEMAND/CAP

5A. GROSS NATIONAL PRODUCT/CAPITA

PERIOD	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975-1980	1.37	0.48
1980-1985	1.33	0.44
1985-1990	1.30	0.40
1990-1995	1.27	0.37
1995-2000	1.24	0.34
2000-2005	1.21	0.32
2005-2010	1.18	0.29

5B. ENERGY DEMAND/CAPTIA

(I). ASSUMING HIGH ENERGY/GNP RATIC

PERIOD	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975-1980	0.22	-0.67
1980-1985	0.18	-0.71
1985-1990	0.14	-0.74
1990-1995	0.11	-0.77
1995-2000	0.08	-0.80
2000-2005	0.06	-0.83
2005-2010	0.03	-0.85

(II). ASSUMING LOW ENERGY/GNP RATIO

PERIOD	ASSUMING HIGH PRODUCTIVITY	ASSUMING LOW PRODUCTIVITY
1975-1980	-1.24	-2.11
1980-1985	-1.27	-2.14
1985-1990	-1.31	-2.18
1990-1995	-1.34	-2.21
1995-2000	-1.37	-2.24
2000-2005	-1.39	-2.26
2005-2010	-1.42	-2.29

TABLE A-7

CONSUMER PRICE INDEX, 1950-1975
(1970 = 100)

Year	United States	West Germany	Brazil	Mauritius	Nicaragua
1950	61.8	63.8	0.4	70.0	51.7
1951	66.6	68.9	0.4	75.0	61.5
1952	68.0	70.3	0.5	82.0	62.2
1953	68.6	68.9	0.6	84.0	69.9
1954	68.6	68.9	0.7	83.0	75.5
1955	68.6	70.3	0.8	81.0	90.2
1956	70.0	71.7	1.0	82.0	82.5
1957	72.1	73.3	1.2	81.0	80.4
1958	74.1	75.0	1.4	82.0	84.6
1959	74.9	75.8	1.9	81.0	81.8
1960	75.6	76.5	2.6	83.0	80.4
1961	76.4	78.8	3.6	83.0	80.4
1962	77.8	80.8	5.5	84.0	80.4
1963	78.6	83.3	9.6	83.0	81.1
1964	79.3	85.0	17.9	85.0	84.6
1965	80.8	88.3	28.8	86.0	86.7
1966	83.0	91.2	42.3	88.0	90.2
1967	86.0	92.8	55.0	90.0	91.6
1968	89.6	94.9	67.0	96.0	94.4
1969	94.4	96.7	82.0	98.0	94.4
1970	100.0	100.0	100.0	100.0	100.0
1971	104.3	105.3	120.0	100.0	105.6
1972	107.7	111.1	140.0	106.0	111.9
1973	114.4	118.8	158.0	120.0	-
1974	127.0	127.1	201.0	155.0	-
1975	138.6	134.6	260.0	178.0	-

APPENDIX B

APPENDIX B

THE TECHNICAL CONSERVATION FIX AND TOTAL ENERGY CONSUMPTION GROWTH

The problem chosen to illustrate the relation between Technical Conservation Fix and Total Energy Consumption growth deals with the consumption of a product "A" which has "X" units of energy associated with it before conservation and "$X - X_c$" units after conservation, where "X_c" units of energy represent the energy saved through conservation. This illustration can also be viewed as one which illustrates the limitation of conservation. The definition of the terms used are given below and the solution illustrated in Figure B-1.

1. Definition of Terms Used

   (i) T_0 - Year in which conservation fix starts.

   (ii) T_1 - Year in which conservation fix ends, i.e., after N_1 years.

   (iii) T_2 - N_2 years after end of conservation fix.

   (iv) E_0 - Total energy consumption associated with product A (e.g., steel) in year T_0.

   (v) E_1 - Total energy consumption associated with product A in year T_1 with no conservation fix.

   (vi) E_2 - Total energy consumption associated with product A in year T_2 with no conservation fix.

   (vii) E_{c_1} - Total energy consumption associated with product A in year T_1 with conservation fix.

   (viii) E_{c_2} - Total energy consumption associated with product A in year T_2. N_2 years after the end of conservation fix.

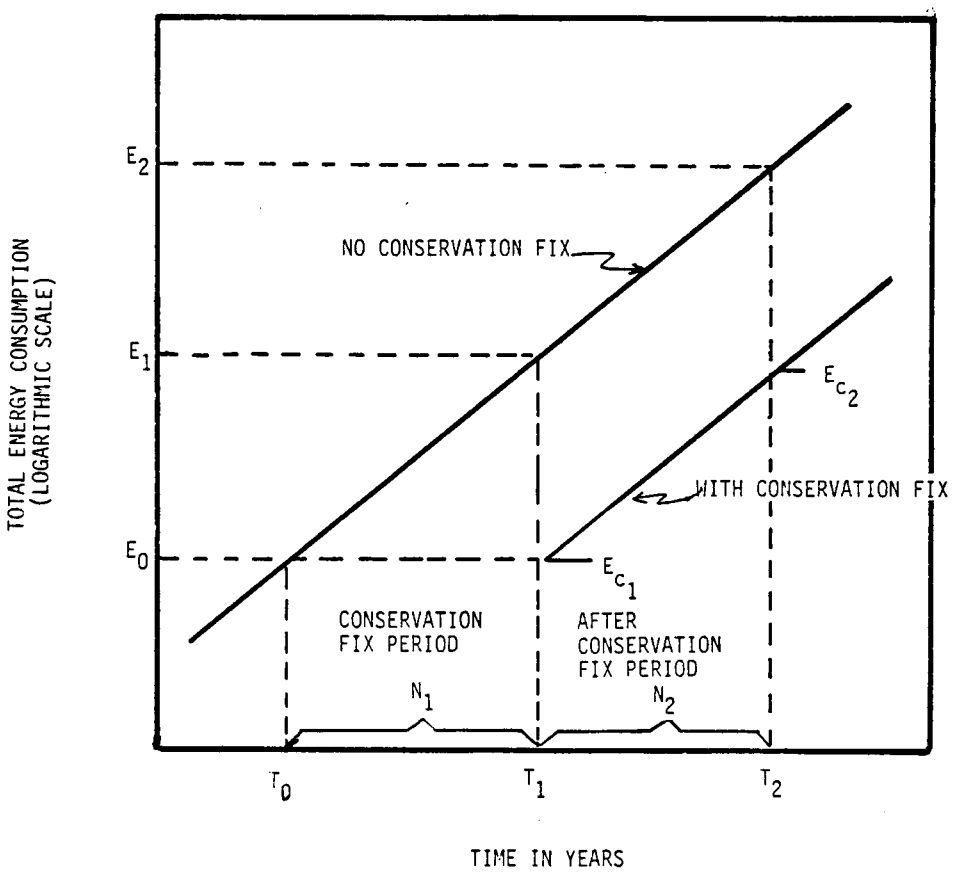


FIGURE B-1. THE TECHNICAL CONSERVATION FIX AND TOTAL ENERGY CONSUMPTION GROWTH

2. Assumptions

a. Before Conservation fix, i.e., year T_0.

(i) X units of energy required to produce Y units of product A.

(ii) Z annual demand/capita of product A.

(iii) r per capita annual growth rate (decimals) in the demand of product A.

(iv) P total population.

(v) þ Annual population growth rate (decimals).

b. During Conservation Fix Period T_0 to T_1, i.e., N_1 Years.

During this period, i.e., $T_1 - T_0 = N_1$ years, any additional energy consumed due to increase in population and increase in per capita demand of product A is equal to energy saved by conservation, etc., i.e., $E_0 = E_{c_1}$.

c. After End of Conservation Fix Period, i.e., During N_2 Years.

$X - X_c$ units of energy required to product Y units of product A where X = unit of energy saved through conservation, etc., r, p annual growth rate same as before year T_0.

3. Calculations

a. Energy Consumption Per Capita and Total Energy Consumption:

Year T_0

Energy consumption per capita = $\frac{X}{Y} \cdot Z$

Total consumption $E_0 = \frac{X}{Y} \cdot Z \cdot P$

(i) Assuming no conservation fix.

Year T_1

Energy consumption per capita = $\frac{X}{Y} \cdot Z\,(1 + r)^{N_1}$

Total energy consumption $E_1 = \frac{X}{Y} \cdot Z\,(1 + r)^{N_1} \cdot P\,(1 + p)^{N_1}$

Year T_2

Energy consumption per capita = $\frac{X}{Y} \cdot Z\,(1 + r)^{N_1}\,(1 + r)^{N_2}$.

Total Energy consumption $E_2 = \frac{X}{Y} \cdot Z\,(1 + r)^{N_1} \cdot (1 + r)^{N_2} \cdot P\,(1 + p)^{N_1}\,(1 + p)^{N_2}$

(ii) Assuming conservation fix.

Year T_1

Energy consumption per capita = $\frac{X - Xc}{Y} \cdot Z\,(1 + r)^{N_1}$

Total consumption $E_{c_1} = \frac{X - Xc}{Y} \cdot Z\,(1 + r)^{N_1} \cdot P\,(1 + p)^{N_1}$

$= E_0$

Year T_2

Energy consumption per capita = $\frac{X - Xc}{Y} \cdot Z\,(1 + r)^{N_1}\,(1 + r)^{N_2}$

Total energy consumption $E_{c_2} = \frac{X - Xc}{Y} \cdot Z\,(1 + r)^{N_1} \cdot (1 + r)^{N_2} \cdot P\,(1 + p)^{N_1}\,(1 + p)^{N_2}$

b. Growth Rates in Total Energy Consumption During Period N_2.

(i) With no conservation fix

$$\text{Growth rate} = \frac{1}{N_2} \quad \text{Ln}\left[\frac{E_2}{E_1}\right]$$

$$= \frac{1}{N_2} \text{ Ln } \left[\frac{\frac{X}{Y} \cdot Z\ (1 + r)^{N_1}\ (1 + r)^{N_2} \cdot P\ (1 + p)^{N_1} (1 + p)^{N_2}}{\frac{X}{Y} \cdot Z\ (1 + r)^{N_1} \cdot P\ (1 + p)^{N_1}}\right]$$

$$= \frac{1}{N_2} \text{ L n } [(1 + r)^{N_2}\ (1 + p)^{N_2}]$$

$$= \text{Ln } [(1 + r) \cdot (1 + p)]$$

(ii) With conservation fix

$$\text{Growth rate} = \frac{1}{N_2} \text{ Ln } \left[\frac{E_{c_2}}{E_{c_1}}\right]$$

$$= \frac{1}{N_2} \text{ Ln } \left[\frac{\frac{(X-Xc)}{Y} \cdot Z\ (1 + r)^{N_1} (1 + r)^{N_2} \cdot P (1 + p)^{N_1} (1 + p)^{N_2}}{\frac{(X-Xc)}{Y} \cdot Z\ (1 + r)^{N_1} \cdot P\ (1 + p)^{N_1}}\right]$$

$$= \frac{1}{N_2} \text{ Ln } [(1 + r)^{N_2} \cdot (1 + p)^{N_2}]$$

$$= \text{Ln } [(1 + r) \cdot (1 + p)]$$

Note that growth rate same in both cases.

4. Conclusions.

The preceding analysis of a hypothetical technical/conservation fix illustrates its temporary nature. Once the particular fix has been maximized, the demand curve associated with a particular product will again grow at the original annual rate unless population growth and/or per capita demand for the particular product have also been diminished.

A succession of technical fixes may, of course, be introduced over a period of years. The theoretical limit for the sum of all such technical fixes is determined by the second law of thermodynamics, and thus the strategy cannot be pursued without limit.

These observations on the limited impact of technical/conservation fixes in no way diminish their importance. There are positive economic and environmental advantages to maximizing the efficiency of all energy consuming processes.

APPENDIX C

APPENDIX C

ANALYSES OF SUGAR CANE AND CORN UTILIZATION FOR ENERGY AND CHEMICAL FEEDSTOCK PRODUCTION

A. Cost of Sugar Cane Production

1. Illustration of Method.

The method used for estimating the cost of production of sugar cane has been based both on the work published by Battele Columbus Laboratories (BCL)[66] in March 1977 and personal experience in the sugar cane industry. Data from the sugar cane industries of the state of Florida, which has sugar growing regions comparable to those of the three LDCs, i.e., Brazil, Mauritius and Nicaragua, have been used for illustrative purposes. Table C-1 together with explanatory notes provided, illustrates the method. From the analysis, which has been based on annual production per acre and adjusted to reflect November 1979 costs, it can be said that the cost to raise one acre of sugar cane and transport the sugar cane stalks to the factory is very close to 700 dollars. At a yield of 35 tons per acre[81] the cost per unit ton of sugar cane is 20 dollars compared to 15 to 18 dollars per ton in the three LDCs. The cost allocation to the two products, i.e., sugar (also referred to as fermentable sugar in the alcohol industry) and bagasse are discussed below. The question of appropriate cost allocations is an important one in any multiple product operation.

TABLE C-1

ESTIMATION OF SUGAR CANE PRODUCTION
IN THE UNITED STATES

	1976 Dollars Per Acre	1979 Dollars Per Acre
Preharvest Cost		
Seed	17.00	
Fertilizer	50.00	
Chemicals	32.50	
Labor	52.75	
Fuels and Lubricants	11.50	
Repairs	15.25	
Interest on Operating Capital	9.50	
Miscellaneous	14.00	
Sub-Total	202.50	243.00
Harvest Cost		
Labor	55.75	
Hauling	47.75	
Fuel and Lubricants	16.50	
Repairs	31.50	
Interest on Operating Capital	6.25	
Miscellaneous	5.50	
Sub-Total	163.25	195.90
Other Costs		
Machine Ownership Costs	54.50	65.40
Land Charge	100.00	150.00
Management Charge	40.00	48.00
Sub-Total	194.50	263.40
Total Costs	560.25	702.30
Cost Per Ton (Short) of Sugar Cane	$16.0	$20.0

Explanatory Notes of Cost Estimation Shown in Table C-1:

(i) Cost of seed has been estimated on the assumption that the field would be planted every five years and the seed requirement would be five tons per acre at approximately 17 dollars per ton in 1976.

(ii) Fertilizer cost based on 800 pounds of fertilizer (primarily in the form of ammonium sulphate with 21% N content)[92] at 125 dollars per ton of fertilizer in 1976.

(iii) Land Charges - according to the U. S. Agricultural and Consumer Protection Act of 1973 a "return on fixed cost equal to the existing rate charged by the Federal Land Banks (FLB)" should be included in the land cost estimates.[81] This implies the use of "opportunity cost" allocation, i.e., what could be earned as interest if the value of the land were invested at the FLB. With the interest rate of approximately 10% at the FLB in 1976, the BCL study included 100 dollars annually for land valued at 1,000 dollars per acre. Since the interest rates in the U. S. for various types of loans are close to 15%, 150 dollars for land valued at $1,000 per acre has been charged in 1979.

(iv) Management charge, BCL assumption of 7% of total gross receipt has been used.

(v) Since inflation has been roughly 10% for the last two years, a 20% increment has been added to all the estimates except land charges, which have been treated as in (iii) above, in order to adjust the cost to 1979.

(vi) In order to estimate the cost per ton of sugar cane (fresh), the average yield for Florida which is approximately 35 tons per acre (millable sugar cane only) has been used.

2. Cost Allocation for Fermentable Sugar and Bagasse

In any multiple product system there are questions as to the assignment or distribution of costs amongst the various components such as raw materials, capital costs of the plant, etc. Traditionally the sugar industry has had only one major product, i.e., sugar itself, and almost all the costs have been assigned to that product with only a very small portion very arbitrarily assigned to molasses (mostly used for alcohol production in the beverage industry). If bagasse becomes one of the products for energy production purposes, it is necessary to reallocate some of the costs from sugar to the bagasse material. This has been done below by using the analogy to an average cost of \$1.00 per 10^6 BTU for other fuel types such as wood, coal, and natural gas.

Calculations:

Harvesting sugar cane stalks only.

Per ton of sugar cane (wet).

Production cost (delivered to sugar factory yard)		\$ 20.00
Fermentable sugar yield (at 12.5% sugar in sugar cane)		250 pounds
Bagasse - 50% wet (at 12.5% dry fiber in sugar cane)		500 pounds
Total heat content of bagasse (at average heat content of 5500 BTU per pound at 50% wet)		2.75×10^6 BTU
Total cost of energy (at \$1.00 per 10^6 BTU)		\$ 2.75
Total cost of bagasse		\$ 2.75
Total cost of fermentable sugar (by difference)		\$ 17.25

Cost per pound:

Bagasse	($\sim$ 0.6 cts.)	\$ 0.0055
Fermentable sugar	($\sim$ 7.0 cts.)	\$ 0.069

There are other possible ways to reallocate the costs to the bagasse. For example, one can use the analogy to the cost of harvesting and collecting wood for fuel uses. Given the uncertainties involved, the great variations among various geographical locations, and the discretionary judgments involved in any of the methods, the above approach is viewed as adequate for the present calculations.

3. Cost of Sugar Cane in the Three Selected LDCs.

Using the same method of calculation illustrated in the above two sections and making use of information gathered through personal contacts and visits to the three selected LDCs, the following costs have been estimated to reflect November 1979 cost of production.

	Cost Per Ton Sugar Cane	Costs in Cents* Per Pound Fermentable Sugar	Costs in Cents* Per Pound Bagasse at 50% Moisture
Brazil	$17	5.7	0.6
Mauritius	$15	4.9	0.6
Nicaragua	$18	6.1	0.6

The low cost of sugar cane in Mauritius can be attributed to very little mechanization in the cane harvesting and loading sector compared to fairly low cost manual labor. Moreover, this allows the Mauritius sugar farmers to extend the time between replanting of cane from around five years to around eight years because not much sugar

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*Calculated by analogy to an average cost of $1.00 per 10^6 BTU for wood, coal, and natural gas.

cane root is damaged when harvesting, and loading is done manually. However, during recent years the cost of labor has been causing the cost of cane to rise very rapidly.

The above costs have been used in Chapter VII to help estimate the cost of production of chemical feedstock, energy, and sugar in the three LDCs.

B. Material and Energy Balance and Economics of Sugar Cane Utilization for Energy and Chemical Feedstock Production

In this section the material and energy balance and the economics associated with the use of sugar cane for the production of ammonia, ethyl alcohol, methyl alcohol, ethylene and electricity are illustrated in detail. The following items and assumptions are common to all the calculations:

(i) Data from BCL publications of March 1977 have been used.

(ii) The chemical engineering cost index and the consumer price index of the U. S. have been used to adjust BCL estimates of 1977 in order to reflect current costs.

(iii) Interest rate has been computed as illustrated below.

(iv) Mainly because sugar (sucrose) was the only product of interest, the sugar cane harvesting period was and still is limited to roughly 150-175 days, the time during which the sucrose content of the sugar cane is at its highest level. With the energy crunch bagasse has become a very important source of energy. Therefore, the harvesting period can be extended, even though the recovery of sucrose would be reduced somewhat. Moreover, because of small annual climatic

variations in Mauritius, Nicaragua, and parts of Brazil, the harvesting season has been extended to 330 days for the purpose of this study.

(v) The average sugar cane crushing capacity of the sugar factories in the selected LDCs is around 3,000 tons per day. By addition of a fourth roller to the already existing three roller mills, the capacity can be improved to 4,000 tons per day, which would in turn decrease the overall cost of production. Thus, the calculations that follow have been based on a 4,000 ton cane supply per day. At 12.5% sugar and 12.5% dry fiber content in the sugar cane by weight, which is a typical sugar and fiber content of sugar cane when only the cane stalk is harvested, the supply of fermentable sugar and bagasse per day are:

Fermentable sugar - 500 tons

Bagasse (50% water content) - 1,000 tons

Water by difference - 2,500 tons

The above figures have been used as the basis of the following calculations:

1. Ammonia Production From Bagasse.

a. Material and Energy Balance

The basic assumptions used for the overall material and energy balances of both the Purox and the ammonia production units are given below:

(i) Heat content of bagasse 50% (wet) is equal to 5,500 BTU per pound.

(ii) Net thermal efficiency of Purox process is 65% and includes the energy required to produce oxygen.[93]

(iii) The heat content of the synthesis gas produced is approximately 300 BTU per SCF (standard cubic feet) and its composition was discussed in Chapter VI.

(iv) Oxygen and nitrogen requirements and the overall material balance are based on equations below and the waste material is calculated by difference.

Purox Process

$$C + \frac{1}{2} O_2 \longrightarrow CO_2 \qquad \text{(exothermic)}$$

$$C + H_2O \longrightarrow CO + H_2 \qquad \text{(endothermic)}$$

$$CO + H_2O \longrightarrow CO_2 + H_2 \qquad \text{(exothermic)}$$

$$C + 2H_2 \longrightarrow CH_4 \qquad \text{(exothermic)}$$

Ammonia Process

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

(v) Conversion of the ammonia process[66] is 33%.

(vi) Steam requirement for the ammonia process is approximately 0.75 pound per pound of synthesis gas produced.

b. Economics

This subsection deals with the estimation of the cost of production of synthesis gas from the Purox process and the cost of production of ammonia using the synthesis. In addition to the

explanations given as footnotes to the tables, the scaling method used in order to estimate the fixed cost is explained below.

The well known functional relationship between capacity and fixed cost[94,95] given by the equation

$$\frac{\text{Fixed capital of new facility}}{\text{Fixed capital of already existing facility}} = \left[\frac{\text{Capacity of new facility}}{\text{Capacity of already existing facility}}\right]^X$$

has been used as illustrated below. Capacity based on raw material bagasse to be treated by Purox facility.

Capacity of facility described by BCL	= 3242 tons/day
Capacity of desired facility	= 1000 tons/day
Fixed capital in 1976 dollars of BCL facility	= 60.72×10^6
Fixed capital of desired facility	= Y
Value of X commonly used[94]	= 0.8

Thus:

$$Y = 60.72 \times 10^6 \left[\frac{1000}{3242}\right]^{0.8}$$

$$= \$23.70 \times 10^6 \ (1976)$$

Finally, using the chemical engineering plant cost index[96], the fixed capital cost has been adjusted to reflect 1979 dollars, i.e., $\$28.44 \times 10^6$. The same procedure has been used in the cost estimation for the facilities discussed in all the sections that follow.

The interest on total capital investment has been computed based on levelized payment arrangement[97] as illustrated below.

Assumptions:

(i) All financing of the capital cost is by debt, i.e., borrowing from banks, etc. . . ., and none is equity financing, e.g., stocks.

(ii) Annual interest rate of 15%, which is approximately the current prime interest rate in the U. S., has been used for the calculations in this appendix. For similar calculations in Chapter VII interest rates the same as above have been used for the selected LDCs, though it is recognized that especially in the case of Brazil the interest rate might be as high as 25% because of its high inflation rate of almost 48% annually.

(iii) Levelized payment arrangement, in which payback is at a fixed annual rate, but the proportion of each payment for principal and interest changes with each payment. The formula for computing the levelized payment and the way it has been applied is illustrated below.

(iv) Amortization is on a modified straight line basis, as implied by the levelized payment formula, with zero residual value assumed.

Equation:

$$A = P\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right]$$

where:

A = Total amount of annual payment

P = Principal

i = Interest rate (= 0.15)

n = Number of payback years (= 20)

Computation of Average Annual Interest on Total Capital Investment:

$$I = A - \left[\frac{F + S + W}{n}\right]$$

where:

I = Total interest on total investment

F = Fixed capital investment

S = Start-up expenses

W = Working capital

The above method has been used to compute the interest in all of the calculations in this appendix.

Figure C-1 illustrates the material and energy balance of the Purox and ammonia processes and Tables C-2 and C-3 give the production costs.

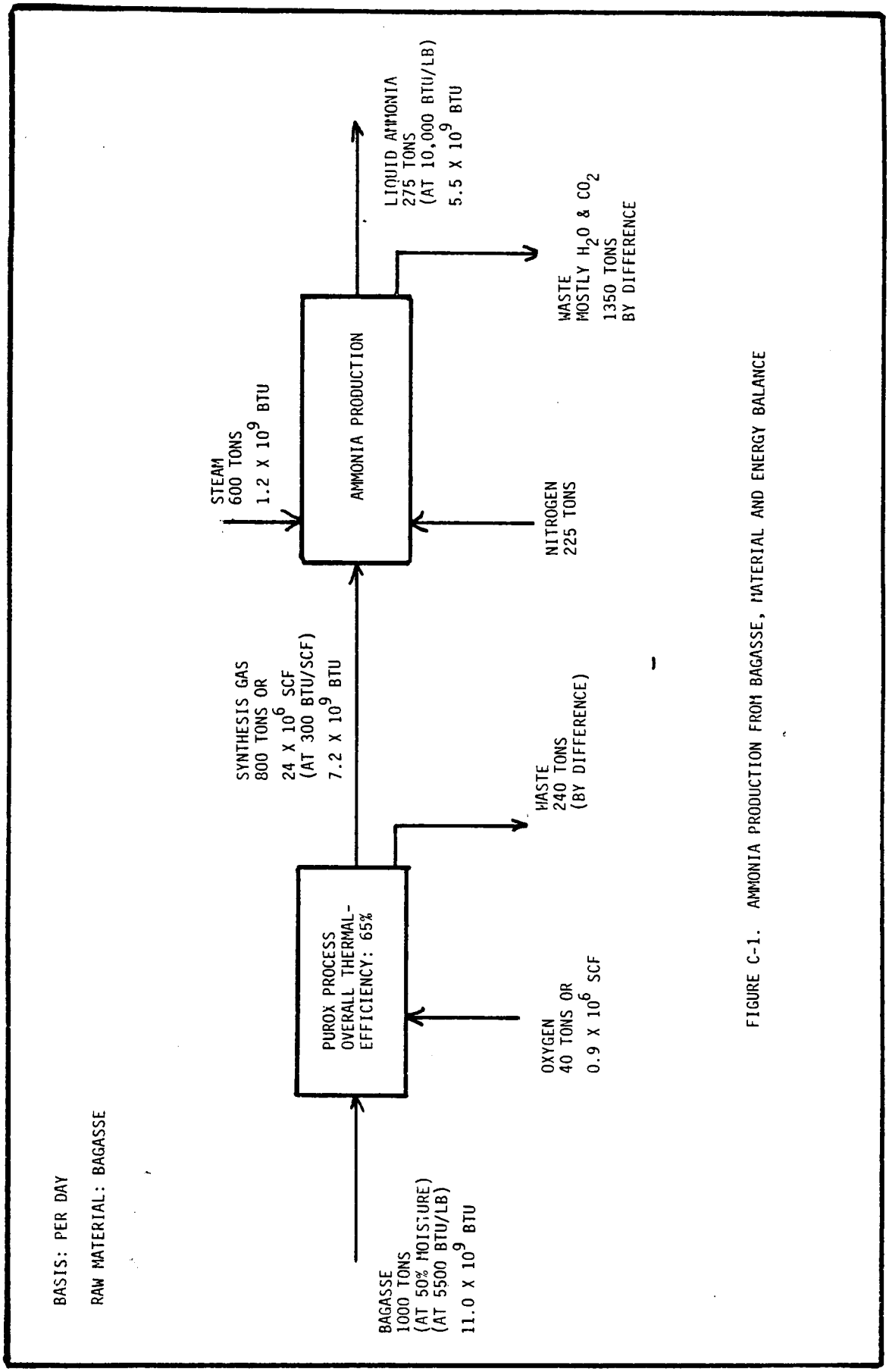


FIGURE C-1. AMMONIA PRODUCTION FROM BAGASSE, MATERIAL AND ENERGY BALANCE

TABLE C-2

COST ESTIMATES OF SYNTHESIS GAS PRODUCTION - THE PUROX PROCESS

Annual (330 Days) Production = 7.92×10^9 SCF Synthesis Gas

Heat Content of Gas = 300 BTU Per SCF

	Million (1979 $)
Capital and Operating Costs	
Fixed capital investment[a]	28.44
Start-up expenses (10% of fixed capital investment)[b]	2.84
Total Fixed Capital Investment	31.28
Working Capital (10% of fixed capital investment)[b]	2.84
Total Capital Investment	34.12
Production Cost	
Raw material (Bagasse 0.33×10^6 tons at $11.00 per ton)[c]	3.63
Annualized operating and maintenance[d]	2.40
Annualized fixed capital charges[e]	1.56
Interest at 15% on total capital investment[f]	3.75
Total Cost	11.34
Total Cost Per 10^3 SCF	$ 1.43
Total Cost Per 10^6 BTU	$ 4.80

[a] Includes land site preparation, interest during construction, etc.

[b] Common practice in the chemical industry.

[c] Raw material bagasse (50% H_2O) estimated 0.55 cents per pound or $11.00 per ton bagasse at 1,000 tons per day and 330 days.

[d] BCL estimate, but adjusted based on plant capacity and inflation rate.

[e] Straight line, i.e., divided evenly over twenty years.

[f] Interest computed based on levelized payment arrangement.

TABLE C-3

COST ESTIMATES OF AMMONIA PRODUCTION FROM SYNTHESIS GAS

Annual (330 Day) Production = 90,750 Tons (Short) Ammonia

	Million (1979 $)
Capital and Operating Costs	
Fixed capital investments[a]	38.00
Start-up expenses (10% of fixed capital investment)[b]	3.80
Total Fixed Capital Investment	41.80
Working capital (10% of fixed capital investment)[b]	3.80
Total Capital Investment	45.60
Production Cost	
Raw material (Synthesis gas 7.92 X 10^9 SCF at $1.43 per 1,000 SCF)[c]	11.34
Annualized operating and maintenance[d]	4.20
Annualized fixed capital charges[e]	2.04
Interest at 15% on total capital investments[f]	4.85
Total Cost	22.43
Total Cost Per Ton Ammonia	$ 247.00

[a] Includes land site preparation, interest during construction, etc.

[b] Common practice in the chemical industry.

[c] Raw materials synthesis gas, total production from Purox process fed to ammonia plant.

[d] BCL estimate but adjusted based on plant capacity and inflation rate.

[e] Straight line and divided evenly over twenty years.

[f] Interest computed based on levelized payment arrangement.

2. Ethyl Alcohol Production from Sugar Cane Juice.

a. Material and Energy Balance

The overall material and energy balance of the process which extracts sugar cane juice from sugar cane and converts it into ethyl alcohol have been based on the assumptions given below.

(i) Heat content of sugar cane - 2,300 BTU per pound, based on wet weight, i.e., fresh sugar cane.[77]

(ii) Imbibition water, i.e., water added to improve sugar extraction is 25% of total sugar cane supply.[98]

(iii) Sugar lost in bagasse - 2% of bagasse by weight, i.e., 20 tons per day.[98]

(iv) Sugar content of sugar cane 12.5% by weight but 12.0% by weight of sugar cane juice because there is loss of sugar in bagasse as shown by (iii) above.

(v) Conversion of fermentable sugar in cane juice to alcohol - 90% and material balance estimated based on the following equation:

$$C_{12}H_{22}O_{11} \longrightarrow 2C_6H_{12}O_6 \longrightarrow 4C_2H_5OH + 4CO_2$$

(vi) Heat content of ethyl alcohol at 95% dry, i.e., 180 proof 12,500 BTU per pound, or 82,400 BTU per gallon. Specific gravity 0.789.

(vii) Steam production and supply: one pound bagasse at 5,500 BTU per pound (50% moisture) produces 2.2 pound steam. 6.3 pounds of steam required for distillation of one pound alcohol to 95% dryness, or 11.0 pound steam per liter alcohol.

Total steam requirement 1,500 tons per day, i.e., equivalent of 680 tons bagasse per day. Seven hundred tons steam left sent to milling department.

Figure C-2 illustrates the overall material and energy balance for the production of sugar cane juice, i.e., production of fermentable sugar which is then converted to ethyl alcohol.

b. Economics

Tables C-4 and C-5 show the cost of production of cane juice and cost of fermentation of the juice for ethyl alcohol production. The ethyl alcohol considered here is dried to 95% but it is recognized that the cost of drying the last 5% rises almost exponentially. A similar scaling method to that discussed in the case of the Purox process has been used and the chemical engineering plant cost index is used to adjust to 1979 cost. Explanatory footnotes have been included at the bottom of the tables.

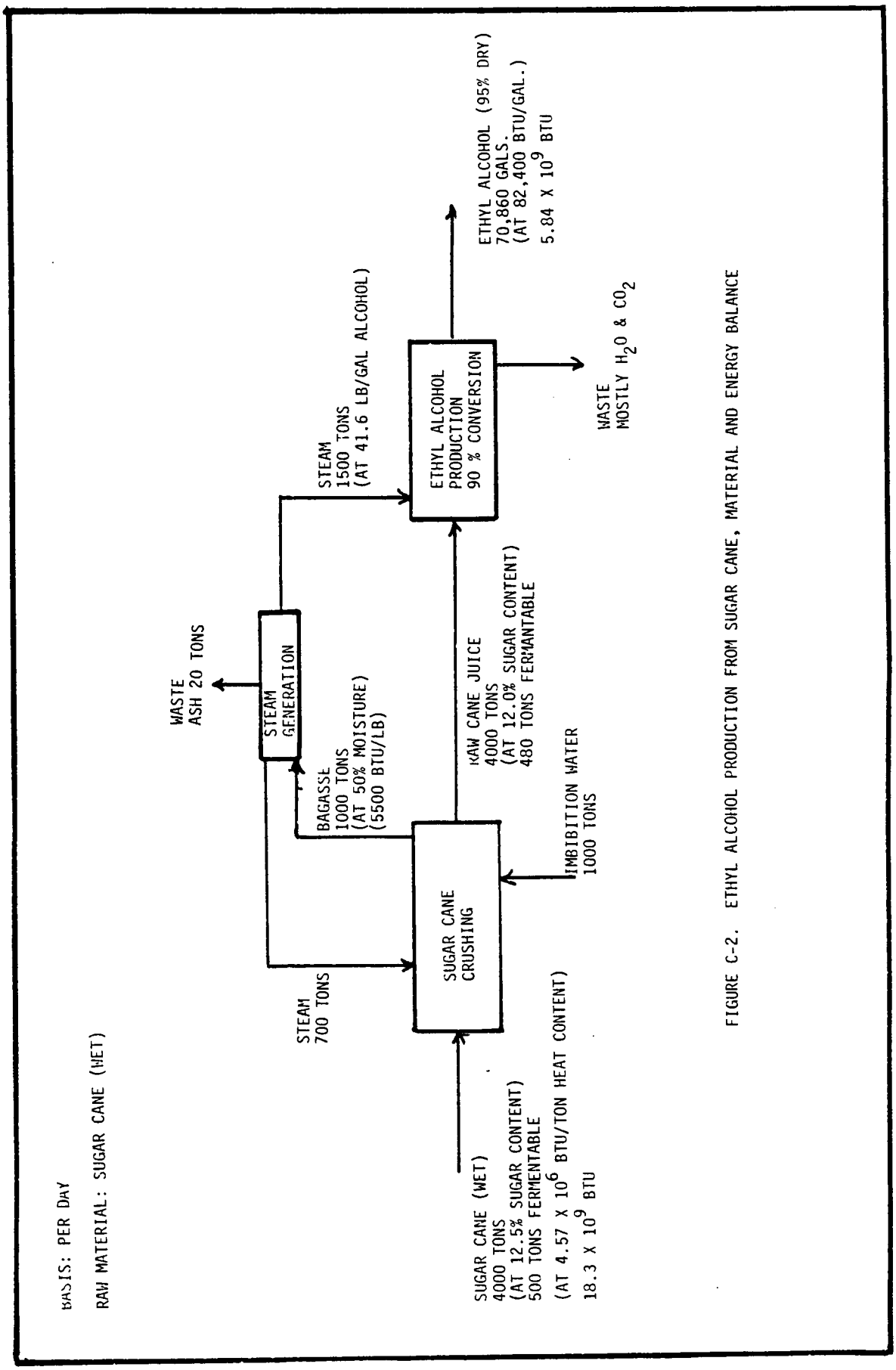


FIGURE C-2. ETHYL ALCOHOL PRODUCTION FROM SUGAR CANE, MATERIAL AND ENERGY BALANCE

TABLE C-4

COST ESTIMATES OF SUGAR CANE JUICE, I.E., FERMENTABLE SUGAR PRODUCTION

Annual (330 Days) Production = 1.32×10^6 Ton Sugar Cane Juice

Fermentable Sugar Production = 0.16×10^6 Tons

	Million (1979 $)
Capital and Operating Costs	
Fixed capital investment[a]	5.0
Start-up expenses (10% of fixed capital investment)[b]	0.5
Total Fixed Capital Investment	5.5
Working capital investment (10% of fixed capital investment)[b]	0.5
Total Capital Investment	6.0
Production Cost	
Raw material (sugar cane 1.32×10^6 tons at $17.25 ton)[c]	22.77
Annualized operating and maintenance[d]	1.50
Annualized fixed capital charges[e]	0.28
Interest at 15% on total capital investment[f]	0.65
Total Cost	25.20
Total Cost Per Ton Cane Juice (at 12.0% Fermentable Sugar)	$ 19.09
Total Cost of Fermentable Sugar Per Pound	$ 0.08

[a] Includes land site preparation, interest during construction, etc.

[b] Common practice in the chemical industry.

[c] Raw material (fresh cane) at $17.95 per ton instead of $20 per ton because it's the allocated cost to the fermentable sugar in the cane.

[d] BCL estimate, but adjusted based on plant capacity and inflation rate.

[e] Straight line, i.e., divided evenly over twenty years.

[f] Interest computed based on levelized payment arrangement.

TABLE C-5

COST ESTIMATES OF ETHYL ALCOHOL PRODUCTION FROM SUGAR CANE JUICE

Annual (330 Days) Production = 23.4 X 10^6 Gallons Ethyl Alcohol (95% Dry)

Heat Content of Ethyl Alcohol = 82,400 BTU Per Gallon

	Million (1979 $)
Capital and Operating Costs	
Fixed capital investment[a]	42.0
Start-up expenses (10% of fixed capital investment)[b]	4.2
Total Fixed Capital Investment	46.2
Working Capital (10% of fixed capital investment)[b]	4.2
Total Capital Investment	50.4
Production Cost	
Raw material (cane juice 1.32 X 10^6 ton at $19.09 per ton)[c]	25.20
Annualized operating and maintenance[d]	2.50
Annualized fixed capital charges[e]	2.31
Interest at 15% on total capital investment[f]	5.53
Total Cost	35.54
Total Cost Per Gallon Ethyl Alcohol[g]	$ 1.51
Total Cost Per 10^6 BTU	$18.32

[a] Includes land site preparation, interest during construction, etc.

[b] Common practice in the chemical industry.

[c] Total sugar cane juice production cost per year from Table C-4, 1.32 X 10^6 tons for $25.20 X 10^6.

[d] BCL estimate, but adjusted based on plant capacity and inflation rate.

[e] Straight line, i.e., divided evenly over twenty years.

[f] Interest computed based on levelized payment arrangement.

[g] Estimated using specific gravity of 0.789.

[h] Estimated using heat content of 82,400 BTU per gallon (U. S.).

3. Methyl Alcohol Production from Synthesis Gas Produced by Purox Process.

a. Material and Energy Balance

Figure C-3 summarizes the overall material and energy balance for the production of methyl alcohol from synthesis gas produced by the Purox process. The analysis is based on a daily supply of 24.0×10^6 SCF of synthesis gas with an H_2 to CO ratio of 0.6 produced originally from 1000 tons of bagasse. The basic assumptions are given below.

(i) Material balance has been calculated on a 50% yield of the stoichiometric reaction given below.

$$CO + 2H_2O \longrightarrow CH_3OH$$

(ii) Specific gravity of methanol is 0.8, and heat content is 60,000 BTU per gallon[99] or 9000 BTU per pound.

b. Economics

Table C-6 summarizes the cost of production of methanol using synthesis gas produced from the Purox process analyzed earlier. Calculations have been based on production of approximately 17.8×10^6 gallons per year of methanol. Other assumptions are explained as footnotes to the table.

BASIS: PER DAY

RAW MATERIAL: SYNTHESIS GAS FROM PUROX PROCESS

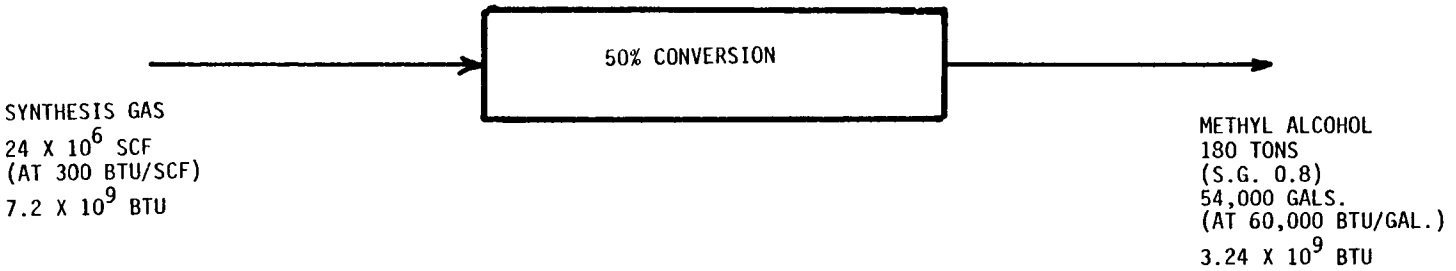


FIGURE C-3. METHANOL PRODUCTION USING SYNTHESIS GAS PRODUCED FROM BAGASSE,MATERIAL AND ENERGY BALANCE

TABLE C-6

COST ESTIMATES OF METHYL ALCOHOL (METHANOL) PRODUCTION USING SYNTHESIS GAS FROM PUROX PROCESS

Annual (330 Days) Production = 17.8 X 10^6 Gallons

Heat Content of Methanol = 60,000 BTU Per Gallon

	Million (1979 $)
Capital and Operating Costs	
Fixed capital investment[a]	18.79
Start-up expenses (10% of fixed capital investment)[b]	1.88
Total Fixed Capital Investment	20.67
Working capital (10% of fixed capital investment)[b]	1.88
Total Capital Investment	22.55
Production Cost	
Raw material (Synthesis gas 7.92 X 10^9 SCF at $1.43 per 1000 SCF)[c]	11.34
Annualized operating and maintenance[d]	2.00
Annualized fixed capital charges[e]	1.03
Interest at 15% on total capital investment[f]	2.48
Total Cost	16.85
Total Cost of Methyl Alcohol Per Gallon	$ 0.95
Total Cost of Methyl Alcohol X 10^6 BTU	$15.98

[a] Includes land site preparation, interest during construction, etc.

[b] Common practice in the chemical industry.

[c] Synthesis gas supply from Purox process using 1,000 tons bagasse as raw material and producing 7.92 X 10^6 SCF synthesis gas per year.

[d] BCL estimate, but adjusted based on plant capacity and inflation rate.

[e] Straight line, i.e., divided evenly over twenty years.

[f] Interest computed based on levelized payment arrangement.

4. Ethylene Production from Ethyl Alcohol Produced by Fermentation of Sugar Cane Juice.

a. Material and Energy Balance

Figure C-4 summarizes the overall material and energy balance of the process. The analysis is based on a daily supply of 232 tons (or 70,860 gallons) of ethyl alcohol produced from 4000 tons sugar cane per day. Basic assumptions are given below.

(i) Yield of 90% on a weight basis (highest theoretically possible) using stoichiometric equation:

$$C_2H_5OH \longrightarrow C_2H_4 + H_2O$$

(ii) Various heat contents are included in the figure.

b. Economics

Table C-7 summarizes the estimated cost of production of ethylene from ethyl alcohol. Explanatory footnotes are included in the table.

BASIS: PER DAY

RAW MATERIAL: ETHYL ALCOHOL

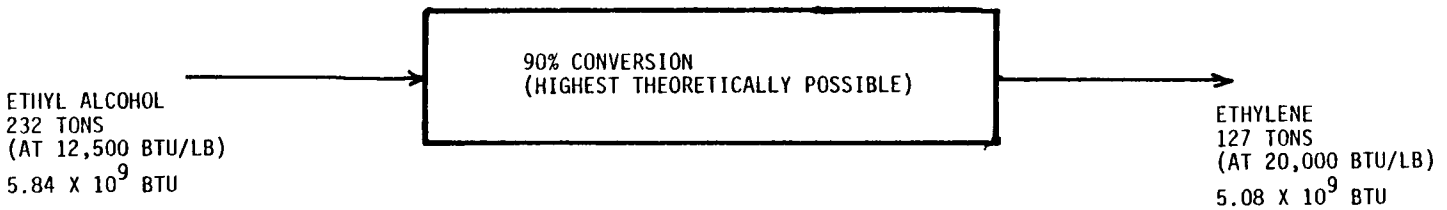


FIGURE C-4. ETHYLENE PRODUCTION FROM ETHYL ALCOHOL, MATERIAL AND ENERGY BALANCE

TABLE C-7

COST ESTIMATES OF ETHYLENE PRODUCTION FROM ETHYL ALCOHOL PRODUCED BY FERMENTATION OF SUGAR CANE JUICE

Annual (330 Days) Production = 84 X 10^6 Pound

	Million (1979 $)
Capital and Operating Costs	
Fixed capital investment[a]	30.0
Start-up expenses (10% of fixed capital investment)[b]	3.0
Total Fixed Capital Investment	33.0
Working capital (10% of fixed capital investment)[b]	3.0
Total Capital Investment	36.0
Production Cost	
Raw material (Ethyl alcohol 23.40 X 10^6 gal. at $1.51 per gal)[c]	35.54
Annualized operating and maintenance[d]	2.50
Annualized fixed capital charges[e]	1.65
Interest at 15% on total capital investment[f]	3.95
Total Cost	43.64
Total Cost of Ethylene Per Pound	$0.51

[a] Includes land site preparation, interest during construction, etc.

[b] Common practice in the chemical industry.

[c] Ethyl alcohol produced by fermentation of raw cane juice at 23.4 X 10^6 gallons per year is fed to the ethylene plant.

[d] BCL estimate, but adjusted based on plant capacity and inflation rate.

[e] Straight line, i.e., divided evenly over twenty years.

[f] Interest computed based on levelized payment arrangement.

5. Electricity Generation from Bagasse.

a. Material and Energy Balance

Figure C-5 summarizes the overall material and energy balance of the unit. The calculations are based on a supply of 1000 tons per day of bagasse at 50% moisture and a heat content of 5500 BTU per pound. Other basic assumptions are listed below.

(i) Overall thermal efficiency of the electricity generation has been assumed to be 30%.

(ii) Conversion factor of 1 KWH = 3410 BTU at 100% efficiency (i.e., approximately 10,000 BTU at 30%) has been used.

(iii) 20 tons ash produced per day or 6600 tons per year.

b. Economics

Table C-8 shows the cost of generating electricity from bagasse. Note that the unit cost of electricity would increase if the tops and leaves from the sugar cane plant are collected and used to produce more fiber, i.e., more bagasse and electricity, due to additional expenses required for collection and transportation. Assumptions are included as footnotes to the table.

BASIS: PER DAY

RAW MATERIAL: BAGASSE

OVERALL THERMAL EFFICIENCY: 30%

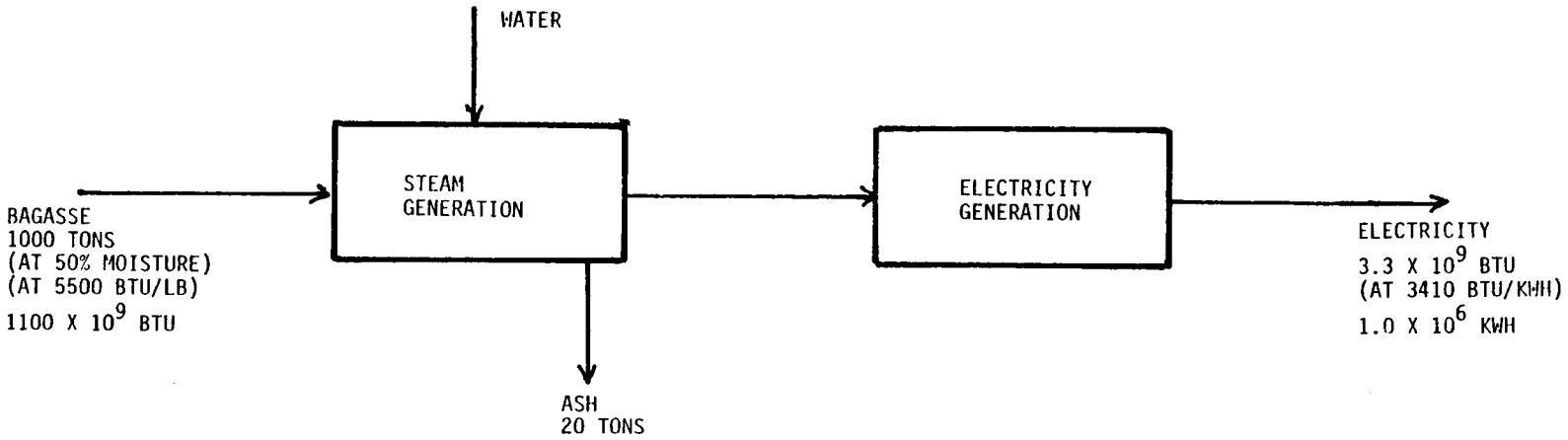


FIGURE C-5. ELECTRICITY GENERATION FROM BAGASSE, MATERIAL AND ENERGY BALANCE

TABLE C-8

COST ESTIMATES OF ELECTRICITY GENERATION FROM BAGASSE

Annual (330 Days) Production = 330 X 10^6 KWH.

	Million (1979 $)
Capital and Operating Costs	
Fixed capital investment[a]	22.96
Start-up expenses (10% of fixed capital investment)[b]	2.30
Total Fixed Capital Investment	25.26
Working capital (10% of fixed capital investment)[b]	2.30
Total Capital Investment	27.56
Production Cost - Ethyl Alcohol	
Raw material (Bagasse at 50% moisture 0.33 X 10^6 ton at $11.0 per ton)[c]	3.63
Annualized operating and maintenance[d]	1.50
Annualized fixed capital charges[e]	1.26
Interest at 15% on total capital investment[f]	3.02
Total Cost	9.41
Total Cost Per KWH	$ 0.03

[a]Includes land site preparation, interest during construction, etc.

[b]Common practice in the chemical industry.

[c]The estimated cost of bagasse (50% moisture) of 0.55 cents per pound ($11.0 per ton) has been used to estimate total cost of raw material.

[d]BCL estimate, but adjusted based on plant capacity and inflation rate.

[e]Straight line, i.e., divided evenly over twenty years.

[f]Interest computed based on levelized payment arrangement.

C. Material and Energy Balance and Economics of Corn Utilization for Energy and Chemical Feedstock Production

This section looks into the energy and material balance and the cost of production associated with the utilization of corn for the production of ammonia, ethyl alcohol, methyl alcohol, ethylene and electricity. The assumptions and factors are listed below:

(i) Corn = 33% grain + 67% waste (leaves, husk, stalk, etc.).

(ii) Composition of grain = 75% by weight starch which can be hydrolyzed and then fermented, and 25% of water and other materials.

(iii) Composition of waste = 40% fiber + 60% water.

(iv) Yield = 3 tons grain per acre and 13 tons fresh waste (or 5 tons dry waste).[99]

(v) Cost of production $120 per ton grain and waste (fresh) at $19 per ton is higher than bagasse because corn waste is more bulky. Note that by using cost allocations similar to those for bagasse the cost of waste would have been ~ $14 per ton compared to $11 per ton.

(vi) Same use of corn waste as for bagasse considered here. Heat content of waste at 60% moisture 5,000 BTU per pound.

(vii) All grain used to produce alcohol.

(viii) Basis of 2,000 tons corn per day which means: 660 tons grain at 75% starch - 495 tons fermentable. 1340 tons waste at 60% moisture - 536 tons fiber. Thus at this basis of 2,000 tons per day, the rate of supply of raw materials in terms of fermentable and fiber is very close to those in the previous appendix. This makes the computation easier.

(ix) Ratio of pound of various products per pound fiber or fermentable assume to be same as in the case of sugar cane.

Using the above factors and assumptions similar computations to those of the previous sections give the results shown diagramatically on Figure C-6. Note that the cost of production of the fuels and chemical feedstocks are comparable to the products using sugar cane as raw material. However, it must be recognized that a much larger area is required, as compared to sugar cane, for the same weight or volume of product. For example, to produce 500 tons fermentable from sugar cane roughly 123 acres of land is required, whereas, to produce the same amount fermentable from corn grain 220 acres are required. Table C-9 summarizes the cost of production of energy and chemical feedstock from corn.

BASIS: PER DAY
RAW MATERIAL: CORN

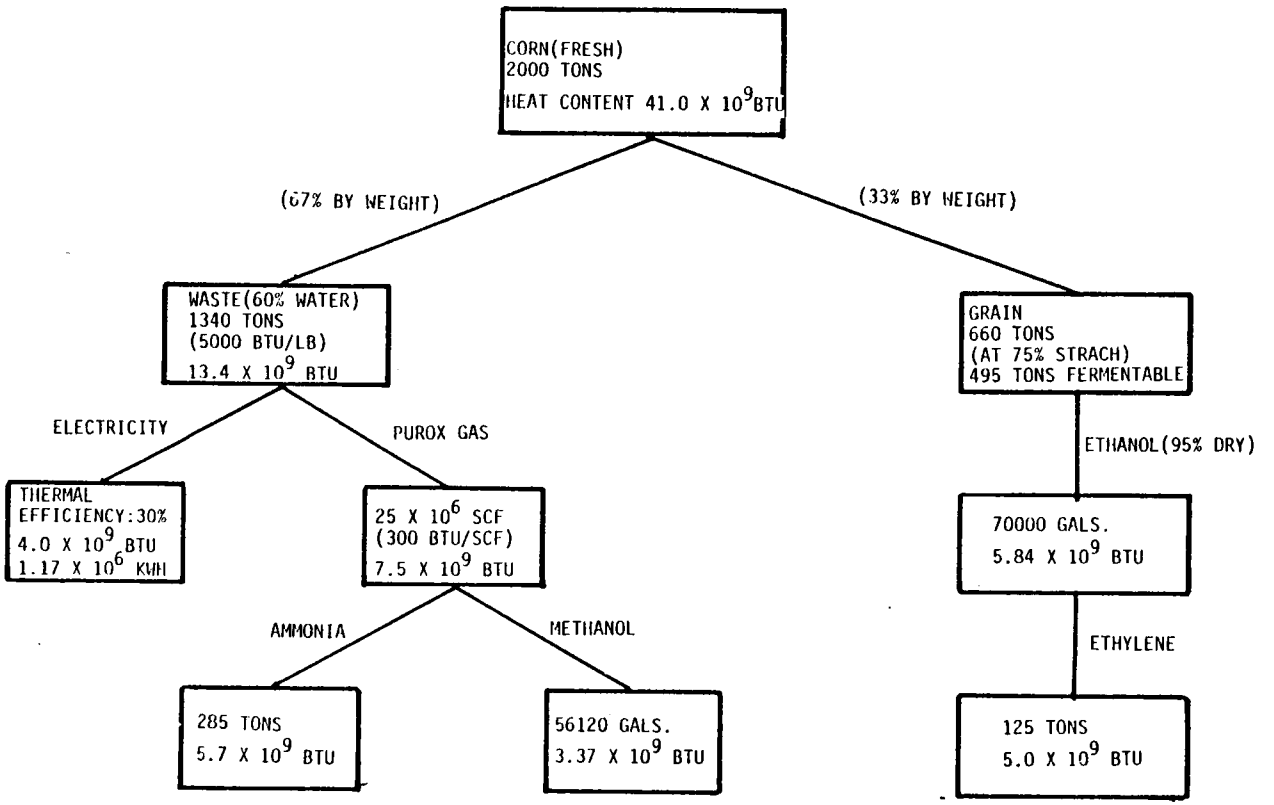


FIGURE C-6. MATERIAL AND ENERGY BALANCE, CORN AND ITS ALTERNATIVE PRODUCTS

TABLE C-9

COST OF PRODUCTION OF ENERGY AND CHEMICAL FEEDSTOCK FROM CORN

Cost of Corn (fresh) - $120 per ton (i.e., 8 cents per pound fermentable).

Cost of Waste (at 60% moisture) - $19 per ton (i.e., $1.90 per 10^6 BTU).

Number of Days Per Year - 330

Plant Capacities - same as those used for sugar cane.

	Annual		
Product	Total Cost of Production 10^6 $ (1979)	Total Production	Cost Per Unit
Ammonia	27.2	94,050 tons	$289/ton
Ethyl Alcohol	36.5	23.1 X 10^6 gals	$1.58/gal
Methanol	21.5	18.5 X 10^6 gals	$1.16/gal
Ethylene	44.6	41,250 tons	$0.54/pound
Electricity	14.2	386 X 10^6 KWH	$0.04/KWH

APPENDIX D

APPENDIX D

CONVERSION FACTORS AND DEFINITIONS

A. Heat Content of

Coal	= 12,000	BTU/Pound
	= 7,000	Cal/Gram
Crude Oil	=130,000	BTU/Gallon
	= 5.46×10^6	BTU/Barrel
Gasoline	=123,800	BTU/Gallon
Natural Gas	= 1000	BTU/SCF
Ethyl Alcohol (Ethanol)	= 82,400	BTU/Gallon
Methyl Alcohol (Methanol)	= 60,000	BTU/Gallon
Bagasse (50% wet)	= 5,500	BTU/Pound
U^{235}	= 3.5×10^{10}	BTU/lb (fissionable only)*
	= 2.49×10^8	BTU/lb (uranium ore)
D-D Fusion	= 7	Mev/Deuterium**
	= 0.665×10^{-16}	BTU/Deuterium
	= 11.38×10^9	BTU/Meter^3 (sea water)

B. Conversion Factors

1. Energy

1 Calorie	≡ 3.968×10^{-3}	BTU
1 KCalorie	≡ 3.968	BTU
1 Calorie	≡ 4.19×10^7	ergs
1 KWH	≡ 3,410	BTU

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*For further information see Table V-3, page 108.

**For further information see Table V-2, page 105.

1 GW $\equiv 10^9$ Watts

1 quad (q) $\equiv 10^{15}$ BTU

1 Quad (Q) $\equiv 10^{18}$ BTU

1 erg $\equiv 10^{-7}$ Joules

$\equiv 9.485 \times 10^{-11}$ BTU

1 Joule $\equiv$ 0.009485 BTU

$\equiv$ 0.239 Calorie

2. Volume

1 Cubic Foot = 28.32 litres

= 7.48 U. S. Gallons

1 U. S. Gallon = 3.78 litres

1 IMP Gallon = 4.55 litres

3. Areas

1 Acre = 43,560 $feet^2$

= 4,047 $meter^2$

1 Hectare = 10,000 $meter^2$

= 2.47 acres

1 Km^2 = 247 acres

= 100 hectares

1 $Mils^2$ = 640 acres

= 259 hectares

= 2.59 Km^2

C. World Dimensions

Total = 196,950,000 $miles^2$

Land = 57,510,000 $miles^2$

Adjusted = 50,560,581 $miles^2$

D. Special Notes of Units Used in This Dissertation

Unless otherwise stated,

(i) All areas are in acres.

(ii) All distances are in miles.

(iii) All gallons are U. S. gallons.

(iv) All currencies in constant 1970 U. S. dollars

(v) Heat energy in BTU.

VITA

Jawaharlall Baguant was born in Camp Ithier, Flacq, Mauritius, on October 19, 1946, the son of Moteelall and Bhawanee Baguant. He received his elementary education at the Primary Government School and his high school education at St. Andrew's School. He joined the School of Agriculture, University of Mauritius in June 1968, and received an Honors Diploma in Sugar Technology in May 1971.

He joined the Chemical Engineering Department of Louisiana State University, Baton Rouge, Louisiana, in the Fall of 1971, and received a Bachelor of Science degree in Chemical Engineering in the Spring of 1973, and a Master of Science degree in Chemical Engineering in the Spring of 1974.

In October of 1974 he was employed by The University of Mauritius as lecturer in Sugar Technology. In September of 1977 he was granted study leave and he joined the Chemical Engineering Department of The University of Tennessee, Knoxville. He will receive the degree of Doctor of Philosophy with a major in Chemical Engineering in June 1980.

He is a member of Phi Lamda Epsilon Honorary Chemical Society, Tau Beta Pi, and Phi Kappa Phi.