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NOVEMBER 1977

FORECAST OF FUTURE AVIATION FUELS
PART I: SCENARIOS

PRINCIPAL INVESTIGATORS
J.M. ENGLISH
C.Y. LIU

UCLA • SCHOOL OF ENGINEERING AND APPLIED SCIENCE

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J.M. English A.K.K. Yin M. Gyamfi
C.Y. Liu G.A. Pan M.R. Arabzadah
J.L. Smith M.B. Ayati

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13. ABSTRACT

A preliminary set of scenarios is described for depicting the air transport industry as it grows and changes, up to the year 2025. This provides the background for predicting the needs for future aviation fuels to meet the requirements of the industry as new basic sources, such as oil shale and coal, are utilized to supplement petroleum.

Five scenarios are written to encompass a range of futures from a serious resource-constrained economy to a continuous and optimistic economic growth. A unique feature is the choice of one intermediate range scenario which is based on a serious interruption of economic growth occasioned by an energy shortfall. This is presumed to occur due to lags in starting a synfuels program.

The interim scenarios are expected to undergo significant revision before they are published in final form.

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M. R. ARABZADAH

PHASE 1 PROGRESS REPORT
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PRINCIPAL INVESTIGATORS

J. M. ENGLISH
C. Y. LIU

School of Engineering and Applied Science
Engineering Systems Department
University of California
Los Angeles , California

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1. Overview

This report represents the results of the first year of a three-year study to develop a set of scenarios on the air transportation industry. The purpose of the study is to establish a framework for evaluating needs as well as determining the direction for research and development of NASA power plant programs. It is generally recognized that aviation fuels of the future will come from different sources than at present. Even if petroleum continues to be the base of future fuels, it will be supplied from new oil fields, and crude oils will have a markedly changed composition from that of present crudes. In addition, however, there is a significant probability that demands will have to be met by supplemental supplies from synthetic fuels derived from coal and shale oil. Whatever the changes, they are likely to force new engine development as well as modifications in fuel specifications.

A major difficulty in planning the research and development program for anticipation of new fuels arises from the essentially long-term nature of the problem. There is a high degree of uncertainty about the characteristics of future energy supplies. While new trends for energy resource development will be established within the next fifteen years, engine and aircraft development programs must be undertaken now in anticipation of whatever future unfolds.

The scenario approach developed in this report is best suited for providing a decision framework for planning such R & D programs. However, scenarios can be developed only by basing them on a very broad experience and a background of generalized knowledge. The utilization of graduate students on this program requires sufficient time for the student team to become familiar with the complexity and extent of the problem. For this reason the scenarios presented below should still be considered preliminary and only partially completed.

A major emphasis was placed on the two futures that were considered to encompass the most likely outcome. Further refinement of these as well as completion of the others in greater detail will be accomplished during the second phase. Furthermore the entire spectrum of the picture of aviation fuels must be elaborated to encompass a more global perspective, including military needs.

1.1 Scope of the Study

Types of fuels and to what extent they will be used in the future of aviation depends on the characteristics of airplanes and the engines that power them, transportation demands, and the economics of supply. Air transport is only one component of transportation. Thus, availability, price and technical characteristics of aviation fuel must fit into the overall energy picture of the future. Finally, transportation demand and other energy demands of the future interact with many socio-economic variables which will have a definite impact on the behaviour of the air transportation system.

1.2 Objectives

The overall objectives of this research are:

(1) To predict the characteristics and availability of aviation fuels in the near term (1977-1985), intermediate term (1985-200), and long term (2000-2025).

(2) To evaluate the economic effects current and projected trends in aviation fuel characterisitcs and availability will have on commercial and military aviation.

The specific objectives of Phase I (which covers a fourteen-month period, August 1, 1976 - September 20, 1977) are:

(1) To develop a data base and descriptive scenarios for air traffic demand, engine technology and fuel supply.

(2) To initiate development of predictive models for air traffic demand, aviation fuel demand, transportation energy demand,

fuel supply, and resulting energy shortfall.

1.3 Background

The changing supply and demand characteristics of aviation fuels over the next fifty years will have a significant influence on the technologies of aircraft design, engine requirements, and airline operating procedures. Furthermore, the growth of the air transportation industry will be significantly influenced by the price of energy relative to other goods and services as well as by strategies adopted by the air transport industry to meet new challenges facing it.

The shift in the source of hydrocarbon fuels, ranging from changing petroleum supplies to synthesis from coal, tar sands and oil shales, may be expected to have a long-term influence on aviation fuel characteristics required for economic airline performance. This influence will carry over to the design of both engines and aircraft needed to replace existing fleets. Whatever effects changes in fuel specification may have on commercial aviation, they will also impact military aviation.

The NASA Fuels Technology Program for evaluation of potential properties of aviation fuels, and the corresponding requirements for changed aircraft design characteristics, may be expected to demonstrate what the range of technically feasible solutions might be. An important objective of the study is the assessment of the economic effects on the airline industry changes in fuel specifications that might occur.

The trends in technological development initiated today will be expected to persist for a long time. These trends will, in turn, shape the future of air transport operating characteristics. Therefore, it is essential to make economic projections of possible or probable outcomes of various policies. Such projections will provide guide-lines for future research and development of aviation fuels, engines, and aircraft.

1.3.1 Problems of Prediction

The difficulty in forecasting future aviation demands was increased immeasurably by the fourfold increase in petroleum prices in 1974. This event occassioned a major change in relative prices and invalidated normal extrapolation of past trends as a means for predicting growing demand. In effect, society may have to undergo a major shift in its consumption values. For example, there may be reduced demand for travel as more reliance is placed on electronic communication; speed may become less important. On the other hand, there are conceivable economic scenarios that would result in greatly expanded air transportation demand. Because of such great uncertainties, any prediction methodology cannot depend solely on extrapolation of air transportation growth trends. Constraining influences on transportation in general and air transport in particular, must be considered carefully. Many significant studies involving scenario developments have been made for overall energy futures. These contribute to the data base on which corresponding aviation scenarios may be developed. In this connection, the study undertaken by the Hudson Institute (The Next 200 Years: A Scenario for America and the World) was utilized as important background. Other studies such as that sponsored by DOT and NASA-Ames on intercity transportation and the Workshop for Alternative Energy Strategies (WAES-MIT) have also been utilized extensively in writing the scenarios for this research.

1.4 Methodology and Approach

The general approach was to blend scenario descriptions of possible economic and energy-states for the world with quantitative models whereby numerical implications of the scenarios may be evaluated. Because development of scenarios and models is essentially iterative and concurrent, efforts on both tend to augment and support each other, the acquisition of an adequate data base is central to both scenario and model development.

1.4.1 The Scenario Approach

A scenario is a hypothesized situation that represents a plausible description of what could occur within predicted economic, political and natural constraints. Because the scenario is perceived as occurring beyond a horizon that necessarily limits visibility of the future, it cannot be construed as a valid prediction. A scenario, therefore, gives rise to this question: if the future unfolded in some supposed way, what then might be the consequences? In the absence of clairvoyance, this is the only reasonable approach that can be made.

The underpinning for predicted outcomes is based on a present concept of the most desirable developments of the future. In short, what are societal aspirations? Delineation of reasonable aspirations requires the forecast of kinds of futures within which such aspirations are attainable. In a sense, aspirations become self-fulfilling predictions. Furthermore, with the scenario approach, long-run projections may be made with some degree of confidence. These concepts of plausible futures are reinforced if expectations are constrained by certain postulations of what will not or could not happen. For example, it is customary to postulate that world development will not be interrupted by cataclysmic occurrences such as world-wide nuclear war or plague, that could annihilate a major portion of the earth's population.

The first consideration in picturing a scenario for the future is that of establishing a time frame of concern. This time frame must be limited by realization that the fundamental purpose of the exercise is to provide insight for making decisions on what R & D activities need to be initiated in the present. However, it is desirable to go well beyond the time interval of specific interest in order to see what sort of influences may begin to emerge in order for long-range goals to be realizable. On the other hand, the actual time at which a goal for reaching some desirable future environment is achieved may not be important. Just as the aspiration itself must remain fuzzy, so the time over which the scenario unfolds to a finale must be indeterminate. The question of concern is more one of eventual achievability of a postulated state rather than the specific date at which that state is attained. Thus, while the year 2025 may be taken as an arbitrary target date, a possibility that the postulated environment may not be reached until 2035 or 2045 should not be a matter of concern.

Figure 1 illustrates this point.

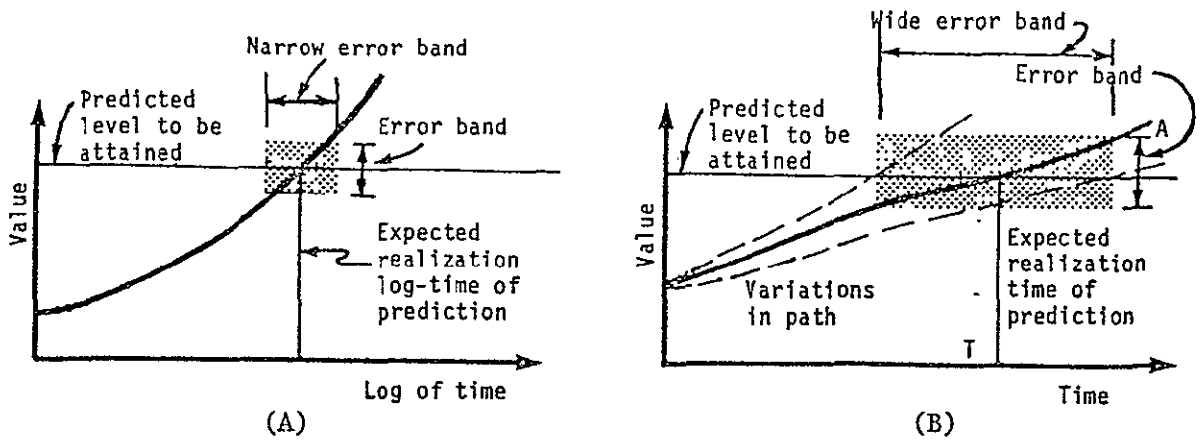

Figure 1.1 - Prediction Band

If curve A represents the path for reaching the goal in time, T, a slight variation from the predicted path may shift the time T over a very wide range. However, the perception of future time and hence its meaningfulness may better be represented by the logarithm of time rather than by a linear real time (English, 1976). The error band in level of achievement then tends to be in the same order as the error band for the log of time for reaching the goal.

1.4.2 Aviation Fuel Scenario

A scenario for aviation fuel development needs to be written within a consistent framework of interrelated scenarios for the world economy as a whole. An aviation fuel scenario is embedded in plausible scenarios of world energy supplies and demands which, in turn, are embedded in the world economic outlook.

Other scenarios which are embedded within socio-economic scenarios are subdivided into different modes of transportation in order to formulate air transportation scenarios. Likewise, energy is subdivided into its component demands in order to depict the case for aviation fuels. Socio-economic indicators which influence the levels of air traffic are examined in order to write air traffic demand scenarios. These indicators include population projections, economic activity as measured by GNP, and propensities for travel for business and pleasure. They are considered and reviewed in detail.

Fuel economy depends on engine and aircraft efficiency. Engines, designed by incorporating better combustors and compressors, improved turbine inlet temperatures and pressure ratios, may increase fuel economy. Even greater gains may be realized from utilization of advanced materials and structural comcepts along with such new designs as the super critical airfoil. Apart from greater efficiency, economies may be realized by means of changed operating procedures that affect speed and range. In this case, however, the economics of air travel will change. Thus, development of technology scenarios, as well as trade-offs between operating characteristics and environmental degradation are discussed.

Future aviation fuel may come from petroleum and/or coal syncrudes, shale oil, and tar sands. In addition to constraints of process technology, costs of processing substitute primary sources may be a significant factor for determining patterns of supply. Furthermore, external factors may affect aviation fuel supply. For example, if a diesel engine is developed for the automobile and causes a major shift away from the present internal combustion engine, the changed demand for heavier fuels for ground transport would have a major impact on aviation. Thus, fuel supply scenarios are developed with consideration for such technological, economic and external factors.

The relationships between air traffic demand, engine and aircraft technology and fuel supply are emphasized in the scenarios. These relationships are decribed in context of five possible levels of economic activity corresponding with five socio-economic scenarios.

1.5 Five Scenarios

A number of scenarios written by various investigators for depicting future states of the world and U.S. economies were examined. These included the Workshop on Alternative Energy Strategies (WAES-MIT, 1977), The Climatic Impact Assessment Program Study (CIAP - DOT, 1974), the Hudson Institute (1976), and the Ford Foundation studies (Energy Policy Project, 1974) as well as others. These scenarios incorporate a common approach of postulating plausible futures ranging from some level of pessimism for the undesirable outcome to the other extreme of optimism. The range is then divided into segments to provide as many intermediate outcomes as deemed practicable for describing the future in the desired level of detail. A common feature of all the studies examined is the assumption of constant growth functions for reaching the outcomes. As will be discussed below, scenario number three of the UCLA set of five, deviated from this constant growth pattern, in that an interruption of growth was postulated.

The WAES scenarios were written specifically for depicting the world energy situation and represented collective views of an impressive panel of experts. The WAES scenarios come closest to the UCLA interrupted-growth scenario to be discussed in Section 3.3. The WAES panel examined demands and supplied separately but drew no conclusion as to how these would be reconciled. By contrast, the UCLA scenarios describe the consequence of an energy shortfall.

The Hudson Institute Study was concerned with the problem of how resource constraints, including energy, might determine the states of world economies. It drew heavily on the work of many others and carefully reviewed the predictions of both pessimistic and optimistic prognosticators. It seemed to represent the most plausible range of estimations and so was chosen as the model on which the scenarios for the UCLA fuels study could be based. The four scenarios developed by the Hudson Institute represented a fairly reasonable range of possibilities for the long-term horizon, 2025.

The CIAP study focused on the most optimistic economic outcome conceivable for the specific purpose of finding a worst-case condition for aviation to impact the earth's atmospheric environment. This "worst case" condition was regarded as being highly unlikely. However, the question of a long-run prediction of air transportation on a global scale was addressed and, thereby, an upper bound on aviation fuel demand was established. The CIAP study was made before the 1973 energy crisis was precipitated by the fourfold increase in petroleum prices. Even at that time it was considered to be a highly unlikely future.

A fifth UCLA scenario, in addition to those based on the four used by the Hudson Institute, is called the "Interrupted-Growth Scenario." In this, an optimistic future is postulated for the long-run of 2025 when the growth rate will correspond with that of the Hudson Institute's reasonably optimistic scenario.. However, an energy shortage will develop and constrain the economy to a zero or negative growth for a period of prolonged depression before growth is again resumed. Such an eventuality may be most meaningful for planning decisions for the air transport industry. This energy shortage provides a focus on action necessary for avoiding or minimizing the effects of energy shortfalls while, at the same time, highlighting the serious consequences of inaction. This scenario might be viewed as the most likely one. Also, a modification is made for the second scenario of the Hudson Institute's "Guarded Pessimistic Scenario" by emphasizing an assumption of a strong government role in allocation and rationing of scarce resources. Although the fundamentals of the Hudson's scenarios 1, 3, & 4 were adapted for our scenarios 1, 4 & 5 respectively, the details are modified to correspond with the emphasis on aviation fuel.

The probability distribution over the five scenarios is not linear and both extreme scenarios, upper and lower, must be considered as highly improbable. The reader may assign his own probabilities to each scenario. Such probabilities, of course, would not apply to the precise outcomes as depicted but rather to the range roughly represented by the mid-points between them. Thus, for example, the actual outcome may be expected to fall between a modest steady growth situation and the intermediate depression situation, possibly characterized by a period of slowed growth.

For purpose of ready identification, the five general scenarios have been called:

1. Resource Limited Scenario
2. Socially Constrained Scenario
3. Interrupted Growth Scenario
4. Uninterrupted Growth Scenario
5. Optimistic Scenario.

2. HISTORICAL PERSPECTIVE AND KEY FACTORS COMMON TO FIVE SCENARIOS

History provides a perspective from which reasonable predictions may be made. "One way of evaluating future forecasts is to look at historical precedents to gain at least some perspective - no matter how flawed the past might be as a mirror of the future." (O'Toole, 1976). The first thing revealed by historical data is a set of key factors associated with the growth or decline of the economy, in general and with air transportation in particular. The list of factors that can affect the economy, and more specifically air transportation, can be very long. The problem is to find the most important factors and to identify the main relationships. For example, innovations in production methods tend to trigger growth, but only if there is capital available and entrepreneurs are ready to exploit the innovations and there is a willingness on the part of society to accept change.

In this chapter, the historical growth patterns of air transportation are reviewed and sectors of the economy that greatly influence the behavior of the air transportation system are examined. From this historical review, a set of key factors associated with each sector of the economy, relevant to air transport are identified and discussed.

2.1 Socio-Economics

Socio-economic indicators which influence the levels of air traffic activities must be examined in order to depict air transportation scenarios. These indicators include population projections, economic activity as measured by GNP, society's spending pattern, pollution levels, and others.

2.1.1 Population

Population, its growth, composition and location determines the future market size for air transportation. One of the major concerns today is population growth which may doom the world to starvation. These fears are not new. Malthus (1798) and his followers felt that population increase was the chief cause of mass poverty. He believed that man was able to increase his numbers faster than he could his means of subsistence. At the other extreme, Colin Clark (1953) believes that population growth is generally beneficial in that it stimulates economic progress by shaking men out of established ways and thereby promoting political freedom. Also, he contends that the world has the capacity to support much larger populations than exist at the present time.

At the time of the Christian era, the world's population was around 200 to 300 million. By 1750, this had reached 728 million. Before 1750, the population had increased very slowly, at a rate less than 0.50 percent per year. Since then, the rate of increase has become much larger until today it is about 2.0 percent as indicated in Table 2.1.

Most forecasts are for continued high growth for some time, even though most developed regions already are experiencing a decline in gross reproduction rates. Figure 2.1 shows projections for the population growth in less developed regions, developed regions, and for the world, (Hudson Institute, 1974). These curves show that even in the worst case, The Malthusian scenario, the growth will not exceed 2.2% for the world, 1.2% for the developed regions, and 2.7% for less developed countries (LDC). On the other hand, in the best case, Optimistic Growth Scenario, the growth is given by the lower-bound curves of the same figure.

TABLE 2.1

WORLD HISTORICAL POPULATION GROWTH BY REGIONS

	Annual Increase (millions)			Annual Rate of Growth (percentage)		
Period	World total	More developed regions	Less developed regions	World total	More developed regions	Less developed regions
1750-1800	3.7	0.9	2.8	0.4	0.4	0.4
1800-1850	5.7	2.0	3.7	0.5	0.7	0.5
1850-1900	7.8	4.5	3.2	0.5	1.0	0.3
1900-1950	17.1	5.7	11.4	0.8	0.8	0.9
1950-2000	78.0	10.2	67.8	1.9	0.9	2.2
1950-1960	48.9	11.9	37.0	1.8	1.3	2.0
1960-1970	62.6	10.8	51.8	1.9	1.0	2.3
1970-1980	78.0	9.9	68.1	2.0	0.9	2.4
1980-1990 (EST)	94.5	9.9	84.6	1.9	0.8	2.3
1990-2000 (EST)	106.1	8.6	97.5	1.8	0.6	2.2

SOURCE: U.N. Department of Economics and Social Affair Population Studies, Number 57, 1975

Projections of other population-related factors such as percent of urban and rural residence are shown in Tables 2.2 and 2.3 (United Nations, 1974).

For various reasons, urban populations have been growing. This trend is expected to continue into the next century. However, the rate of urbanization may diminish and major megalopolises may show signs of reversing this trend even while more large cities are evolving.

The causes of increasing urbanization and concentration of population in large cities are, to a great extent, inherent in the processes of modern economic development. Fundamental are:

- relative contraction of employment opportunities in agriculture, coupled with expansion in other sectors, resulting from more rapid growth of demand for non-agricultural products;
- efficiencies in production and distribution of products in non-agricultural sector (economies of scale, transportation, complementaries, industries, etc.)

It is worth emphasizing, however, that non-economic factors also influence the currents of migration.*

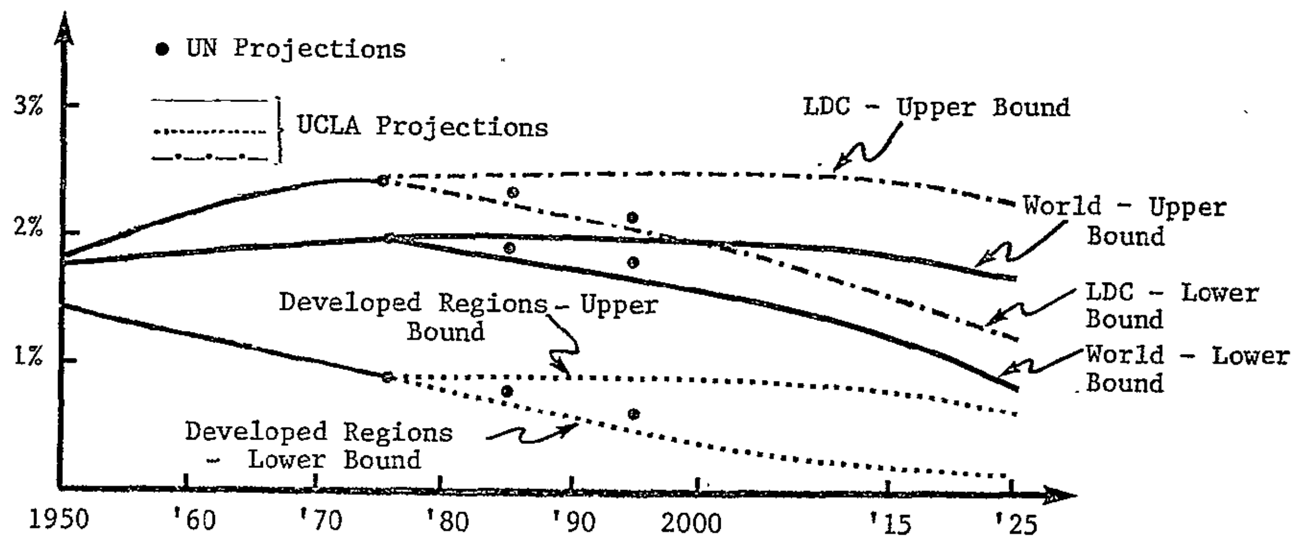

Figure 2.1: Growth of Population (1950-1970) and Projection to 2025

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* Kuznets concisely sums up the factors of modern economic growth which facilitate the movement out of agriculture; loc. cit., par. 12; Relevant literature is surveyed in The Determinants and Consequences of Population Trends, Chapt. VI, paras. 188-192.

TABLE 2.2 CHANGES IN URBAN AND RURAL POPULATIONS IN MAJOR AREAS OF THE WORLD BY DECADES, 1950-1970, AND PROJECTIONS TO 2000

(Percentage)

Major Areas	1950-1960	1960-1970	1970-1980	1980-1990	1990-2000
	Urban Population				
World Total	+41	+35	+36	+35	+32
More Developed Regions	+29	+23	+20	+18	+14
Less Developed Regions	+62	+50	+54	+50	+45
Europe	+18	+18	+15	+13	+12
USSR	+48	+31	+26	+22	+17
Northern America	+31	+21	+17	+16	+12
Oceania	+28	+30	+26	+24	+21
East Asia	+78	+40	+48	+37	+30
South Asia	+43	+50	+54	+55	+51
Africa	+64	+60	+64	+63	+58
Latin America	+56	+54	+48	+44	+37
	Rural Population				
World Total	+11	+14	+13	+12	+ 9
More Developed Regions	- 2	- 6	-10	-13	-18
Less Developed Regions	+15	+19	+18	+16	+12
Europe	- 2	- 5	- 8	-10	-13
USSR	0	- 4	- 9	-10	-12
Northern America	- 1	- 2	-10	-11	-14
Oceania	+21	+ 9	+11	+10	+ 8
East Asia	+ 6	+11	+ 7	+ 2	- 1
South Asia	+20	+24	+24	+22	+16
Africa	+18	+23	+23	+24	+23
Latin America	+15	+11	+10	+ 8	+ 6

SOURCE: Population estimates and projections available to the United Nations as of March 1974 (U.N. Population Conference at Bucharest, 1974)

TABLE 2.3: URBAN AND RURAL POPULATION, AND PERCENTAGE OF URBAN POPULATION, BY AREA AND REGION (1970-2000)

Area and region	*Urban population (millions)*				*Rural population (millions)*				*Percentage of urban population*			
	1970	*1980*	*1990*	*2000*	*1970*	*1980*	*1990*	*2000*	*1970*	*1980*	*1990*	*2000*
World total	1,315	1,791	2,419	3,205	2,306	2,610	2,927	3,202	36.3	40.7	45.3	50.0
More developed regions	693	830	977	1,118	391	353	306	250	63.9	70.2	76.2	81.8
Less developed regions	622	961	1,443	2,087	1,914	2,257	2,621	2,952	24.5	29.9	35.5	41.4
Africa	75	122	199	315	277	340	422	518	21.2	26.5	32.1	37.8
Eastern Africa	10	19	34	58	89	113	147	188	10.5	14.2	18.6	23.4
Middle Africa	7	13	22	35	33	39	45	53	16.9	24.5	32.5	39.7
Northern Africa	31	49	77	115	55	65	77	87	35.9	42.9	50.0	56.9
Southern Africa	10	14	21	31	14	18	21	25	41.2	44.9	49.8	56.0
Western Africa	17	28	46	76	85	105	132	165	16.3	20.8	25.9	31.6
Latin America	161	238	342	470	123	136	147	155	56.7	63.7	69.9	75.1
Caribbean	11	16	22	31	14	16	17	18	44.0	50.2	56.7	63.2
Middle America	36	56	86	126	31	37	42	47	53.7	60.6	67.0	72.8
Temperate South America	28	35	41	47	8	7	6	6	77.4	82.6	86.6	89.5
Tropical South America	86	131	192	267	70	76	81	84	55.2	63.4	70.3	76.0
Northern America	168	196	228	256	59	53	47	40	74.2	78.8	82.9	86.4
East Asia	246	363	498	645	681	724	737	728	26.5	33.4	40.3	47.0
China	167	256	363	484	605	651	670	658	21.7	28.2	35.1	42.0
Japan [a]	56	72	86	99	49	45	40	34	53.2	61.4	68.4	74.3
Other East Asia	23	35	49	63	27	27	27	25	45.5	56.1	64.7	71.3
South Asia	231	356	550	834	880	1,094	1,334	1,551	20.8	24.5	29.2	35.0
Eastern South Asia	56	89	140	213	229	285	349	405	19.7	23.8	28.7	34.4
Middle South Asia	145	218	333	508	604	753	921	1,075	19.3	22.5	26.6	32.1
Western South Asia	30	49	76	113	47	55	64	71	38.7	46.8	54.5	61.4
Europe	284	326	370	414	175	162	145	127	61.9	66.9	71.8	76.6
Eastern Europe	55	65	75	86	48	45	41	36	53.2	58.8	64.6	70.4
Northern Europe	59	64	70	77	21	20	17	15	73.9	76.7	80.1	83.8
Southern Europe	59	72	87	102	68	65	60	54	46.5	52.8	59.2	65.5
Western Europe	111	125	138	149	37	32	27	22	74.7	79.6	83.6	87.1
Oceania	14	17	21	26	6	7	7	8	69.9	72.5	74.9	77.0
Australia and New Zealand	13	16	19	22	2	2	2	2	84.2	86.9	89.4	91.6
Melanesia	0	1	1	2	2	3	4	4	10.2	17.6	25.8	32.9
Micronesia and Polynesia	0	1	1	1	1	1	1	1	27.6	32.2	37.8	44.1
USSR	137	172	210	245	105	96	87	76	56.6	64.2	70.8	76.3

[a] Urban population is that of "densely inhabited districts".

SOURCE: Population estimates and projections available to the United Nations as of March, 1974. (U.N. Population Conference at Bucharest, 1974)

2.1.2 Economic Growth

Economic activity is measured by GNP per capita and its growth rate. The historical data were extracted from the United Nations, International Bank for Reconstruction & Development (World Bank), the U.S. Bureau of the Census (Department of Commerce), and the Hudson Institute Reports and Publications, especially the final report on the corporate environment study (The Business Environment 1975 - 1985) and The Next 200 Years. Projected figures are based on reasonable assumptions consistent with the five scenarios.

In projecting GNP growth rates, accounting procedures should be kept in mind. Labor force and wages are the main elements of GNP accounting. Goods and services which people produce for themselves are not included in the GNP. Entry of women into the labor force (wage earners) and the movement of peasants into industry increases the GNP sharply, while their real productivity may not have been increased at the same rate.

As a base line, average annual growth of GNP per capita was taken for the fourth scenario (Uninterrupted Growth) for which the assumption was that economic activity will grow at the historic rate. For this purpose, historical growth for the last 10 - 15 years of the U.N. yearbook of National Account Statistics, 1975, was used. (Table 2.4).

2.1.3 Pollution

Pollution is another important factor which affects not only the life

TABLE 2.4

GROWTH OF GROSS NATIONAL PRODUCT AND GROSS NATIONAL PRODUCT PER CAPITA BY REGION

(Percentage per Annum)

Area	Period	Gross National Product	Gross National Product per Capita
World [a]	1960-1965	5.5	3.4
	1965-1970	5.4	3.3
	1960-1970	5.6	3.5
Centrally Planned Economies	1960-1965	5.9	4.8
	1965-1970	7.1	6.0
	1960-1970	6.7	5.6
Market Economies	1960-1965	5.2	2.9
	1965-1970	4.8	2.6
	1960-1970	5.1	2.9
Developed Market Economies	1960-1965	5.3	4.0
	1965-1970	4.6	3.6
	1960-1970	5.1	4.0
Developing Market Economies	1960-1965	5.0	2.3
	1965-1970	5.8	3.1
	1960-1970	5.2	2.5
Africa [b]	1960-1965	4.4	1.8
	1965-1970	5.0	2.3
	1960-1970	4.7	2.1
North America	1960-1965	4.9	3.5
	1965-1970	3.4	2.3
	1960-1970	4.6	2.1
Caribbean Area and Latin America	1960-1965	5.3	2.4
	1965-1970	5.8	2.6
	1960-1970	5.4	2.4
Asia and the Middle East	1960-1965	7.1	4.2
	1965-1970	7.5	4.5
	1960-1970	7.4	4.4
South-East and East Asia [c]	1960-1965	4.2	1.6
	1965-1970	5.5	2.8
	1960-1970	4.4	1.8
Europe	1960-1965	5.0	3.8
	1965-1970	4.8	4.0
	1960-1970	4.7	3.8
Oceania	1960-1965	5.1	2.9
	1965-1970	5.3	3.2
	1960-1970	5.1	2.9

SOURCE: Yearbook of National Accounts Statistics, 1971, Vol. III

TABLE 2.4 (Continued)

(United Nations Publications, Sales No. E.73.XVII.3), international tables.
a Excluding China
b Excluding South Africa
c Excluding Japan.

quality of society but economic growth as well. Costs of antipollution devices require trade-offs between consumer goods and better environments. Future transportation, and specifically air transportation, depends on the ability to solve the pollution problem. The climatic effects of air transportation were discussed in CIAP Monograph 2.

2.1.4 Consumer Travel Expenditure

The spending patter of the consumer, including the percentage of personal income spent on transportation, has a definite correlation with GNP per capita. Figure 2.2 shows the percentage of personal income in the U.S. that has been spent on transportation since 1929. It can be

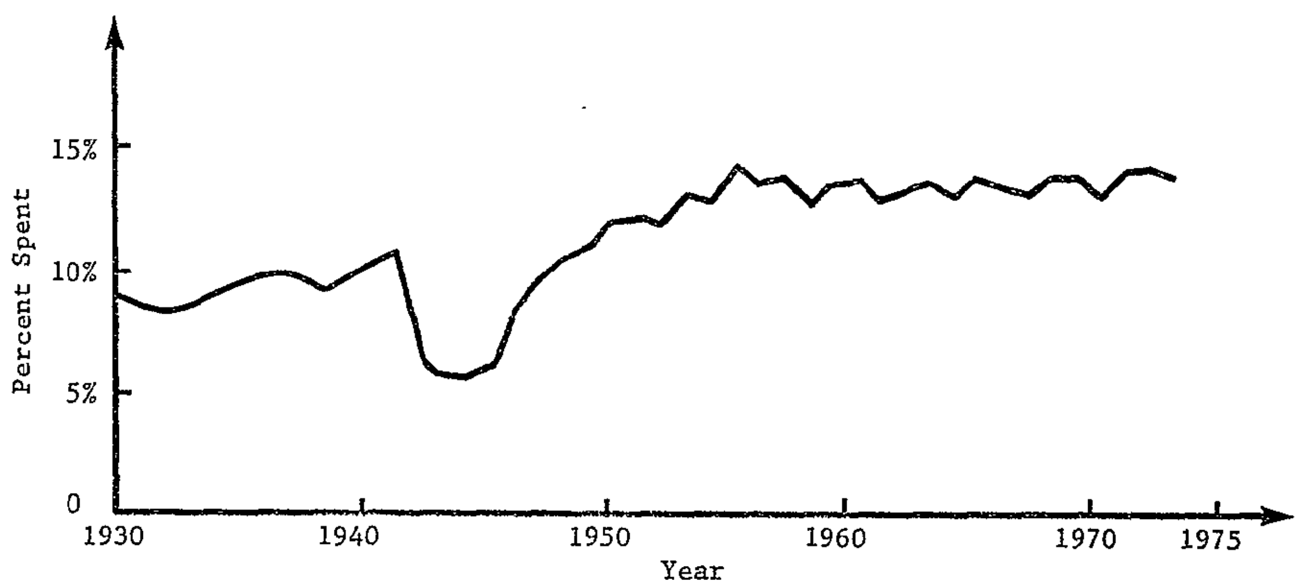


Figure 2.2: Percentage of Personal Income Spent on Transportation in U.S.

seen that except for the gap during World War II, the percentage of GNP per capita spent on transportation increased from 9% in 1929 to about 13.5% in the 1950's and then remained essentially for the past two decades. Table 2.5 shows the spending pattern of American consumers.

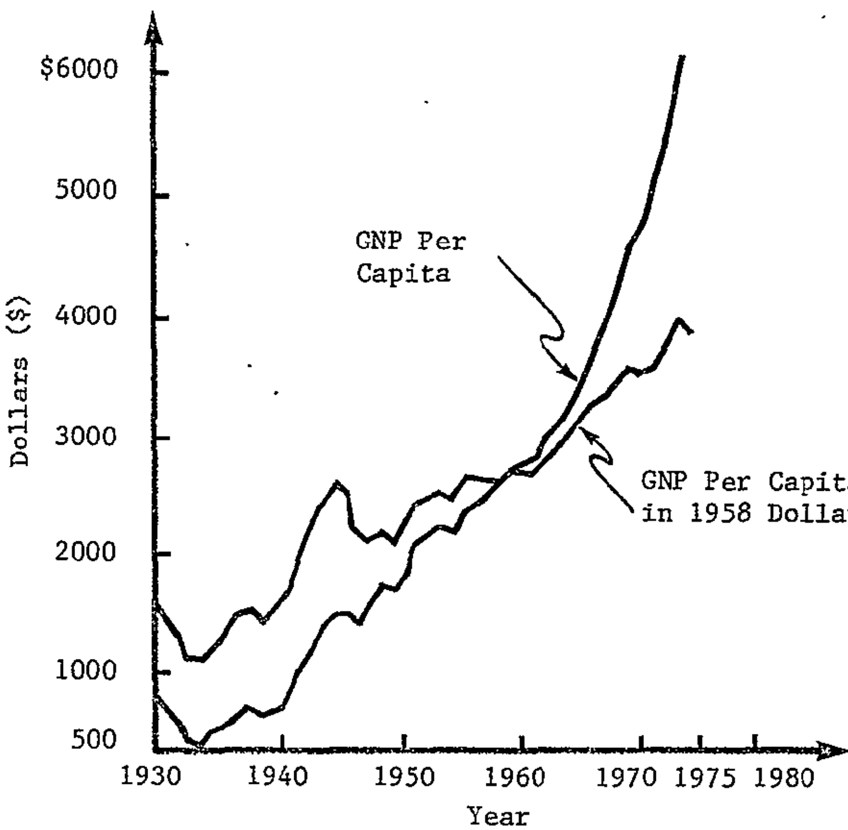


Figure 2.3: Growth in U.S. GNP Per Capita

By comparison, the percentage of GNP per capita spent on food has been declining. Whether 13%-14% for transportation represents saturation level, or will increase further, depends on the position of transportation in the hierarchy of consumer preferences. Any further increase depends on the limits imposed upon the traveler and on his motivations. In this respect, the time value element of passenger and goods transportation costs has special significance.

TABLE 2.5: PERSONAL CONSUMPTION EXPENDITURES, BY TYPE OF PRODUCT (1930 - 1970)

PRODUCTS	1930	1935	1940	1945	1950	1955	1960	1965	1970
Percent Distribution									
Food, beverages, and tobacco	27.8	31.6	31.1	36.4	30.4	28.4	26.9	24.8	23.2
Clothing, accessories, and jewelry	13.9	12.6	12.5	16.4	12.4	11.0	10.2	10.0	10.0
Personal care	1.5	1.4	1.5	1.7	1.3	1.4	1.6	1.8	1.7
Housing	15.8	13.8	13.3	10.4	11.1	13.3	14.2	14.7	14.7
Household operations	13.7	13.9	14.8	13.0	15.4	14.7	14.4	14.8	14.0
Medical care expenses	4.1	4.1	4.3	4.2	4.6	5.0	5.9	6.5	7.6
Personal business	5.3	5.5	4.7	5.9	3.6	4.0	4.6	5.1	5.7
Transportation	8.8	9.5	10.1	5.7	12.9	14.0	13.3	13.4	12.0
Recreation	5.7	4.7	5.3	6.1	5.8	5.5	5.6	6.1	6.5
Other	3.4	2.8	2.4	3.2	2.4	2.8	3.3	3.5	3.9

SOURCE: Historical Statistics of the U.S. (1970)

Past data for the U.S., which is leading the world economically, can provide a valuable guide for prediction of transportation demand in other places. For example, if we predict that GNP per capita in the presently countries in real terms, will be $6600 by 2025 - the GNP per capita of the USA in 1975 - then people in those countries might be expected to spend their income in a manner similar to that in which Americans spend their incomes today. However, cultural and geographical differences among nations of of the world might instigate such tendencies.

2.2 Energy Requirements

To evaluate potential energy demand and supply and how it could affect aviation fuel supply in the future, it is necessary to review the historical energy trends and examine some of the key factors affecting energy supply and demand.

2.2.1 Energy History

Historically, various energy sources have become scarce or abundant in relation to the technologies of the period. This has been largely overlooked in recent energy studies but has been clearly pointed out by O'Toole (1976) and by Pearce (1975). Fuel wood, used primarily for space heating constituted about 91% of U.S. energy sources in 1850 but was largely replaced by coal between 1850 and 1910. Four other substitutions have taken place during the last 120 years. Coal was progressively replaced by natural gas and oil. Although coal reserves amount to about 90% of U.S. proved energy reserves, the U.S. switched from using coal for over 90% of its energy needs to depending on oil and gas for 75% of its energy needs (Federal Energy Administration, 1976). Another energy substitution occurred when horsepower derived from animal feed was partially replaced by railroad coal in the late 1800s and early 1900s and a further substitution occurred between 1920 and 1950 with animal feed and railroad coal both being replaced by distillate motor fuels. Hydroelectricity took the place of direct wind and water power between the years 1890 - 1940 (Fisher, 1974). As these energy substitutions, with accompanying changes in life-styles, occurred, supply and consumption patterns adapted.

Energy Consumption

Energy consumption has increased each year in all but five years since 1947. In three of these years, declines resulted from lessened economic activity. The first decline occurred in 1954 and the last two in 1974 and 1975 when the energy price increase was a contributing factor causing recession. Gross energy consumption increased from 33.0 quadrillion BTUs (quads) in 1947 to 74.7 quads in 1973, when it declined to 73.1 quads in 1974 and 72.2 quads in 1975. This represents a 2.8% annual rate of growth of energy demand for the 1947-75 period as compared with a 2.2% decline for the 1973-74 period and 1.3% for the 1974-75 period (Bureau of Mines, 1975).

It is interesting to note that during the 1960-69 period, real prices of energy declined and real income per capita increased. This may have contributed to increased energy consumption. Of total energy consumption, the petroleum share increased at an annual rate of 3.8% and natural gas at a 5.5% rate. During this same period, coal consumption declined at an annual rate of 0.7% and hydropower and geothermal increased at the rate of 3.1%. Petroleum and natural gas contributed about 77% to total U.S. energy consumption in 1975 while coal accounted for only 18% as shown in Figure 2.4. Imports constituted 21% of overall consumption in 1965, rose to 27% in 1974, and increased to 42% in 1976.

The four main energy consuming sectors of the economy are transportation,

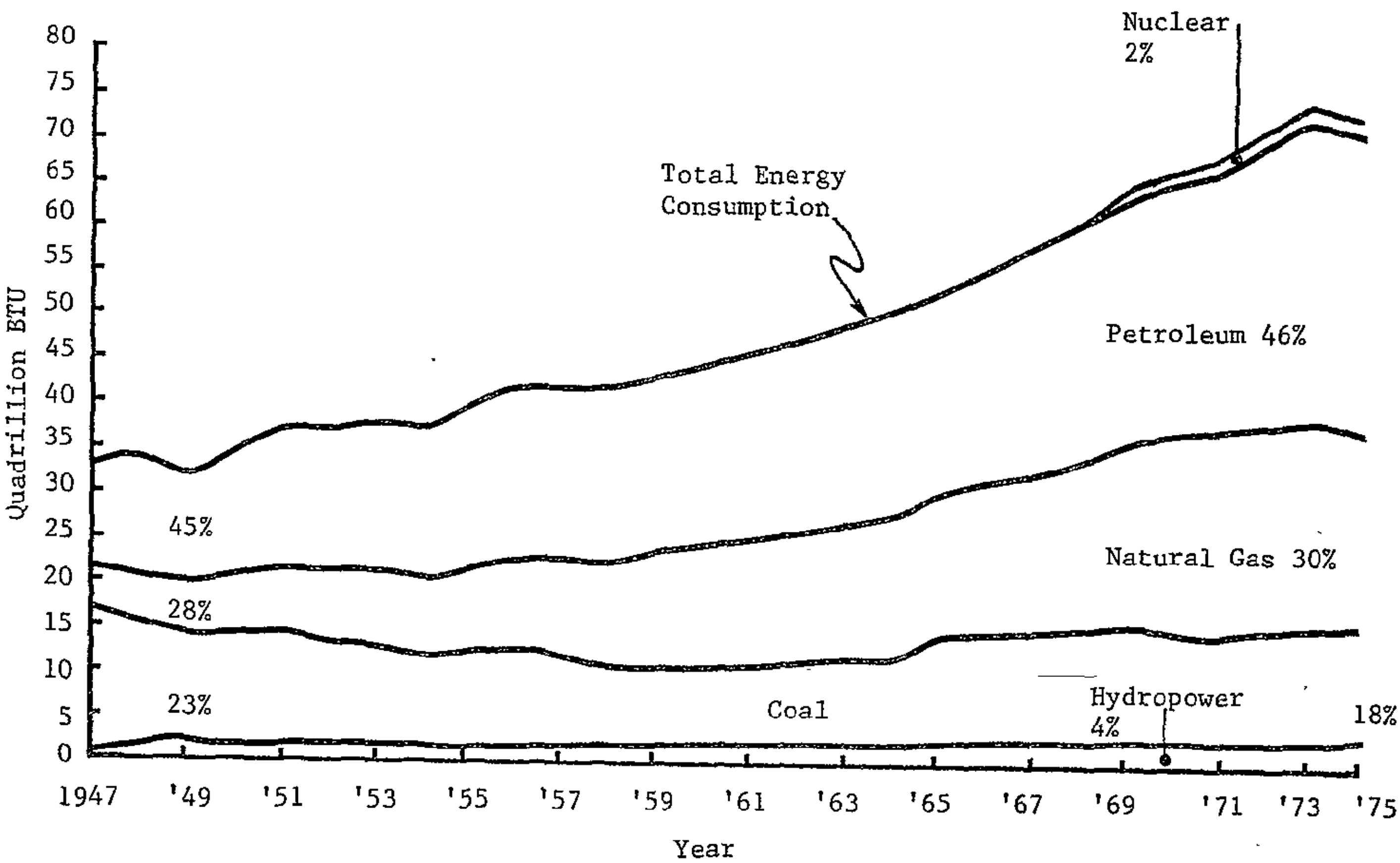


Figure 2.4: U.S. Gross Energy Consumption by Source, 1947-1975.

Source: U.S. Bureau of Mines, 1975.

industrial, household and commercial, and the electrical sectors. During the 1947-75 period, total transportation energy consumption increased at an annual rate of 4.1% with gasoline consumption at a 4.1% annual rate. In the industrial sector, energy consumption for fuel (direct combustion) uses increased at 1.6% during the same period. However, since 1960, consumption of coal for fuel use has declined at an annual rate of 0.6%. The industrial sector energy consumption for non-fuel (petrochemical, etc.) uses increased at an annual rate of 3.9%. This occurred with an insignificant change in coal consumption and 1.2% rate for natural gas (Bureau of Mines, 1975).

Energy consumption in the household and commercial sector increased at an annual rate of 3.2% during the 1947-75 period, while coal consumption declined at an annual rate of 8.5%. In 1975, natural gas constituted 43% of total energy consumption in this sector. In the electrical energy sector, consumption increased at a slightly higher rate, 5.7%, than all other sectors. Coal consumption in this sector increased at 5.3% while petroleum products and natural gas consumption in this sector increased slightly more each year, 7.2% and 7.8% respectively. The contribution of nuclear energy to the electrical sector increased at an annual rate of 48.5% between 1970 and 1975. In 1975, its share of total energy consumption was 8.2%. These consumption patterns are shown in Figure 2.5.

The consumption/GNP ratio is a proxy for measuring the energy intensity of an economy. Historically, U.S. energy intensity has been declining at a rate of approximately one-half of one percent per year. It is interesting that a temporary reversal occurred between 1965 and 1970, due largely to the decline in automobile efficiency associated with the anti-pollution program.

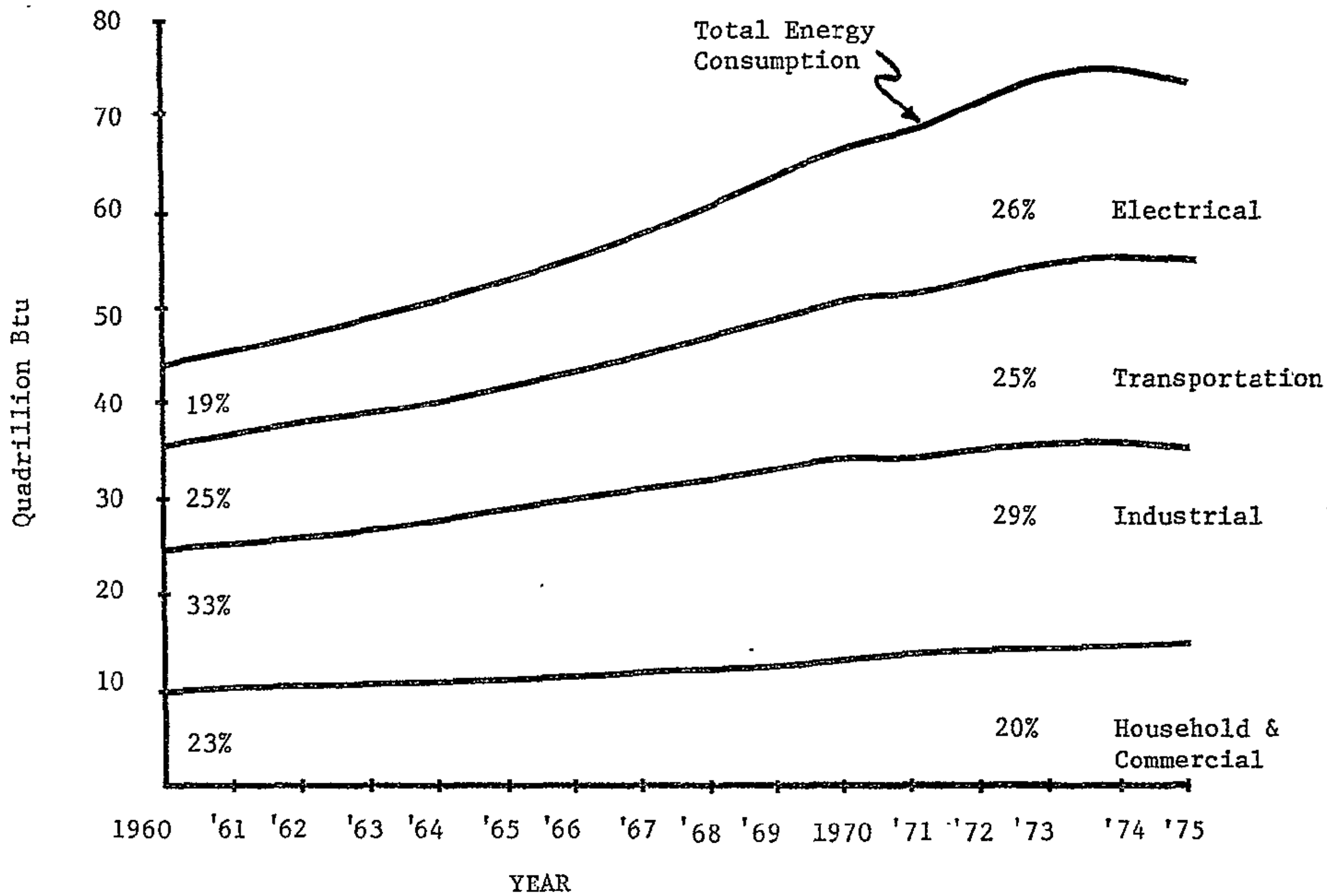


Figure 2.5: U.S. Gross Energy Consumption by Sector.

On the supply side, U.S. energy production increased at an annual rate of 1.9% from 1947 to 1975. Petroleum production increased at an annual rate of 1.8% and natural gas production at about 5.5% during this same period. In 1975, petroleum furnished 30% of U.S. total energy production and natural gas furnished 37%. These production trends reversed during the 1970-75 period with petroleum production declining at an annual rate of 2.2% from a peak of 9.5 MMB/D in 1970 and natural gas declining at a rate of 1.7% from a value of 22 trillion cu/ft in 1974. Production of electricity has grown at about twice the rate of total energy. Of this, nuclear power constitutes approximately 9% at present. These trends are shown in Figure 2.6.

2.2.2 Key Factors Affecting Energy Supply and Demand

Factors which affect energy supply and demand, directly or indirectly, also affect air transportation. Supply factors are: energy resources; capital investment, technology, energy prices, availability of water, conservation, environmental considerations and availability of imports. Demand factors on the other hand, are: population, number of households, income per capita, consumption pattern; and social and institutional environments.

Energy Resources

Reserves do not constitute a measure of total resources but rather the established amounts known to be recoverable at current prices. A rise in price will automatically increase reserves. Nevertheless, reserves do

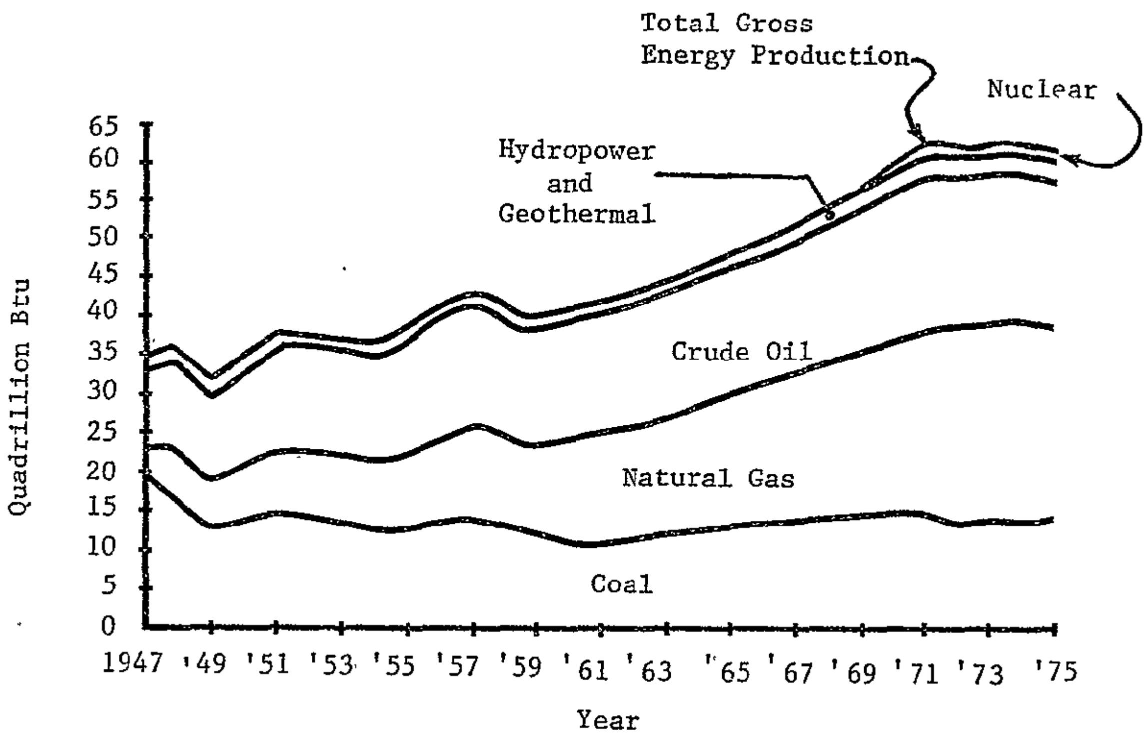


Figure 2.6: U.S. Gross Energy Production.

Source: U.S. Bureau of Mines, 1975

provide a crude proxy for estimating energy potentials in the near term. The WAES (1977) report shows world oil reserves as of January, 1976 in table 2.6.

TABLE 2.6

WORLD OIL RESERVES

Region	Remaining Proven Reserves (billion barrels)	Cumulative Prod. to end of '75 (billion barrels)
*OPEC:		
Saudi Arabia	152	23
Other Mid-East	208	61
Other OPEC	90	55
Total OPEC	450	139
North America	40	133
Western Europe	25	2
Rest of WOCA**	40	17
Total Non-OPEC	105	152
Total WOCA	555	291
Communist Countries	103	50
Total World	658	341

SOURCE: WAES -- Global Energy Prospects (1985 - 200), 1977.

* OPEC - Organization of Petroleum Exporting Countries.
**WOCA - World Outside Communist Areas.

It is evident from Table 2.6 that both North America and Western Europe have insignificant proven reserves remaining. Though oil has been discovered recently in the North Sea and Alaska, the amounts are not large enough to account for appreciable potential future supply. The OPEC nations have used up over 23% of their reserves. Saudi Arabia alone has the largest share of OPEC reserves and had used over 13% by 1975. Therefore, if the OPEC is to continue supplying world oil as it has in the past, additions to these reserves will be essential. The share that these reserves contribute to future total energy supply is discussed in Chapter 3.

Coal

Another resource vital to future energy supply is coal. Table 2.7 shows coal reserves as of 1973.

TABLE 2.7

WORLD COAL RESERVES

Region	Known Measured Reserves (Billion Metric tons)	Economically Recoverable Reserves (Billion metric tons)
USA	396	248
Canada	13	6
Total North America	409	254
West Germany	100	16
United Kingdom	99	4
Rest of W. Europe	26	21
Total Western Europe	225	41
Japan	3	1
Rest of WOCA	140	53
Total	143	54
Total WOCA	777	349
USSR	349	287
East Europe	201	101
Total	550	388
World Total	1327	737

SOURCE: WAES "Energy Global Prospects," (1985 - 2000), 1977.

The U.S. has the largest reserves of coal -- over 30% of world total. Production in the U.S. has declined in the recent past. In Europe, production has been stable, as the supply from new mines offset declining output from old mines that are being depleted. However, with known reserves of 99 billion metric tons, the U.K. has the potential for expanding production. Likewise, West Germany's reserves of 100 billion metric tons indicates similar potentials. Japan, with insignificant reserves, is not expected to contribute to total world coal supply.

Natural Gas

Total world natural gas reserves are approximately 58% of the energy equivalent of world oil reserves, 386 billion barrels of oil equivalent, (Table 2.8).

TABLE 2.8

WORLD NATURAL GAS RESERVES

Region	Remaining Reserves in 10^{12} cu ft. (quad cu ft.)	Remaining Reserves (in billion barrels oil) equivalent)
OPEC:		
Iran	330	57
Saudi Arabia	103	18
Other Mid-East	96	17
Algeria	126	22
Other Non Mid-East	133	23
Total OPEC	788	137
North America	268	46
Western Europe	181	31
Rest of WOCA	160	28
Total Non-OPEX	609	105
Total WOCA	1397	242
Communist areas	835	144
World Total	2232	386

SOURCE: WAES -- Global Energy Prospects (1985 - 2000), 1977

As noted in Section 2.1, natural gas production in the U.S. has been declining since 1970 and no significant additions have been made to reserves during the last few years. Next to communist countries, the OPEC countries have the largest share of world reserves. However, OPEC nations have indicated they will limit production until transportation facilities are made available for interregional transport. Western Europe has significant deposits of natural gas including additional reserves associated with the newly discovered North Sea oil.

Other Sources of Energy

Other sources of energy include shale oil, oil from tar sands, gas and liquids from coal. The U.S. has the largest known reserves of shale oil, estimated to be about 2,000 billion barrels of oil. Roughly 5% - 6% of the reserves are accessible for development. However, development of shale oil will require sizable capital costs and large quantities of water which will cause waste disposal and air quality problems. It is estimated that approximately 145.4 gal of water are needed per barrel of oil recovered from shale oil. Significant quantities of shale exist in Brazil, Canada, USSR and China where development programs are in progress.

Capital Investment Availability for Energy Development

The oil embargo of 1973 clearly demonstrated that the U.S. must develop its domestic resources of energy to meet the growing demand for energy. Various alternative sources of energy currently being considered include coal gasification, coal liquefaction, shale oil and nuclear energy development. Historically, the percentage of fixed business investment which has gone into energy investment ranges from 18% to about 26% (Project Independence, 1974). The trend is shown in Figure 2.7. In order to develop the energy reserves discussed earlier, huge investments are needed. The U.S. Federal Energy Administration estimates available total energy investment money at between $379 and $474 billion (in 1973 dollars) by 1985. This estimate is within the ranges estimated by other agencies and study groups such as Brookings Institute and the Bureau of Labor Statistics (Project Independence, 1974). This view is shared by O'Toole (1976). However, there is a growing realization that many of these early estimates were much too low. With rapidly escalating construction costs for coal conversion projects, it now appears that $1 Billion will be required for each plant scaled for a production of 250MM BTU/day.

Availability of Water

A considerable amount of water is required to develop energy resources. Water is used during extraction of the raw material from the earth as well as during the actual processing of the materials into useful fuel. Moreover, water is essential for disposing of waste materials and may be used for transportation of processed fuels. For instance, to mine uranium and to cool thermal discharges in nuclear power plants requires about 0.8 gallons per kilowatt hour or almost 235 gallons per million BTU of energy produced. In the case of oil shale 145.4 gals of water are required per each barrel of oil produced. (Project Independence, 1974). Consumption of water for coal processing varies from 6-14.7 gals of water

Figure 2.7: Energy's Annual Share of Business Investment.

Source: FEA's "Project Independence"

per ton of coal for Western coal to 15.8 - 18.0 gals of water per ton of coal in the case of Eastern coal. Large quantities of water are needed for processing other energy forms such as coal gas and coal liquids. However, the actual amount of water required depends on the particular energy resource, environmental regulations in force, and the area in which the energy source is located.

2.3 Transportation

In the recent past, the volume of overall transportation has increased markedly. This growth is shown in Figure 2.8. The intensity level of transportation activities depends on the following key factors: Economic growth (GNP, GNP per capita, disposable personal income, etc.), population growth, energy resource availability, technological development, social and institutional environments (pollution concern, urban and rural population distribution, consumption pattern, etc.). For instance, as a result of increasing population and GNP per capita; transportation has more than doubled since 1950. Its future growth should be dictated by the key factors mentioned above.

2.3.1 Historical Background

The total volume of intercity passenger and freight traffic from 1950 to 1970 is illustrated in Figure 2.8. During this period the volume increased by more than a factor of two for both passenger and freight traffic, with a significant change in modal distribution. The changing patterns of modal distribution during this period are better illustrated in Figures 2.9 and 2.10 in which the shares of the total market are plotted on semilogarithmic coordinates. From these two figures, one can see that since the end of World War II, the railroads have steadily lost their share of the market while surface highway transportation (private automobiles and trucks), on the other hand, has expanded steadily. The reasons behind this are ever-expanding highway systems, door-to-door

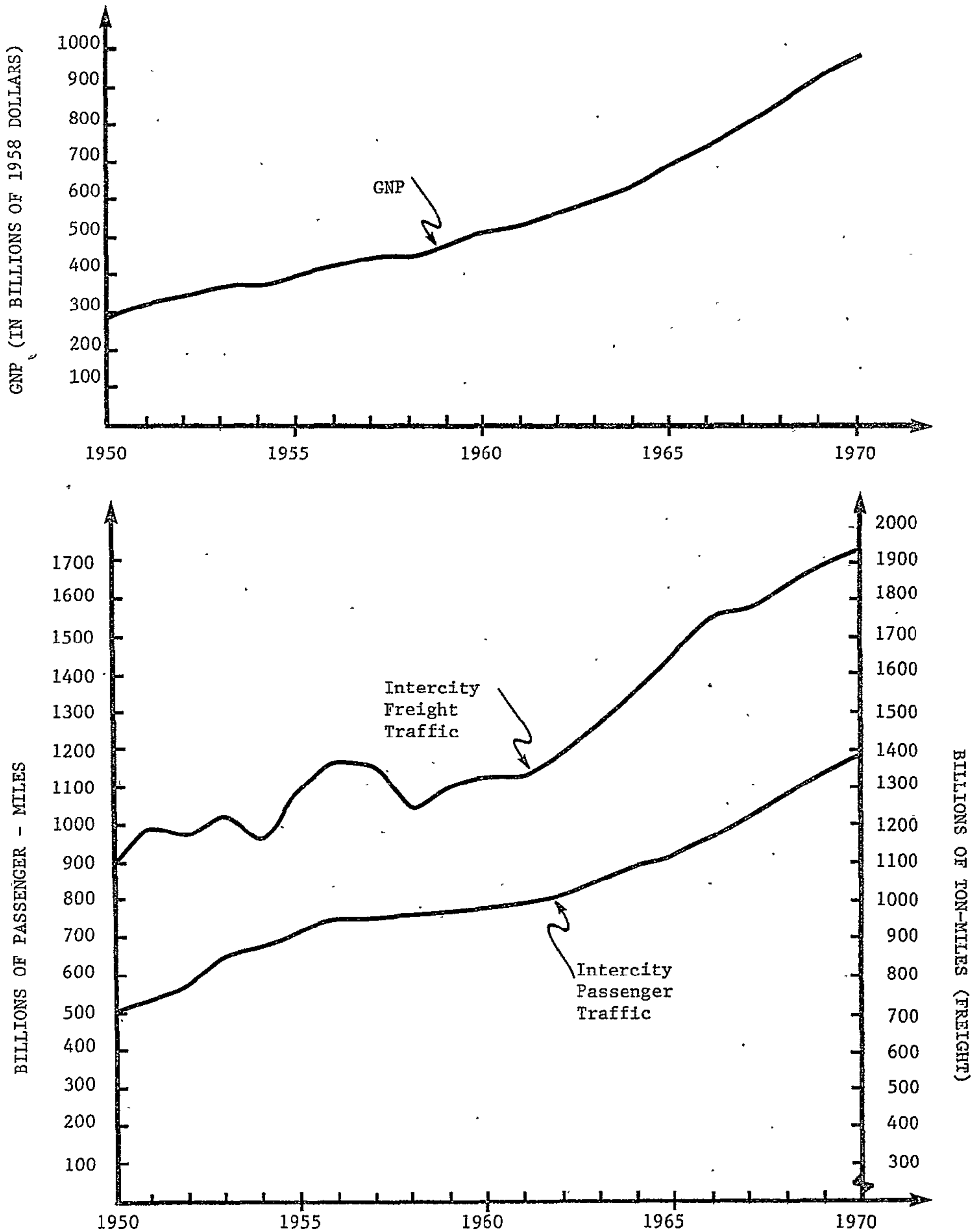


FIGURE 2.8: Growth Pattern in GNP and Intercity Transportation

services that can not be offered by rail, increasing population growth in suburban regions and a competitive rate structure.

Pipelines have expanded steadily as well, offering a low-cost transportation means for petroleum and gas. Water transportation has expanded at about the same rate as overall transportation and, consequently, its share of the market has remained relatively constant.

The most dramatic change has been in air transportation. While the absolute value of passenger and freight carried by this mode is still relatively small, its penetration in the market has been dramatic (approximately 12.5% of total transportation in 1975). This rapid increase in market share has been due to the superior services that air transport can offer regarding speed, better passenger and cargo survivability, and other factors that are not features of competing modes.

Passenger Travel

Automobile traffic has accounted for about 87% of the total intercity passenger miles during the period from 1950 to 1970 (Figure 2.9 and Table 2.9). During this period, railroad passenger traffic declined consistently from 6.4% in 1950 to less than 1% of total passenger-miles, while bus travel also declined from 5.2% to 2.1% of total intercity passenger miles. Air travel, on the other hand, increased its share from 2.0% to 9.7% -- almost fivefold. These data clearly indicate the role which the automobile and airplane play in the intercity passenger sector.

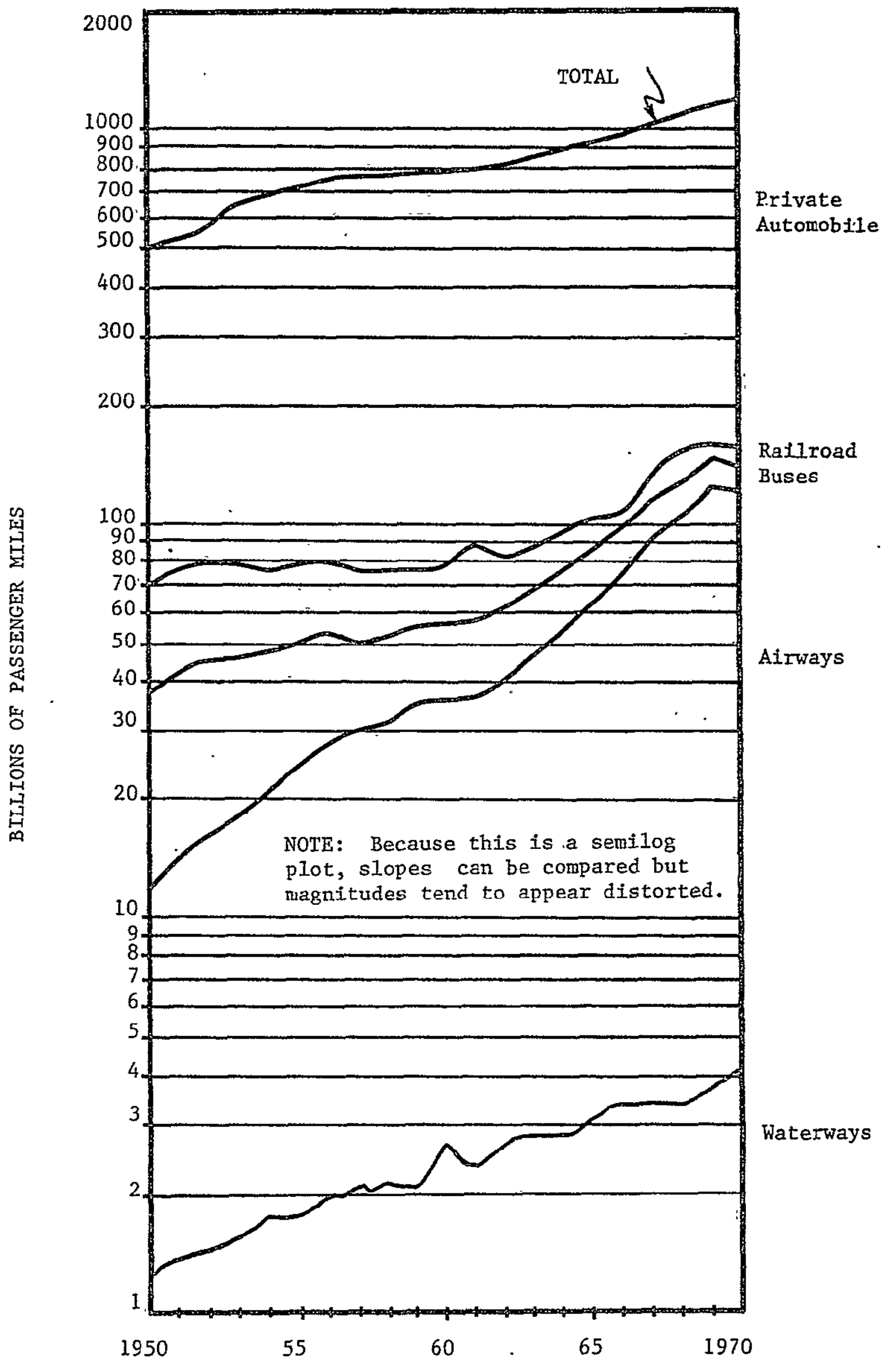


Figure 2.9: Volume of Domestic Intercity Passenger Transportation, By Type of Transport; 1950 to 1970.

Table 2.9: MEANS OF INTER-CITY PASSENGER TRAFFIC (1950 - 1970)

Year	Total Passenger-Miles ($X 10^9$)	Percentage of Total Passenger-Miles: Automobile	Airplane	Bus	Railroad
1950	510	86.8	2.0	5.2	6.4
1955	720	89.5	3.2	3.6	4.0
1960	780	90.1	4.3	2.5	2.8
1965	920	88.8	6.3	2.6	1.9
1970	1,180	87.0	9.7	2.1	0.9

Source: Hirst, 1972: 10 (data from Statistical Abstract, 1970, and from Transportation Facts and Trends, 1971).

The trend of auto registrations and usage in urban regions since 1940 is shown in Table 2.10. Unless energy shortages lead to a reversal of this trend, automobiles will be more important in the future than they are now. (The main impact of energy problems on automobile ownership seems to be towards smaller and more efficient cars rather than fewer cars.) While public transit ridership declines as incomes increase, the opposite is true of auto ownership and thus auto riders. As Table 2.10 shows, passenger car registrations continued to rise (at least up to 1970), but after some point in time the increase in registrations may merely reflect the increase in population. The trend toward greater automobile ownership is probably over, except among very low income groups. A further exception to this equilibrium state exists in under-developed and developing nations.

Table 2.10: UNITED STATES PASSENGER CAR REGISTRATION AND VEHICLE MILES IN URBAN AREAS, 1940-1970

Year	Auto Vehicle Miles in Urban Areas (Billions)	Passenger Car Registrations (Thousands)	Population Per Car Registration
1940	129.1	27,466	4.8
1950	182.5	40,339	3.8
1960	284.8	61,682	2.9
1965	378.2	75,421	2.6
1970	494.5	80,388	2.5

Source: U.S. Bureau of the Census, Statistical Abstract of the U.S.: 1973, Government Printing Office, Washington, 1973, pp. 545, 547.

The trips that depend most heavily on public transit (journy-to-work trips) are shown for 1970 in SMSAs (Standard Metropolitan Statistical Areas) over 250,000 population (Table 2.11); however, an even larger proportion of other than journey-to-work trips is by auto. Thus, data on all trips, including those for shopping and leisure would show even more dependence on automobiles. The automobile remains the predominant transportation mode in the urban areas of the United States and that public transit, even though more energy-efficient, plays a supplementary role.

Table 2.11: JOURNEY-TO-WORK TRIPS BY MODE IN SMSAs OVER 250,000 POPULATION, 1970

Journey-to-Work Trip Mode	SMSA RESIDENTS WORKING In Central Cities	Outside Central Cities
Private automobile (driver)	60.7%	73.0%
Private automobile (passenger)	10.6	11.4
Bus or Streetcar	11.6	3.2

Continued

Table 2.11 (Continued)

Journey-to-Work Trip Mode	SMSA RESIDENTS WORKING In Central Cities	Outside Central Cities
Subway or elevated train	6.3%	0.2%
Walked to work	6.0	6.8
Worked at home	1.5	2.5
Other, including railroad and taxi	3.3	2.4
	100.0%	100.0%

Source: 1970 U.S. Census of Population, Journey to Work, PC(2)-6D, Table 2.

Freight Transportation

Primary means of freight transportation are waterways (barges and ships), trucks, railroad, domestic and international air transports, and pipelines. Figure 2.10 and Table 2.12 show the role each mode has played during this period as well as changes in modal distribution. During this period railroading, although still controlling over 40% of the market, has lost some share of the market (from 57.4% of total ton-mile freight in 1950 to 40.1% in 1970). On the other hand, trucking increased its share from 15.8% of total ton-miles freight in 1950 to 21.4% in 1970, while air freight increased from 0.03% in 1950 to 0.18% in 1970. This implies that air transportation could play a much more significant role in freight transport in the future, provided there is no shortage of fuel. The increases of truck and air freight in total intercity freight transportation are mainly due to practical reasons. Trucks are flexible regarding pickup and delivery points, and air freight is the fastest and safest means of all modes of freight transportation.

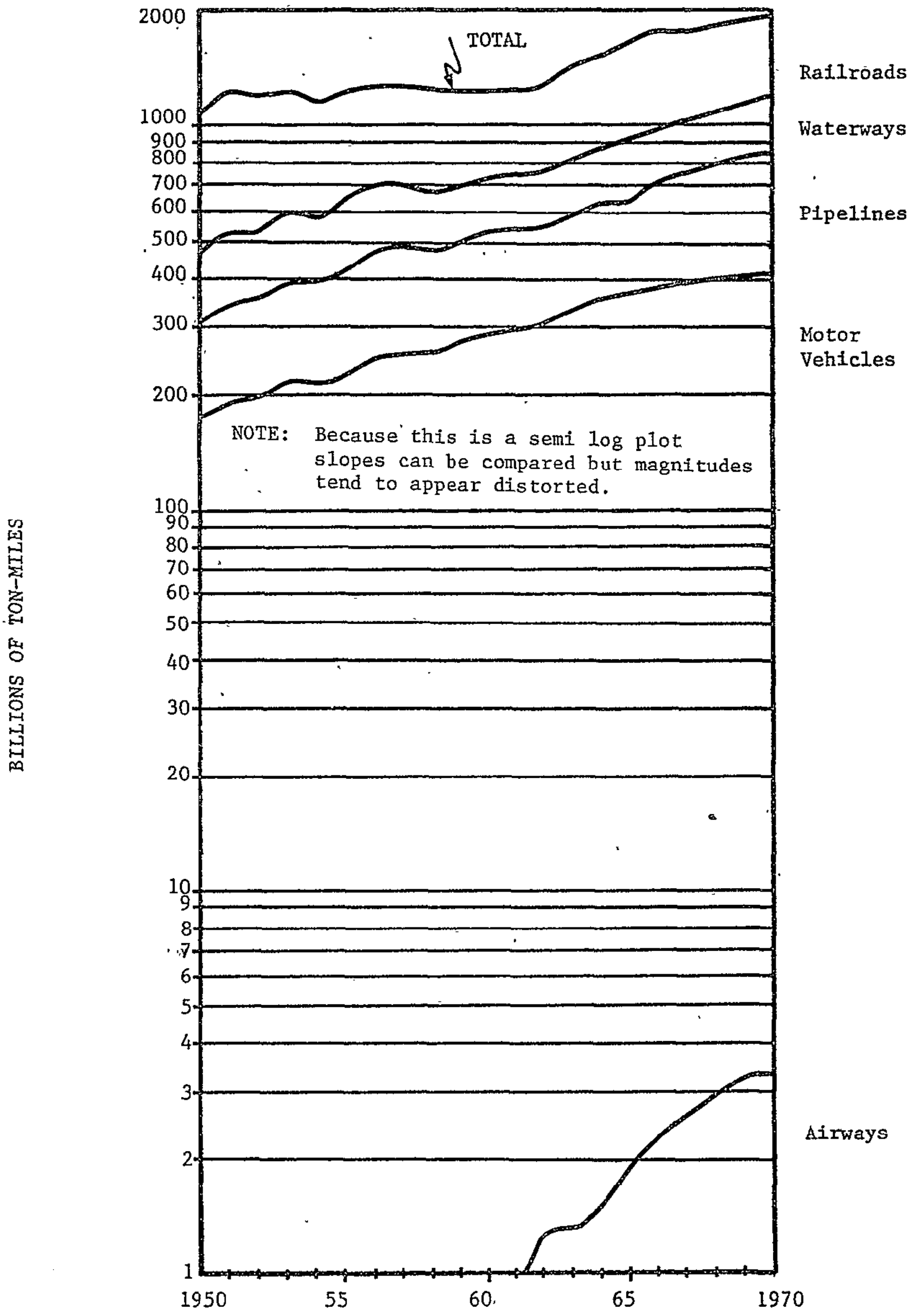


Figure 2.10: Volume of Domestic Intercity Freight Transportation By Type of Transport, 1950 to 1970.

Table 2.12: METHODS OF INTERCITY FREIGHT TRAFFIC (1950-1970)

Year	Ton-Miles Freight (10^9)	Percentage of Total Ton-Miles: Railroads	Trucks	Waterways	Pipelines	Airways
1950	1,090	57.4	15.8	14.9	11.8	0.03
1955	1,300	50.4	17.2	16.7	15.7	0.04
1960	1,330	44.7	21.5	16.6	17.2	0.06
1965	1,650	43.7	21.8	15.9	18.6	0.12
1970	1,930	40.1	21.4	15.9	22.4	0.18

Source: Hirst, 1972: 6 (data from Statistical Abstract, 1970, and from Transportation Facts and Trends, 1971).

Water transport, as mentioned earlier, has expanded at about the same rate as the growth of total freight transportation, and consequently its share of the market has remained relatively constant. Pipelines have almost doubled their share of the market during this period and should continue to grow at about the same rate as in the past 20 years.

Like automobiles, trucks are essentially the only means of freight transportation in urban areas. As population growth is increasingly concentrated in the suburbs, a further demand for trucks is created.

2.3.2 Key Factors Affecting Transportation

In order to forecast future transportation activities, one must first establish a set of key factors likely to stimulate or deter the growth of this sector of the economy. From the preceeding section, we can conclude that intensity of transportation activities is highly correlated to the economic activity. Since 1950, transportation growth has maintained

2.4 Air Transportation

Ever since it emerged as a new transportation mode in the 1930s, air transportation has been the fastest growing component within the transportation sector. In addition to convenience and speed, the key factors which have caused this are rise in per capita income, rapid technological development, and overall economic advantage relative to other transportation modes.

2.4.1 Historical Growth of Air Transportation

The development of air transportation has grown rapidly since World War II which provided the impetus for take-off of the industry. The fastest growth occured over the past 20 years, with the introduction of the commercial jet which provided great improvements in speed, comfort, and economics. The growth in both speed and capacity are shown in Figures 2.11 and 2.12, respectively. Direct operating cost (DOC),Figure 2.13, has been greatly reduced due to technological and operational improvements.

The world scheduled air passenger traffic has increased at a rate of 13.8% per year, from 35 x 10^9 pass-km in 1951 to 500 x 10^9 pass-km in 1973 (Figure 2.14). North America (including Central America and the Caribbean states) has the highest air traffic volume. In 1973, it accounted for 290 x 10^9 pass-km, or about 48% of the world total air traffic volume. However, the historical trend shows that the percentage of the North American share has been decreasing. This can be seen in Figure 2.15 (USSR data are not included). On the other hand, percentage traffic of the Asia-Pacific

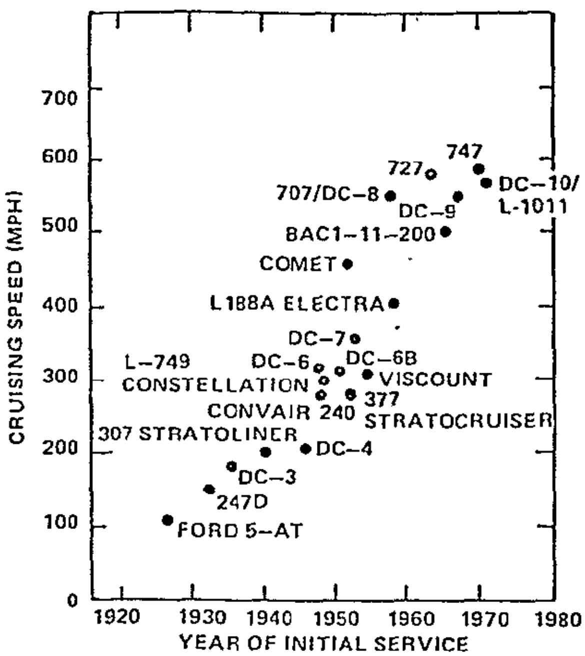


Figure 2.11: Speed History of Transport Aircraft

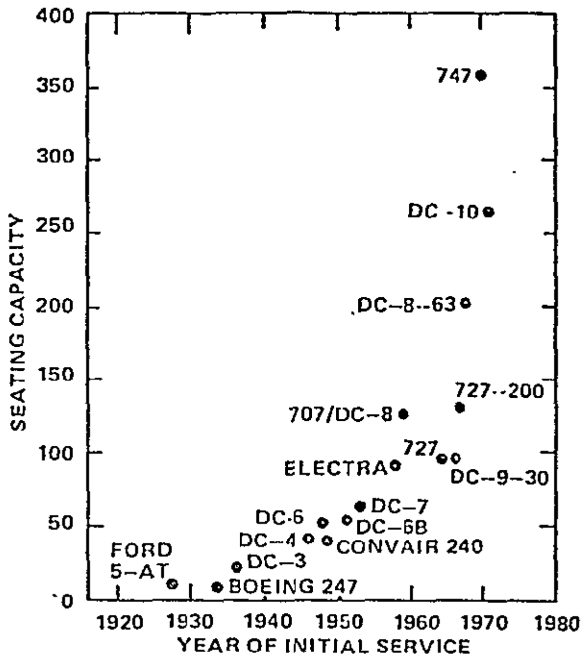


Figure 2.12: Growth of Passenger Capacity

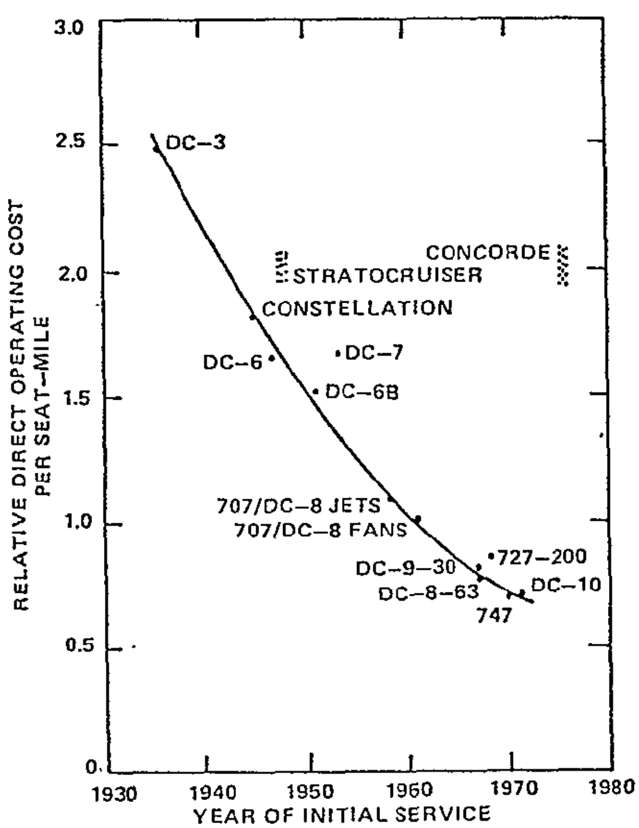


Figure 2.13: Direct Operating Cost From the DC-3 to the DC-10

Source: Workshop on Technology Assessment of Future Passenger Transportation System, Vol. 3, 1976.

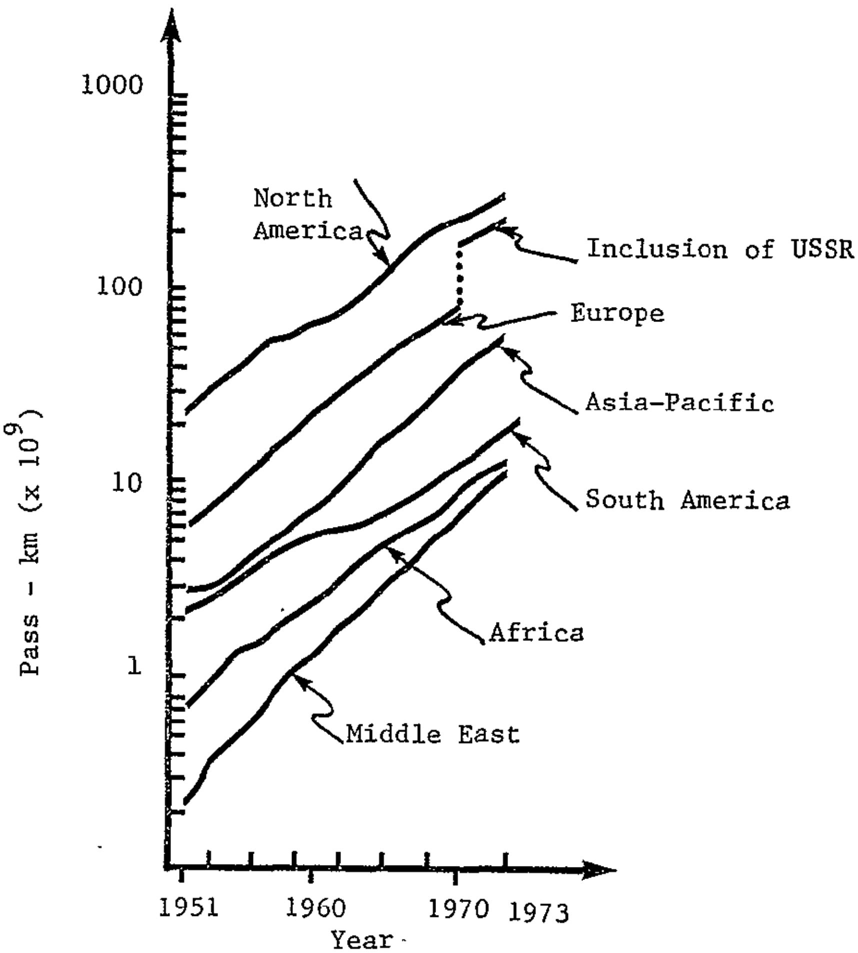


Figure 2.14: Historical Air Passenger Traffic

Source: ICAO, 1973

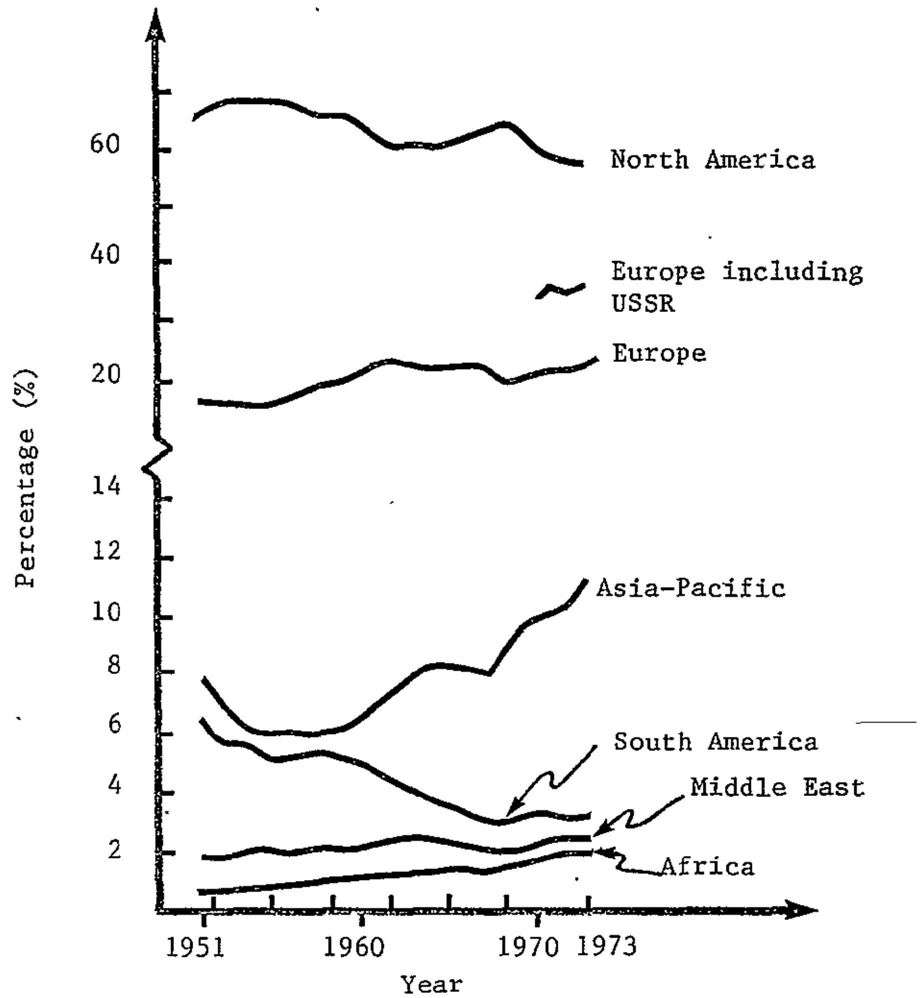


Figure 2.15: Shares of World Passenger - Kilometers
By Region of Airline Registrations

Source: ICAO, 1973

region has been increasing dramatically from a minimum share of 6% in the 1950s to 11.5% in 1973.

Air cargo volume has risen even more dramatically, with an annual average growth rate of 14.3%.

As a result of this traffic growth, energy consumption for air transportation has increased tremendously. In the United States, energy consumption for passenger aviation has risen from 130.1×10^{12} BTU (0.13 QUAD) in 1955 to 1070.9×10^{12} BTU (1.071 QUAD) in 1970, almost tenfold. This represents an annual average growth of 15.1%, somewhat higher than the growth in passenger travel. This would indicate an increasing energy intensity of air transportation. The economic recession in 1970-71 caused both a decrease in passenger traffic and energy use. On the other hand, growth in energy consumption for air cargo continued to accelerate, having an average annual growth rate of 19.4% during the same period, (Figure 2.16).

2.4.2 Factors Affecting Air Transportation

Air transportation growth is influenced by demography, per capita income, technological advance, and societal attitude. These factors are discussed as a background for the transportation scenarios.

Demography

Population and its composition by age and geographic distribution is a major factor in air transportation development. Holding other factors

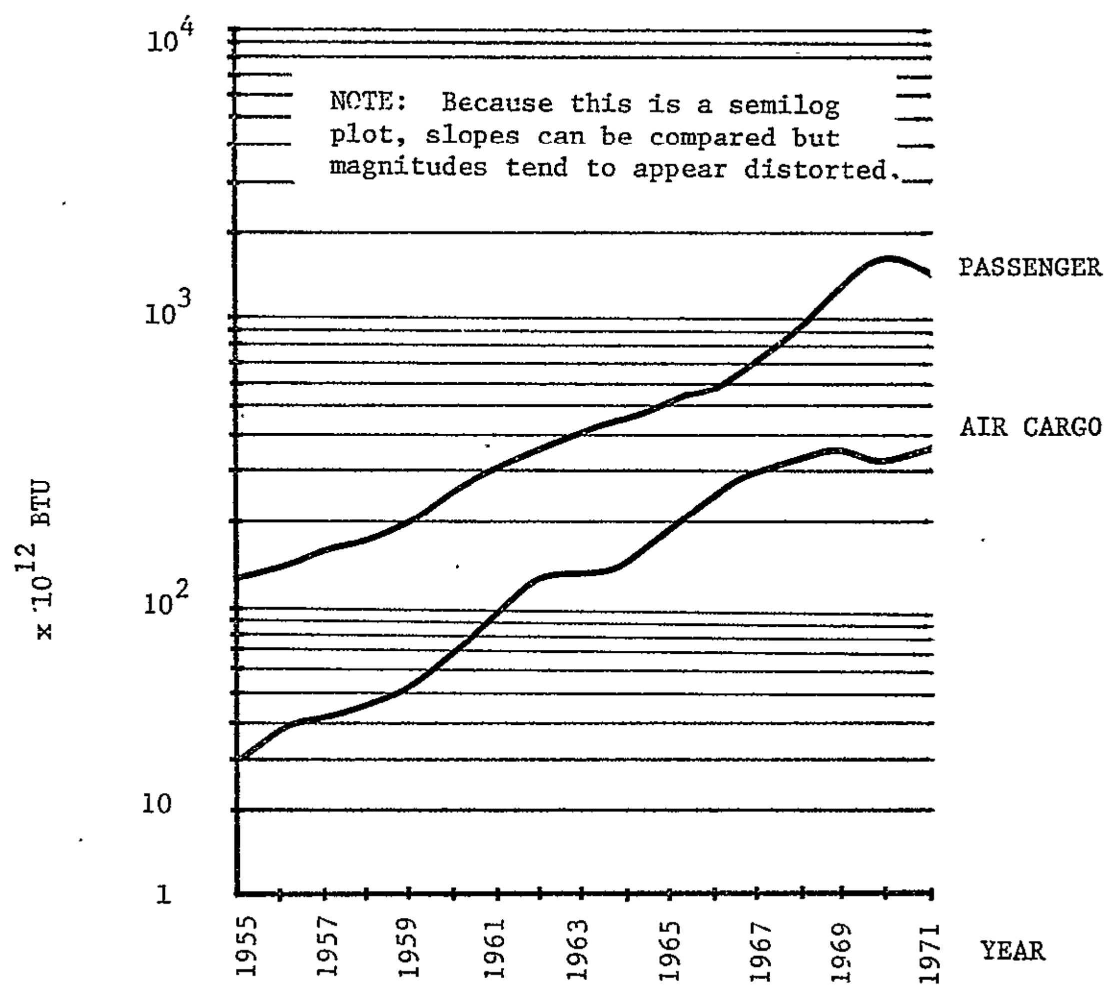


Figure 2.16 U.S. Energy Consumption In Air Transportation

constant, the level of air transportation would be proportional to population. Historical measures of air travel versus population can be seen in Figure 2.17.

Economic Conditions and Per Capita Income

Economic conditions have played a major role in air transportation development. As incomes increase, people tend to travel more for both business and for pleasure. This is illustrated in Figure 2.18. However, growth can not continue without limit because of decreasing marginal utility for air travel. Furthermore, available time for travel is also limited. In Figure 2.19, length of stay at destination versus travel distance is shown. There tends to be longer stays -- up to 15 days -- for personal trips than for business trips -- up to 7 days. Length of stay reflects the available time for travel. The 15 day pattern for stays is possibly due to the present average two-week vacation period established for business. As vacations lengthen, this length of stay will also tend to become more extended. Also, there is a substitution effect between available time for travel and personal income.

Figure 2.20 shows how typical U.S. Urban households spend their income on gasoline (i.e., automobile transportation). The middle income households have the highest percentage spending (4.5%) while the opposite is true for the upper income households.

Other Factors

Other factors, such as technological advances, societal attitudes, and

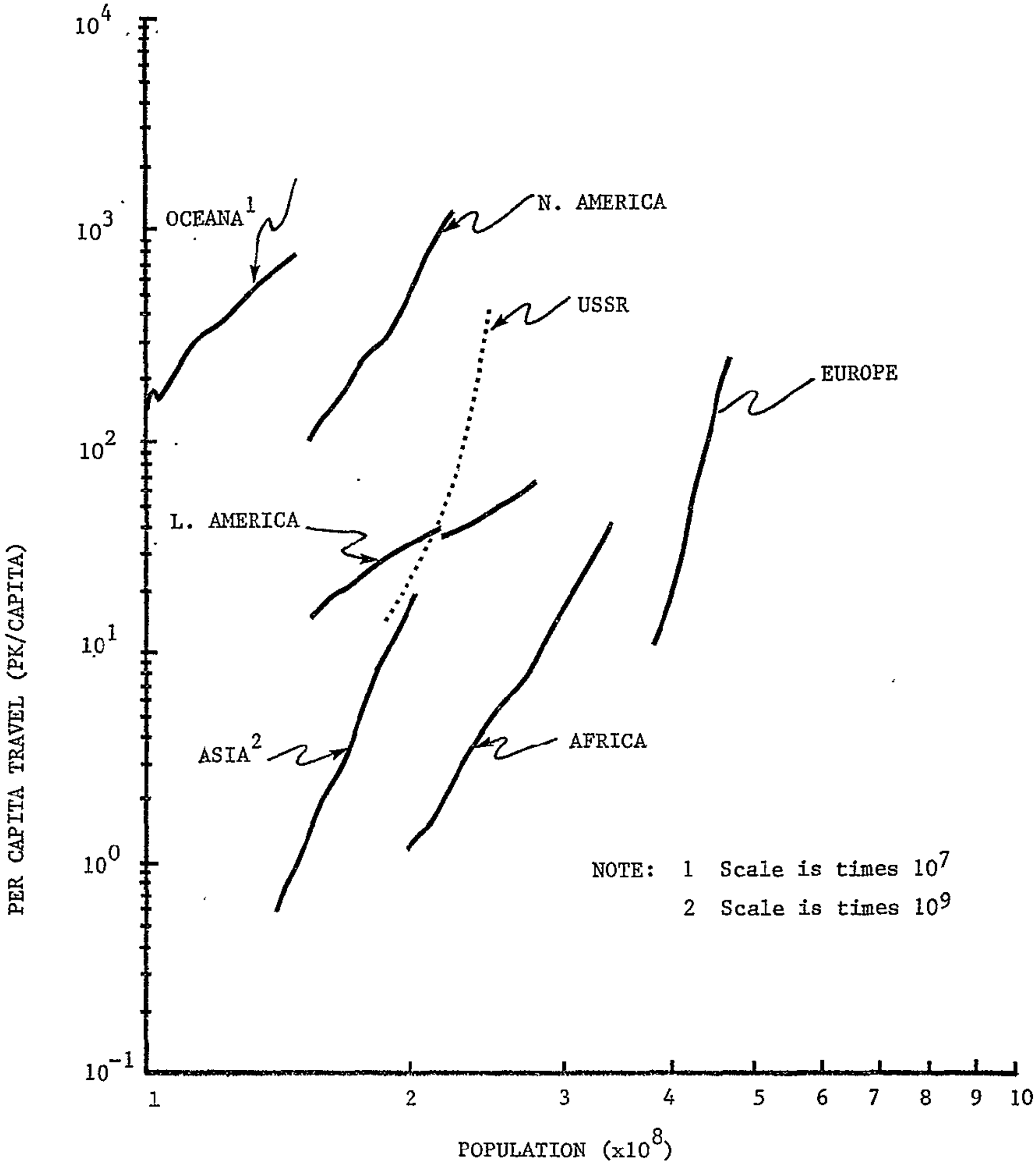


Figure 2.17: World Regional Population and Air Travel.

Source: Davis, R.E.G., The History of the World's Air Lines, Oxford University Press, London, 1964; ICAO, Traffic, Digest of Statistics, No. 169, 1972; UN Total Population Estimate for World, Regions, and Countries, Population Division, ESA/P/WP. 34, 1970

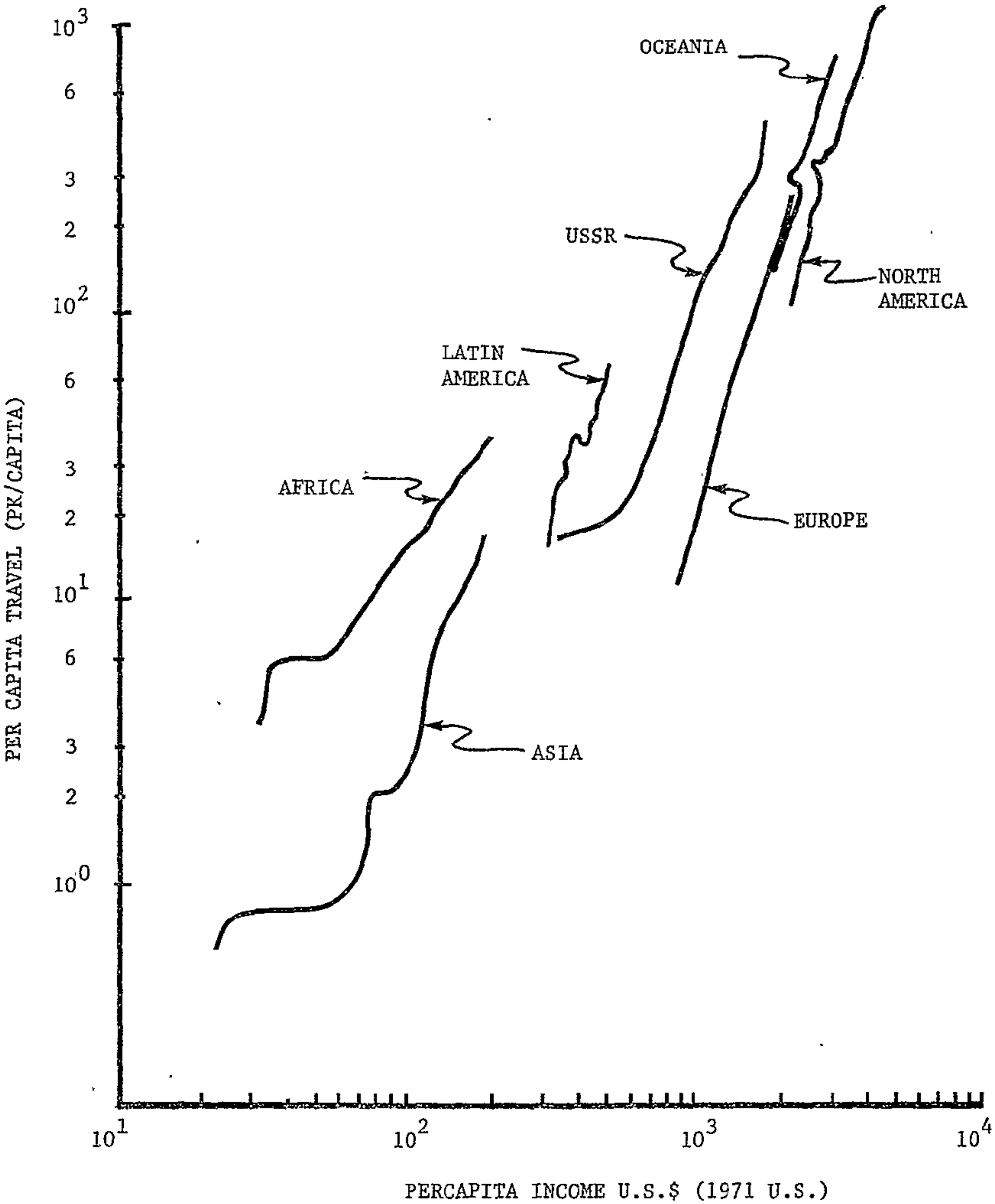


Figure 2.18: Regional for Capita Travel and Per Capita Income.

Source: Davis, R.E.G., The History of the World's Air Lines, Oxford University Press, London, 1964 ICAO, Traffic, Digest of Statistics No. 169. 1972 AID, GNP Statistics & Reports Divsion, Office of Financial MGN, March, 1973

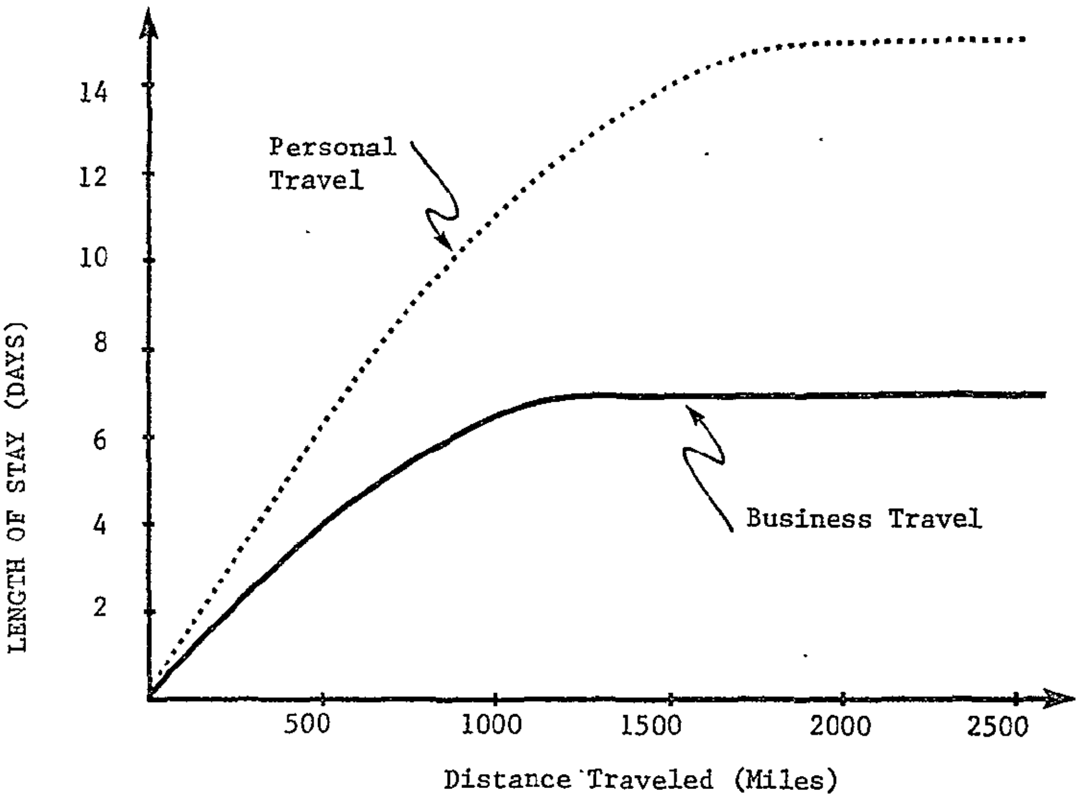
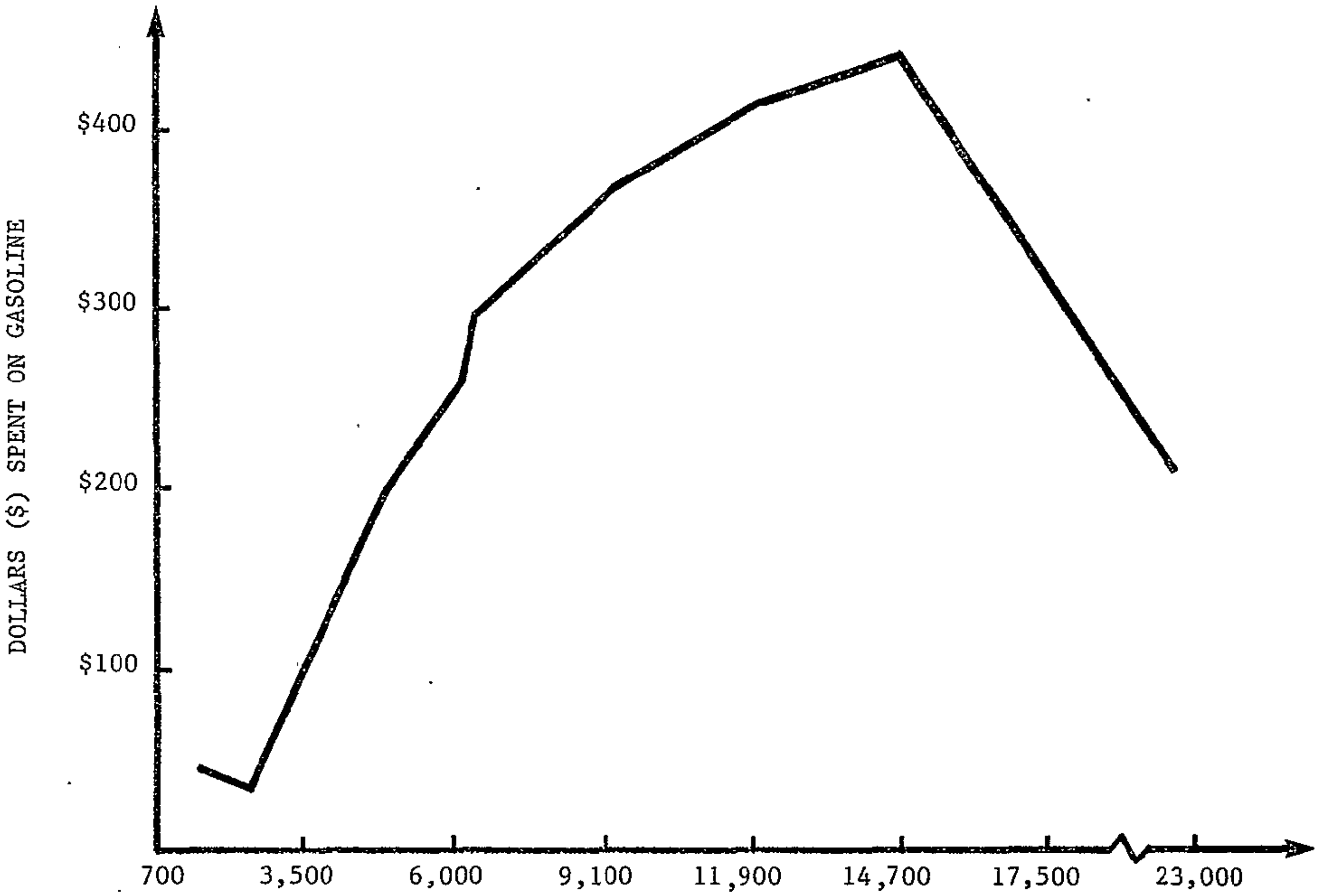
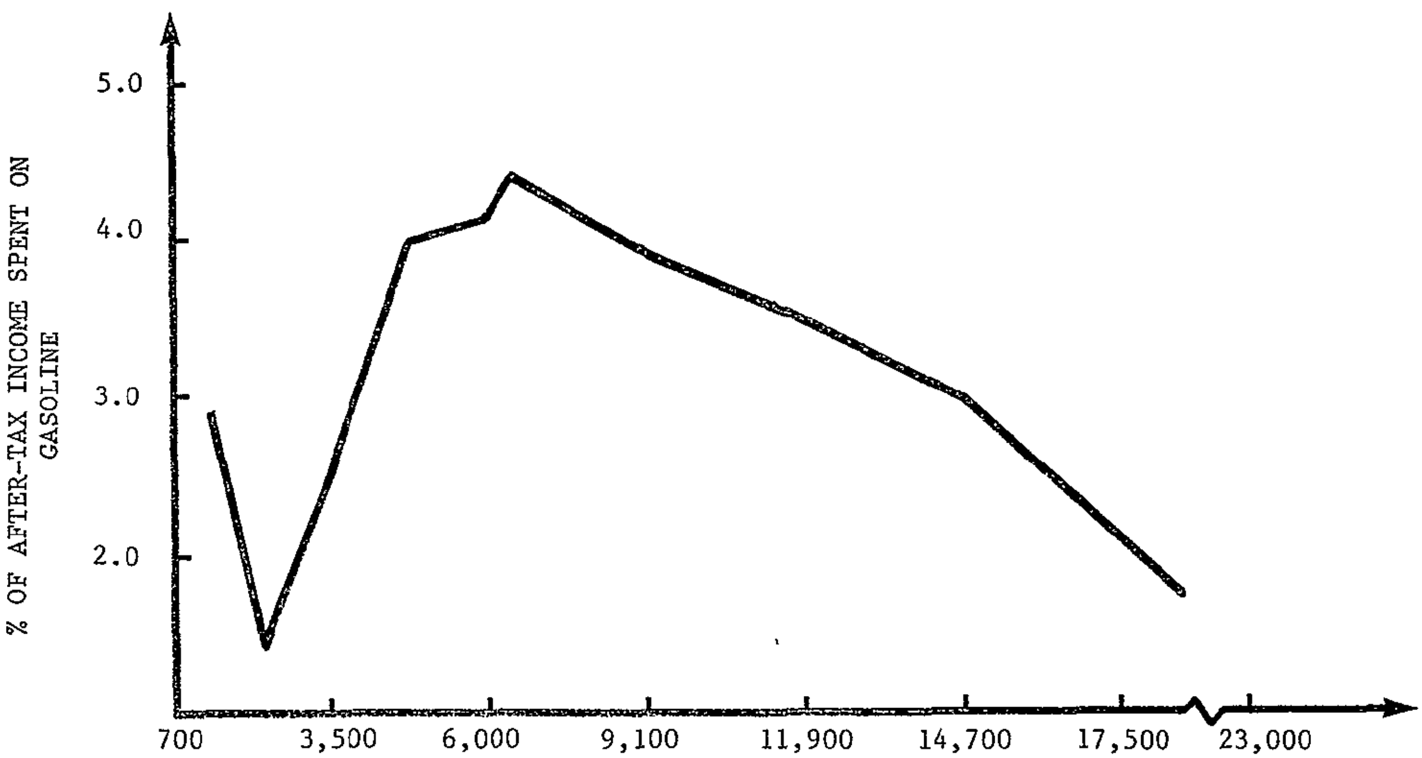


Figure 2.19: Length of Stay With Respect To Distance Of U.S. Travel.

Source: U.S. Bureau of Census, 1973



(A)
INCOME (1971 DOLLARS)



(B)
INCOME (1971 DOLLARS)

Figure 2.20: After-Tax Income Spent On Gasoline By Urban Households (1973)

energy availability, have been or will be discussed in other parts of this report. Research and development key factors will be discussed in the following section, under Aircraft and Engine Technology, while societal attitudes and energy availability have been discussed in Section 2.1 (socio-economic) and Section 2.2 (energy requirements), respectively.

2.5 Aircraft and Engine Technology

Fuel efficiency and thus fuel demand in air transportation is influenced by advances in aircraft and engine technology. Technological developments in turn come about as a consequence of social and economic pressures. For example, motivated by extreme necessity, many important aviation technical gains were accomplished during World Wars I and II. Advancement in technology, in short, is not only the natural course of progress, but also a response to exigencies of the times. Recently, air- and noise-pollution regulations forced the automobile and aircraft manufacturers to improve engine standards in order to meet new environmental requirements. Furthermore, the current energy crisis has focused attention on needs for engineering improvements for utilizing energy alternatives and effecting fuel saving.

Since the inception of the commercial jet age in 1958, aircraft performance and efficiency has been steadily improved. For example, the introduction of the turbofan, represented a significant step forward in engine technology. Engine manufacturers have continued to improve turbofan engines by utilizing increasingly higher by-pass ratios in order to improve specific fuel consumption.

A new version of the turboprop to emerge in the 1980s, to provide an even greater potential for fuel conservation, can be expected. During the past two decades the improvement in fuel economy due to advances in engine technology has been significant. Since the introduction of commercial jets, improvement resulted in a reduction of approximately 15% in specific fuel consumption. Projected improvements in technology to the turn of the century is expected to reduce the cruise fuel consumption a further 25%, as shown in Figure 2.21.

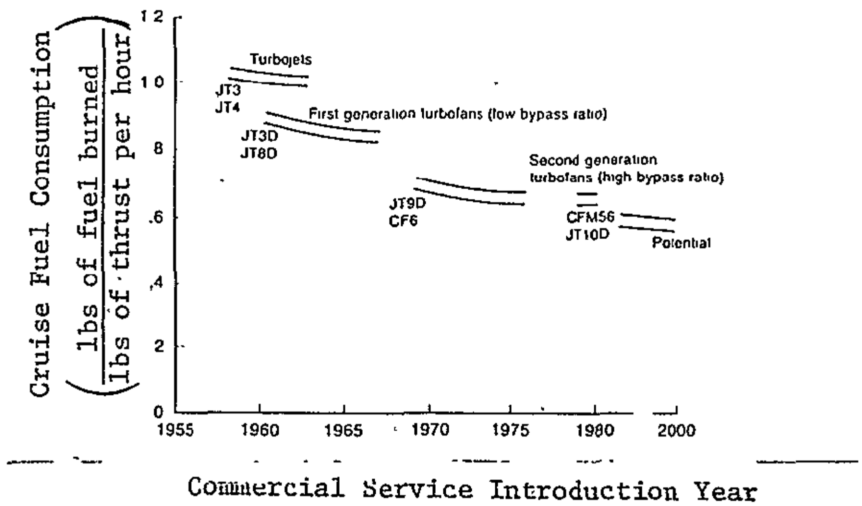


Figure 2.21 Improvement of Cruise Fuel Consumption for Different Jet Engines.

Source: Steiner, AIAA (January 1977)

Three areas in aircraft technology are expected to contribute to this improved efficiency of fuel utilization in air transportation. These three areas discussed below are: aircraft structures technology, aerodynamics technology, and engine technology.

2.5.1 Aircraft Structures Technology

Within aircraft structures technology two important improvements are in the offing.

Improved Structural Materials

The currently increasing strength-to-weight ratio of fiber-reinforced composite materials shows promise of saving up to 25% in the structural weight of future transport aircraft (these composites comprise of filaments of boron or graphite arrayed in an epoxy, polymide, or aluminum matrix). Compared to all-metal aircraft, one would expect a 10% to 15% fuel saving corresponding with structural weight reduction of 25%. It would seem reasonable that 10 to 20 years from now, aircraft will appear with major structural use of composite materials (Grey - AIAA, 1974).

Active Control Technology (ACT):

Active Control Technology offers two sources of improvement for structural efficiency: The first of these (the primary one) is that of decreasing the flight loads on a given aircraft. The fin gust-alleviator of the Boeing 747 and the active lift-distribution control system of the C-5A are examples of these. The second potential source of improvement offered by active control systems is that allowing new aircraft configurations that are inherently superior in structural weight and aerodynamic drag. This technology is farther in the future than that of ACT. Nevertheless, it has been estimated that structural weight could be reduced up to 14% by using Active Control Technology (Grey, AIAA, 1974).

Aerodynamic Improvements

Several methods for drag reduction and hence fuel saving are in the development stages. These can be delineated as follows.

Laminar Flow Control (LFC):

During cruise of current subsonic aircraft, approximately one half of the power needed to maintain level flight is required to overcome boundary layer skin friction; 70% of the fuel used on a transcontinental flight is consumed during cruise. Prevention of transition from laminar to turbulent boundary layer can reduce skin friction by 90% (Grey, AIAA, 1974). In terms of fuel savings, maintenance of laminar flow on 80% of the wing and 90% of the empennage during cruise can reduce fuel consumption by more than 20%.

The most effective means known to maintain laminar flow is by application of suction through slots or porous surfaces. However some of the energy from drag reduction is used up in powering the laminar flow and increased structure. It is estimated that an aircraft using laminar flow control could possibly be introduced into service by 1990, and depending on the extent of application as well as on length of route segment, 20% to 40% fuel saving may be gained.

Induced-drag reduction:

For most transport aircraft, the induced drag is approximately 40% of the total drag at cruise condition. Induced-drag reduction of about 15% may also be obtained for existing transport aircraft by adding a vertical wing-like protuberance to the upper surface of the wing, near the tip and toward the trailing edge (winglet). Around 6% fuel saving by using winglets could be gained.

Delay of Transonic Drag Rise:

Transonic drag rise substantially influences the cruise efficiency and fuel consumption of high subsonic speed transport, whenever the aircraft operates in this speed regime. The recently developed NASA super critical wing section (airfoil) significantly delays the onset of transonic drag. Possible improvements can provide a total reduction in both cruise and climb fuel consumption of about 5% (Grey).

Control and avionics for reduced drag during approach:

Avionics for improved management of the approach with delayed flap section and climb, cruise, and descent guidance are estimated to provide a potential fuel saving of 2% to 7% (Grey).

2.5.2 Aircraft Engine /Fuel Technology

There are two directions in which efforts are being made to advance aircraft engine technology which have direct relevance to aviation fuel consumption. The first of these is the effort to improve the efficiency with which the fuel energy is converted to thrust for propelling the aircraft. The second is the effort to improve the capability of the engine to utilize "lower-grade" fuels, that is, fuels having specifications less rigorous than current specifications. These two areas are discussed below.

By-Pass Ratio & Thermodynamic Efficiency

The highest by-pass ratio for current engines is 5 but it is expected to reach 10 within the next decade. High by-pass ratio engines have higher fuel efficiency but they need more maintenance than low by-pass ratio engines. One of the goals in designing new engines is to minimize the maintenance cost of high by-pass engines. A total of 10% fuel saving is expected due to this aspect of the propulsion system improvements (Pinkel, 1976).

The thermodynamic efficiency can also be improved through increases in compression ratio and in turbine inlet temperature. These improvements are paced to a major extent by the improvements in the technology of engine materials -- particularly the high temperature strength of materials for turbine blades and for combustors. However, it should be mentioned that because higher temperatures tend to increase NO_x emissions, environmental constraints may tend to inhibit taking advantage of possible engine thermal efficiencies.

A related potential source of improved efficiency is that of cooling-system technology to ameliorate the effects of higher operating temperatures. It is projected that the development of improved materials and/or cooling systems in 15 years may provide up to a 10% saving in fuel. It has been estimated that a fuel saving of 10% might be possible by further increases in the by-pass ratio, relative to current engines (Grey). These benefits are not being utilized on most commercial aircraft because the cost of fuel saved does not justify the cost of retro-fitting. Also the amount of maintenance required has tended to increase as by-pass ratio is increased.

Improved Capability to Use Alternative Fuels

Aircraft fuel technology is intimately related to that of aircraft engine technology; current engine design characteristics are matched to the characteristics of currently-available aircraft fuels.

The commercial jet fuel in use today is obtained from "high-grade" crude oil by a relatively simple and economical refining process. However, the supply of this high-grade crude may soon have to be supplemented by, and eventually replaced by, a supply of "lower-grade" crude from which it will be significantly more costly to refine jet fuel to meet current specifications so as to minimize, or eliminate, this potential cost increase.

Current commercial jet fuel (Jet A) is a high-quality kerosene-type fuel. Military jet fuel (JP-4) is a mixture of kerosine and naphtha fractions. A special high-flash-point fuel (JP-5) is used by the Navy on carriers because of safety reasons.

Fuel characteristics of interest include the following:

- Chemical Composition (Aromatics, Olefins, H/C Ratio)
- Impurities (Nitrogen Compounds, Sulfur, Trace Metals)
- Thermal Stability
- Freezing Point and Boiling Range
- Volatility
- Toxicity
- Combustion Characteristics

For example, one of these characteristics having important implications for fuel-specification economics is that of proportion of the aromatics in the fuel. Aromatics are undesirable, (the two predominant classes are paraffins and naphthenes) because of their ratio of hydrogen to carbon is only about half that of the other two components. This lower H/C ratio not only results in a lower heating value per pound of fuel but also tends to produce soot when it is burned. Soot not only causes environmental problems but also changes the radiation characteristics of the flame in such a way as to produce higher temperatures in the walls of the combustion chamber. It also forms deposits.

Current specifications call for a maximum of 22 percent aromatics in commercial fuels and 25 percent in military fuels. (Again the relaxed specification for military fuel is based on considerations of increased availability). During the 1973 embargo waivers were obtained to allow 25 percent aromatics in commercial aircraft.

Aromatics content can be reduced by extraction and hydrogenation (a high-pressure catalytic process) but this significantly increases the consumption of energy and of cost.

Recent research (Gleason and Bahr) has shown the possibility of burning fuels of aromatic content in the range of 30 to 40 percent without excessive soot formation. The burners used differ considerably from those of conventional design and will require a concerted development effort.

Situations analogous to that described above exist for other fuel characteristics, such as freezing point. It is clear that the choice of the optimum fuel/engine/aircraft combination is a matter of great complexity, since there are many technical, economic and supply considerations.

Maintenance Procedure

In addition to the two areas discussed above, there is a further area that deserves mention -- that of engine maintenance.

The fuel consumption performance of current engines deteriorates with use. The range of fuel consumption increases has been from 3% to 8%. On a fleet average basis, the rate of increase per year has been approximately 0.4% to 0.6% per year on the older JT3D and JT8D engines and from 1% to 1.5% per year on the newer higher performance engines. It is believed that a better understanding of engine component deterioration and revised maintenance procedures to incorporate more fuel efficient components could result in fuel savings of 3% in low by-pass engines and from 1% to 3% or more in high by-pass engines. An associated economic consideration is that maintenance costs are domestic expenditures while fuel costs are partly an import expenditure.

3. SCENARIOS

As described in Chapter 1, a scenario is a hypothesized depiction that represents a plausible description of what could occur over some prescribed time and within predicted environmental constraints. Such constraints are dictated by key factors which have been identified and discussed in detail in Chapter 2. In this chapter, five plausible scenarios will be presented. The five scenarios that have been established for this study are:

1. "<u>Resource Limited</u>" - based on Malthusian Theory, in which population is assumed to be increasing faster than food production and supply of other needs. This is the "Limits to Growth" viewpoint.

2. "<u>Socially Constrained</u>" - based on the assumption of inefficiency and wastes associated with market imperfections and institutional inadequacies.

3. "<u>The Interrupted Growth</u>" - based on the assumption that interruption in energy supply will be reflected in a corresponding interruption in economic growth but that society will eventually overcome the difficulties and growth will resume.

4. "<u>The Uninterrupted Growth</u>" - based on the assumption that the economy will continue to grow more or less as it has in the past (i.e., "business as usual") and energy will

not be constraining.

5. "Optmistic Growth" - the most optimistic scenario in the realm of feasibility. It is based on ever-increasing capacity to learn and innovate. Recessions and reversals will be negligible.

The fundamental assumptions of each scenario for North America and the world are presented in Tables 3.1 and 3.2 (Scenario Summary Charts), respectively.

TABLE 3.1: SCENARIOS SUMMARY CHART - NORTH AMERICA (1970 - 2025)

Variables	Scenario I Resource Limited Growth	Scenario II Socially Constrained Growth	Scenario III Interrupted Growth	Scenario IV Uninterrupted Growth	Scenario V Optimistic Growth
Population Growth (1976 - 2025)	1.2%	0.7%	0.6%	0.4%	0.2 - 0.3%
Total Population By 2025	400 Million	320 Million	300 Million	280 Million	260 Million
(% of the world)	3.5%	4%	3.2%	2.5%	3.6%
Location of Population	Move back to towns	Move to small towns and villages		Middle size cities will expand	Small and middle size cities will expand
Growth of GNP (1970 - 2025)	<1%	2%	3%	3.4%	4%
GNP Per Capita, $	6,000	12,000	20,000	26,000	33,000
Income Distribution		Large middle, end accelerated	Widening gap	Bottom comes up	Wealthy avg. - Very few rich
Quality of life -Pollution	Intolerable, growing much higher	Moderate, many pollution control devices	Moderate; comparable with GNP growth	Rather low; lower than GNP growth; more gain than loss	Low, almost no problem
-Unemployment, Crime & Violence	High	Costly-controlled	High in beginning, low later	Rather low	Very low
-Food & Health	Very poor	Poor, diet/nutrition controlled	Moderate	Satisfactory, improving	No problem
-Others					
State of Technology	Rather advanced in destructive technology	Slow technological growth	At the beginning, depressed; later high growth	Advancement in all areas. Aid from computers.	Exponential advancement. High level of automation.
Resources	Exhausted	Tight	At the beginning rather tight; later high growth.	Advancement in all areas. Aid from computers.	Exponential advancement. High level of automation.
Comparative Advantages & International Trade Situation (Import, Export)	Decline in trade, trend toward self-sufficiency.	More control on trade. Moderate - high rate of trade in specific areas (e.g., energy), but low rate of trade in general.	Drastic change in composition of trade, especially in energy-related areas.	In general moderate - High rate of trade.	Successfully computerized & automated society. Exports: Highly technological equipment & services. Imports: Low technological & labor consuming goods.

Variables	Scenario I Resource Limited	Scenario II Stability-Constrained	Scenario III Interrupted	Scenario IV Uninterrupted	Scenario V Optimistic
Fundamental Assumptions and Concerns	The resources on the earth are finite and their recyclability have practical limitations. Population is growing faster than food production and supply of other needs (neo-Malthusian). Pollution is increasing. People's interests and faith are declining.	Growth is not necessarily progress. We achieve something but also lose other things. Resources are not inexhaustible. There should be more order (exercised by gov't.), more controls, more careful (but slow) planning.	Energy is becoming a big bottleneck. There has not been enough capital investment in the energy area. The severity of the situation is not realized by people and governments. A depression period of 10-15 years develops during the next 20 years. After that period, the results of the research and investments will lead to renewed boom.	Energy problem temporarily will be solved by coal and shale oil production. By that time breeder reactor will be built. Many conservation measures will be implemented. We will be able to overcome resource scarcity. Our increasing efficiency (through advancement of technology) will always catch up with the increasing degree of dilution of resources. However, while this is optimistic, growth will be modest and steady.	Our learning capacity is always increasing. Computers artificial intelligence devices will increase this capacity exponentially. We will be able to use energy and material with increasing efficiency. Abundant energy at our service and the high level of our knowledge will enable us to get much more from much less material.
Economic Factors: Population Growth (1976 - 2025)	2.2%	1.5%	1.8%	2.1%	1.4%-1.6%
Total Population by 2025	11.4 billion	8 billion	9.4 billion	11 billion	7.8 - 8.6 billion
Population Distribution: - In developed countries	Move back to towns and villages	Move to towns	Little change in cities & towns	Middle size cities will expand	Middle size cities will expand
- In LDC	Congested large cities	Restrictions on large city development		Middle and Large size cities	Small and middle size cities
GNP Growth (Average) Between now & 2025	2.5%	3.0%	3% for developed 3.5% 4.5% for LDC	4% for developed 4.6% 5% for LDC	4.5% for developed 5% 5.5 for LDC
GNP Per Capita (Now $1,300)	$1,500	$2,600	$3,100	$4,500	$7,200
Income Distribution -Between Individuals	Increasing gap between rich & poor	Trend toward uniformity	Start to improve	Uniform gains	Gaps are closing
-Between Nations	Greater disparity between OECD & LDC	Little change	Start to improve	Uniform gains	Gaps are closing
Capital Investment	Low	Moderate	Low in early stage; moderately high later	Moderate to high	High
Trade	Trend toward self-sufficiency	Controlled, moderate-high in specific area; low in general.	Moderate in general. Disrupted in early stage. Moderate-high later.	Moderate to high	High
Quality of Life Pollution - keyed to development	Intolerable	Moderate	Moderate; comparable with GNP growth	Improving	Relative improvement.
Unemployment, Crime, Violence	High	Costly - controlled	High in beginning, low later	Moderate	Low
Health, Food	Poor	Diet/nutrition controlled	Moderate	Satisfactory	Improving
Education	Poor. A disturbed and confused system	Medium Standard & controlled. Low quality.	High oriented to technology.	Highly professional. Widening general background.	Long, efficient, and enjoyable learning period. Wide & deep general background.
Resources	Exhausted.	Tight.	At the beginning, rather tight. Later, sufficient.	Sufficient but not abundant.	Abundant.
State of Technology	Rather advanced in destructive technology.	Slow technological growth.	At the beginning, depressed; later high growth.	Advancement in all areas. Aid from computers.	Exponential advancement. High level of automation.

3.1 Resource Limited Scenario

This scenario is characterized by the concept of real and imminent finite limits to world resources. It is assumed that non-renewable resources can be estimated accurately enough to demonstrate the reality of the running-out phenomenon. It is further postulated that whatever amounts of the world's resources are consumed will forever be denied to others, and that proposed technological solutions to problems of pollution or scarce resources are short-sighted illusions that only compound the difficulties. In short the Neo-Malthusian theory is valid.

In the other scenarios, energy resources have annual additions to reserves arising out of vigorous exploration activities or development of other resources such as coal. However, in this scenario, resources are "finite" and no additions are assumed to be made. Moreover, the postulate is made that mankind is steadily and rapidly depleting earth's potential resources for foods, fuels and minerals and overwhelming its capability to absorb or recycle pollutants. A convincing case for this Neo-Malthusian resource-limited scenario is presented in the book, "The Next 200 Years" by Herman Kahn. It is the most pessimistic future, on the opposite end of the scale from the optimistic growth scenario which probably overestimates our aspirations and capabilities. Under this resource-limited scenario, society may not be capable of improving on existing technology and definitely would not have breakthroughs in technology to support new technology-oriented programs. This undoubtedly would have the most far-reaching effects on all sectors of the economy. Transportation, which depends to a large extent on petroleum products, would be severely curtailed as energy resources become depleted. Air transportation, as part and parcel of total transportation, as well as being an energy intensive mode, would be directly affected, even though it uses less than 15% of total transportation energy. Aviation fuel supplies could decline as energy resources are depleted. If society continues to use resources as it has in the past, the economy would degenerate to a situation characterized by unemployment, crime, chaos, and massive world-wide starvation. Such a prospect would force so great a major change in life styles that no reasonable options could remain open for expanding air transportation. Because of this, no serious consideration has been given so far to developing a detailed description of this scenario.

3.2 Socially Constrained Scenario

In this scenario the assumption is made that there is inefficiency and waste associated with imperfect markets as well as inadequate institutionalism. Institutional constraints are prevalent and impede growth and progress of the economy. Resources are capable of supporting the economy only if institutional regulations are imposed to control consumption. In this scenario, the effects of institutional constraints on development are huge, resources will not, in themselves, be constraining and economic growth will continue without serious interruption. However, smooth growth is much slower than it has been historically.

Under this situation, coal will not grow at the 5% rate announced by the U.S. Administration, as society may not be prepared to accept its associated environmental impacts. Neither will nuclear energy grow at the 17% per year rate projected by various studies. Society may not be willing to accept standards proposed to safeguard nuclear reactor operation. Cartel behavior and international politics are assumed to decrease production from OPEC nations. These socio-economic constraints together with the complexities of world oil pricing would affect energy supply. If this is so, all sectors of the economy would experience a slow growth. This would most likely have an attendant effect on air transportation which may then be expected to experience a related slow growth. This might be due partly to a fuel supply insufficient to support the air transportation industry. Coal resources for obtaining new fuel for the aviation industry or a break-through in the technology required for oil shale development may be a factor in aviation fuel supply. In such a societally-constrained scenario, institutions would inhibit both coal and shale development because of inherent safety and pollution impacts. Furthermore, financial institutions would be slow in raising needed capital.

While this scenario has greater significance as a basis for NASA R & D policy, it remains to be developed more completely.

3.3 Interrupted Growth Scenario (or Energy Constrained Scenario)

The interrupted-growth scenario is determined by a lag in development of new energy resources as world petroleum production sags. This will result in a gap between potential demand and available supplies. Of course supply and demand will be equilibrated somehow by price adjustment, rationing, or simply by failure to develop full economic potentials. Therefore, instead of steady growth or steady decline, there will be a period of depression. However, this depression will be followed by a resurgence of growth as new energy production comes into being. As described in section 2, which dealt with historical and key factors, there is a well-established historical correlation between energy consumption and GNP. While there are those who contend that this is not a causative relation, there is supporting evidence that indeed it may be so. If energy does underpin GNP, then it is clear, as the world shifts its energy dependence from petroleum to coal, nuclear, and other sources, that an inability to provide a continuing smooth energy supply will indeed cause a disruption of world economies. This scenario is predicated on dependence of GNP on energy and so the possibility for such an energy development-lag must be considered.*

The U.S., which accounts for over 30% of world petroleum consumption (Bureau of Mines, 1976), may be the key economy in determining the

*The WAES workshop recognizes the same problem of a gap, but their scenarios are not conceived in such a way as to explain how the gap will be filled. They clearly recognize that either the supply side must adjust upward or the projected GNP growth will fail to materialize as envisioned.

shape the world energy future. If the U.S. does not move quickly enough to convert from a major dependence on oil to some other energy source, a disruption to the world economy may occur regardless of what other countries do. For this reason, the energy-constraint scenario is developed largely in terms of events within the U.S.

It would take 10 to 15 years from the initiation of a serious program to develop new energy sources before the rate of production of new energy is sufficient to offset declining petroleum production. This may occur even if a serious conservation effort is made. Oil and gas production have been declining in the U.S. at a rate of 2% and 1.7% per year respectively since 1970 and their decline seems likely to continue or even accelerate unless a major program for secondary and tertiary recovery is pressed. Synthetic fuels from coal, as a result of an intensive 10 year capital expansion program, could conceivably start to grow at a rate of 10% per year or even higher by 1990. However, in order for this to happen, production will be limited by inadequacy of existing facilities during the early 1980s, and so might not grow at more than a 2% per year rate of increase. Thus, a decline in U.S. energy output might accelerate. This situation, arising from declining production rates of oil and gas in the U.S., which is now compensated for by expanding imports, will be exacerbated by a drying up of OPEC sources as a result of policy decisions or otherwise. Imports, expanding at present, could therefore give way to zero growth rate for a few years and then, towards the end of the century, decline at a rate of 10% per year, or more. The curve in Figure 3.1 shows total energy supply and its components under

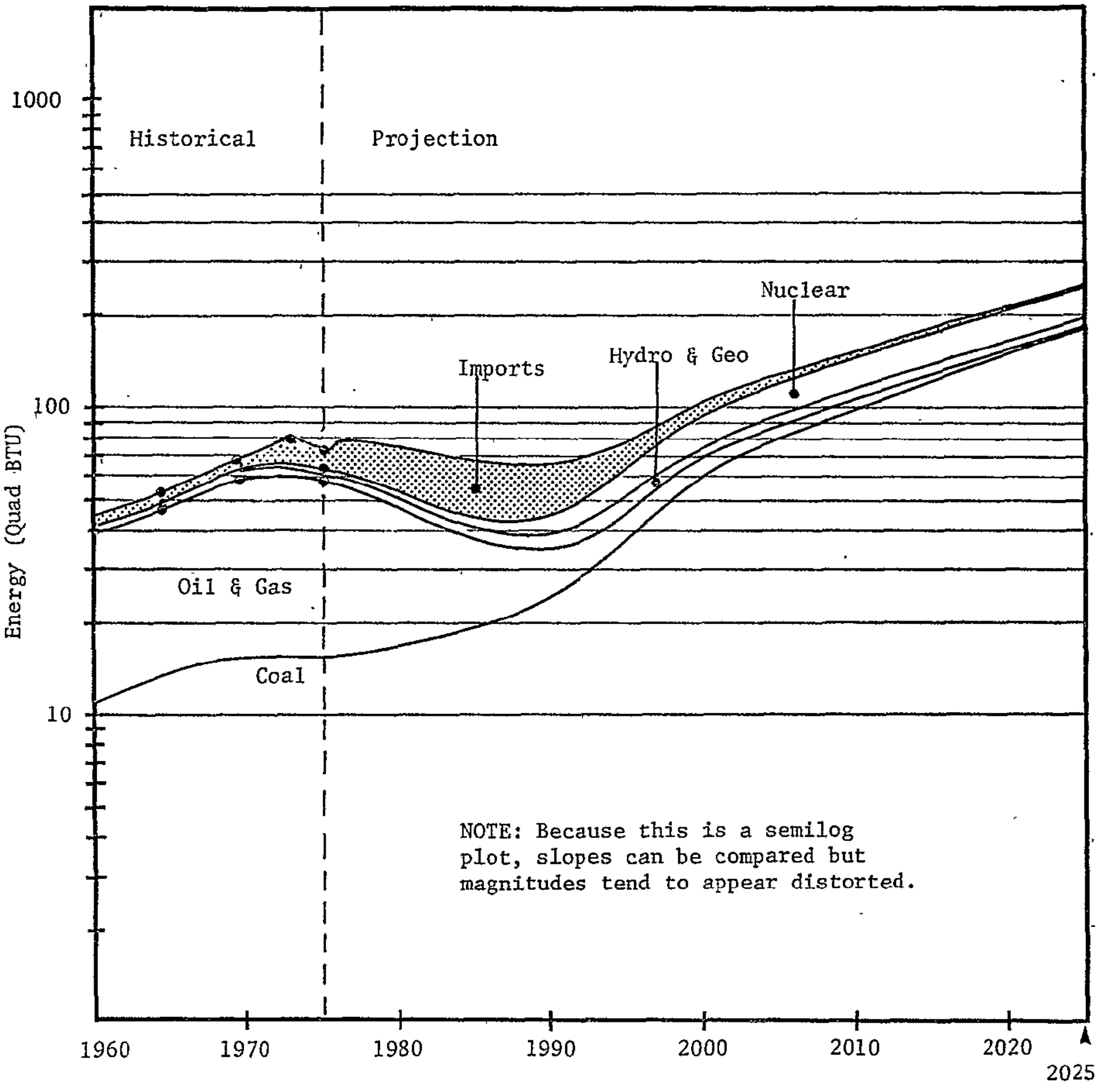


Figure 3.1: U.S. Energy Supply -- Historical and Projected to 2025

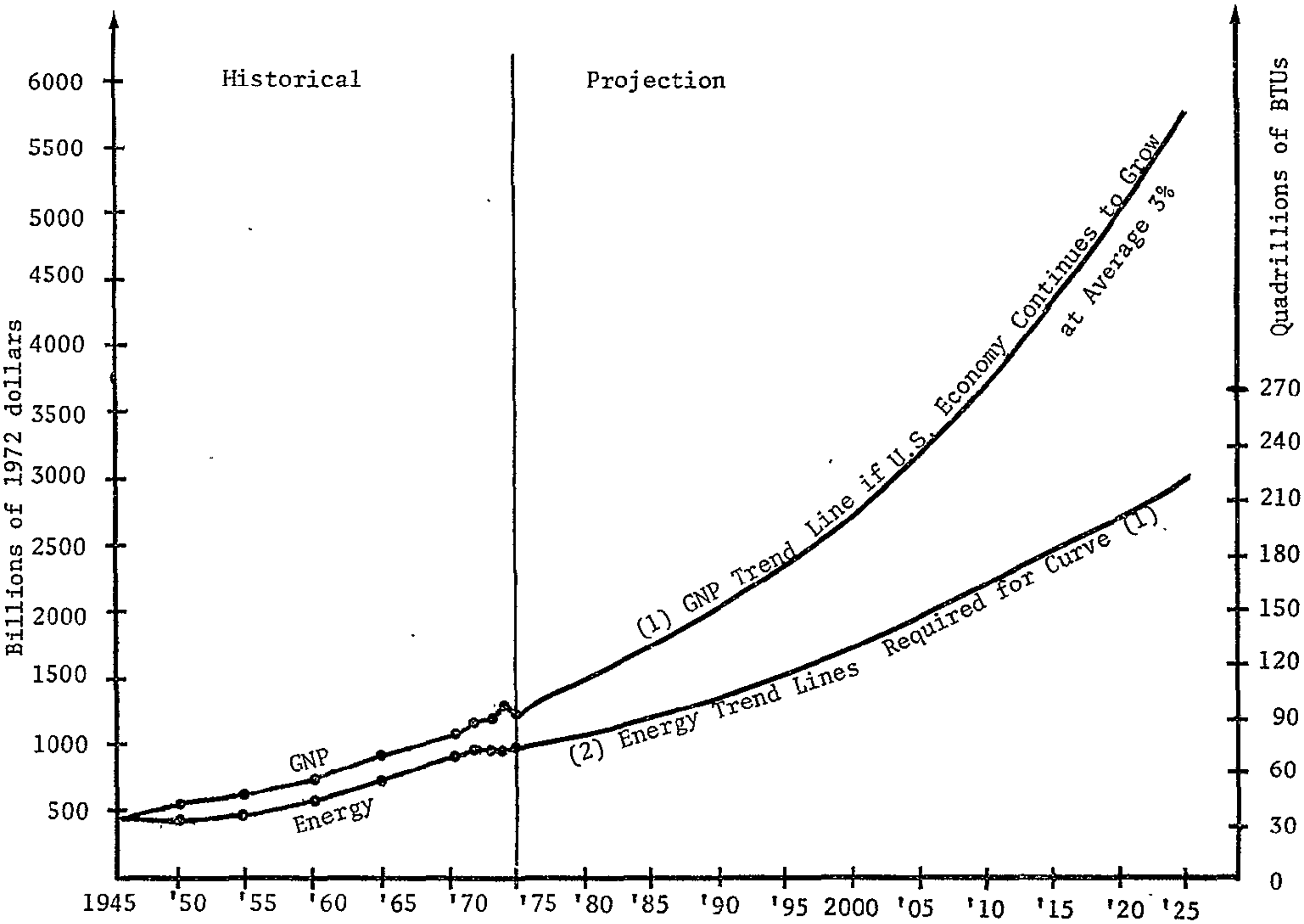
Source: Historical Data
Bureau of Mines 1976

the following postulations:

1. Coal: 2% annual growth to 1984, 4% to 1990, 10% to 2000, and 4% to 2025 as demands may again be in balance with supply.
2. Domestic Oil & Gas: 2.2% annual decline to 1978, 10% decline to 1995, and constant production to 2025.
3. Hydro & Geothermal: 3% annual growth to 2025 (a small and non-determinant component).
4. Nuclear: 8% annual growth to 1984, 10% to 2000, 6% to 2010, and 4% to 2025 as the demands may be in balance with supply.
5. Imports: 10% annual growth to 1982, 0% to 1990, and 10% decline to 2025.

3.3.1 Economic Growth and Energy Consumption

The economy, as measured by GNP, has been closely coupled with energy use. There has been, however, a decline of energy use per unit of GNP. This relationship is expressed as energy intensity -- BTU's per dollar of GNP. Since 1920, the energy intensity of the U.S. economy has been declining at the rate of about one-half percent per year. It is conceivable that this long-term trend might accelerate under conditions of a constrained energy supply. Emphasis on conservation, improved automobile efficiency, more efficient heating and cooling, might lead to an expectation that considerable savings of energy are possible. However, the potential savings may be illusory, because two things serve to reduce hoped-for savings. Firstly, government policies for encouragement of energy conservation might go largely unheeded. Secondly, many programs aimed at conserving energy over the long run, might even, in the short run, impose additional energy demands. These added demands would, in effect, be energy-capital investments essential for saving energy. Switching to smaller automobiles, increasing insulation in homes, building of solar systems, and the like, will all require energy investments. Such new business activity may be needed as a stimulus to GNP growth to offset the depressing effects of reduced energy demands in the consuming sector. For these reasons, it is logical to assume that the long term trend of declining energy intensity will continue in the future much as it has in the past -- about 1/2% a year (Figure 3.2). At the same time, a net energy savings during the depression period might induce an acceleration of the improvement in energy intensity of the economy. Therefore, in Figure 3.2, a 1% per year rate of decline of energy intensity during the depression years is assumed. Even with this somewhat optimistic early gain from conservation, a 30% shortfall in energy, relative to requirements by the trough in 1990, will occur (see Figure 3.3). Thus, with the assumed causative relationship between energy and GNP, there will be about a 30% disparity between potential and actual GNP. Such a disparity assumes catastrophic proportions. Clearly, technological advances would also slow so that a 30% gap would not reflect in a proportionate increase in unemployment. Nevertheless, this gap between potential output and capacity utilization could translate into unemployment in the order of 15% to 20% and a subsequent overall decline in living standards. Such a depression level is roughly the same as the depression period of the 1930's. On the more optimistic side of the scenario, expanding new energy supplies during the late 20th century will spark recovery of the economy. However, institutional



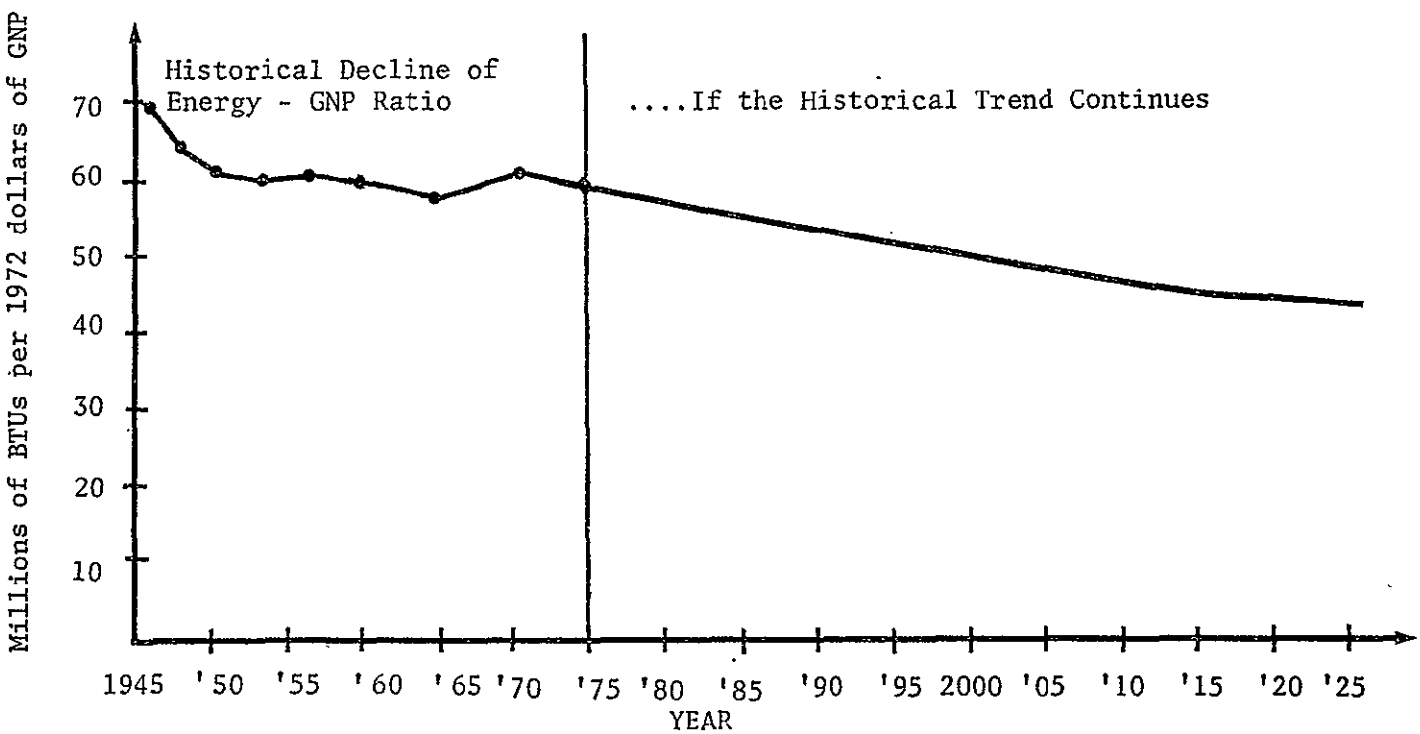


Figure 3.2: Energy and GNP Trend Lines

Source: Historical Data
Business Week, 4/25/77

structures, evolving new life styles, as well as perceived consumption goals may be markedly different from what they are at the present. Under steady growth conditions, societal characteristics change by evolutionary processes, but major economic disturbances such as postulated here undoubtedly would create revolutionary change.

Technological change which accounts for productivity increases can be expected to develop normally at a rate of 2% to 3% in consonance with the uninterrupted growth scenario. With allowance for the declining trend of energy intensity, the normal expectation of energy demand would be 110 Quads by 1990. However, the availability of energy at the low point of supply is only 69 Quads. This means that at the nadir of the depression period, the economy will be operating at about 70% of its potential (Figure 3.3), in terms of available energy. Under such depressed conditions, the rate of technological changes, as already noted, will also tend to be considerably retarded, so that the potential demand will be well below an energy economy that demands 110 Quads.

3.3.2 Energy Sharing

In context with the depression economy, an intense competition may arise from the "squeezed down" supply of energy. Those sectors more vital for survival will command higher priorities than the luxury-oriented sectors of the economy. However, recall that the scenario requires eventual economic turn-around accompanied by a renewed rapid energy expansion in the 1990's. In order for this to happen, large-scale capital projects will have to be pushed ahead vigorously during the 1980's. Therefore, even during depressed conditions, heavy indus-

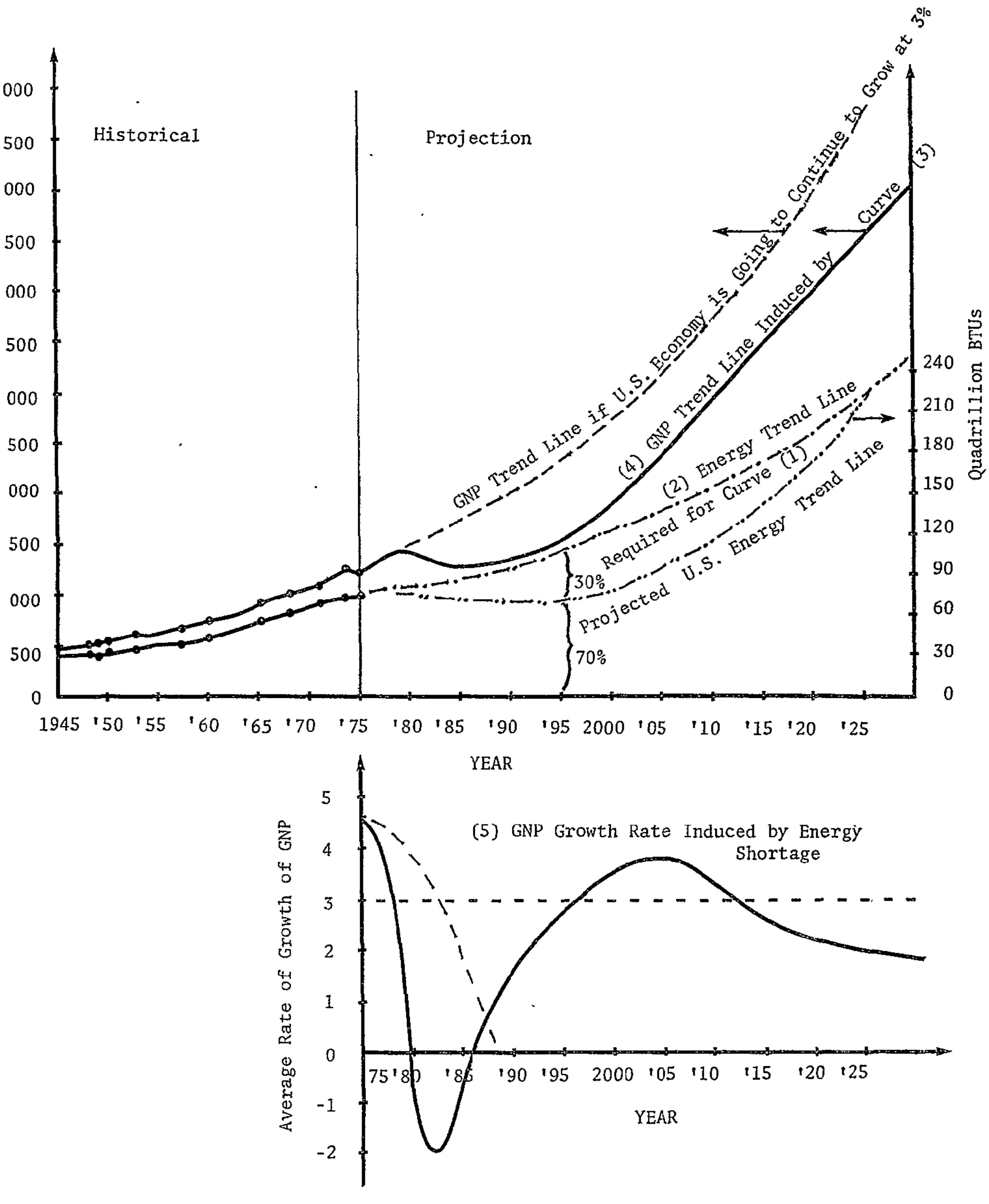


Figure 3.3: Energy and GNP Trend Lines

Source: Historical Data
Business Week, April 1977

trial expansion must be taking place. Thus, the industrial sector will be growing and, even with improved efficiencies, will be creating proportionately higher energy demands. If coal and nuclear energy are expanding at a rate of 10% per year by the 1990's, the capital goods industries will have had to expand at a comparable rate all through the 1980's. This could require 10% - 15% growth rates for the energy-related industrial sector.

On the other hand, strong government emphasis on energy conservation for space heating and automobile use is bound to have its effect, even if less than desired. A decline in demand of 5% per year for each of these uses, while quite ambitious, is plausible, as shown in Figure 3.4.

3.3.3 World Effects

When we examine energy production possibilities in various regions of the world, we can see that there are indications that world oil production could sag around 1990 as mentioned earlier. For instance, OPEC nations which have supplied the greatest share of oil in the recent past, have announced possible production limits (WAES, 1977). If this happens, it is inconceivable that there will be significant production increases in the 1990's. Moreover, countries such as Nigeria are producing at levels consistent with their desired economic development. Other potential suppliers such as Venezuela, are concentrating on developing their heavy oil reserves in the Tar Belt and though the recently discovered North Sea oil reserves are being developed now, it is improbable that significant supplies would come

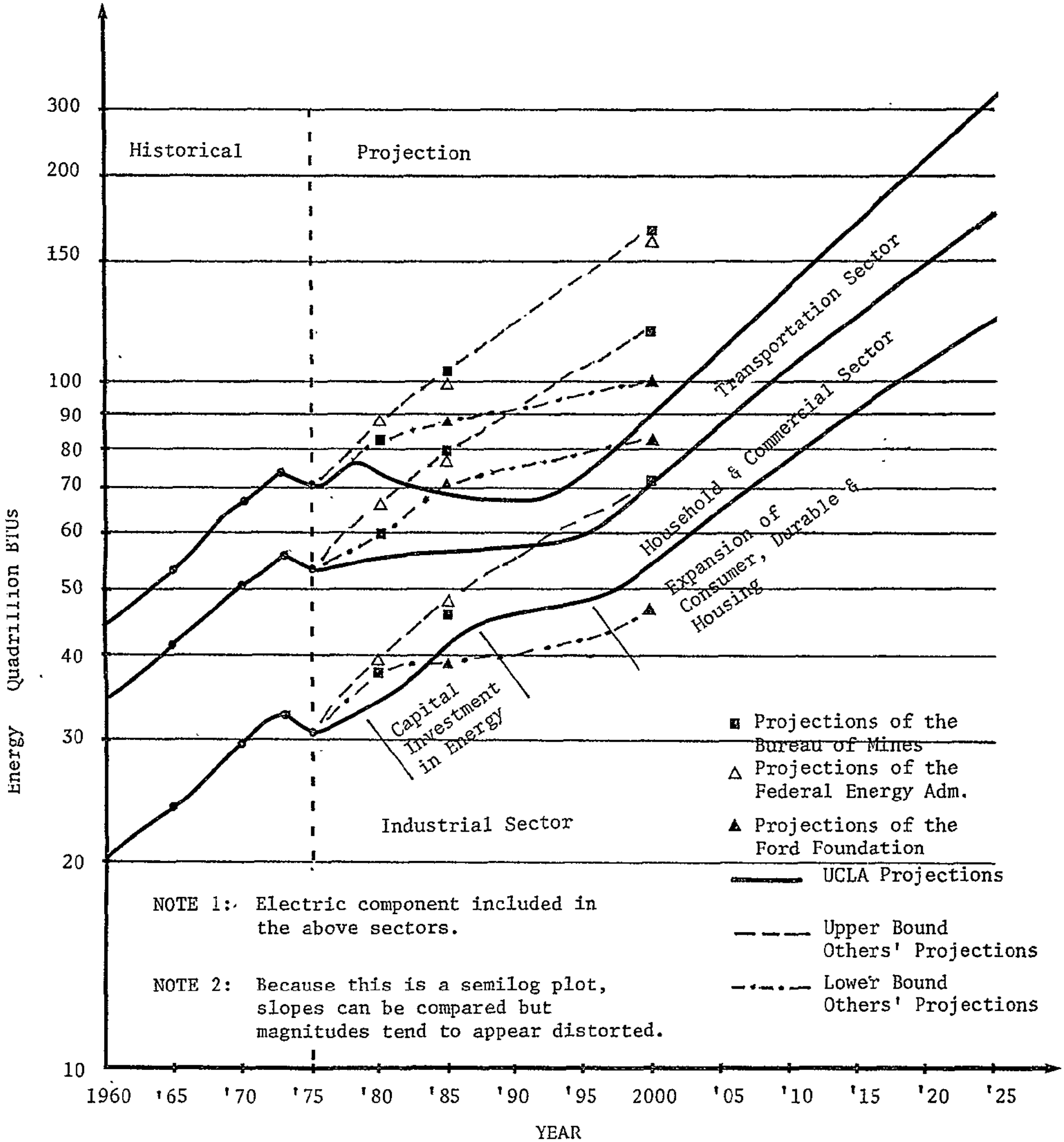


Figure 3.4: U.S. Sectorial Gross Energy Input

Source: Historical Data
Bureau of Mines, 1976

from these two areas before 1990. As can be seen in Table 2.7, the U.S. has the greatest measured reserves of coal in the world. Its coal production could not grow at more than 4% per year because of limited facilities. If this is the case, slight increases in coal production would be felt before 1990. Europe's production is almost stable with a potential for slight increase as old mines are depleted and new ones developed. Canada, Latin America and the Far East could increase production if facilities are expanded. Since it takes some time to expand facilities, production in these areas is expected to increase, but not significantly before 1990. Therefore, overall world coal production could increase, but not significantly, before 1990. Natural gas reserves are widely distributed as can be seen in Table 2.8. OPEC nations have potential to increase production. However, increased production is predicated on construction of pipelines and transportation facilities for interregional and international gas movements (see Section 2.2). It is not likely that such facilities could be built and completed soon enough to permit flows before the end of the century. Hence, the contribution to total world energy, from natural gas, is not expected to increase before the 1990's. Neither is nuclear energy expected to grow, partly because of international fears surrounding the possibility of nuclear arms proliferation and partly due to environmental constraints. Other sources of energy are tar sand, oil shale and solar energy. Although there are significant deposits and accelerated development of tar sand in Canada, it is not likely that its contribution to the total energy supply would be felt before the end of the century. Shale oil deposits in the U.S., Brazil, and Canada are massive as seen in Section 2.2 but developmental work is progressing slowly because of technological and environmental constraints. Therefore, the benefits added by this resource to total energy supply are not expected until after the 1990's. From the foregoing, it could be postulated that world energy production will sag around the 1990's and possibly resurge shortly after that as new energy forms contribute to the total supply. The effect of the energy situation on transportation outlooks is developed in the following section.

3.3.4 Transportation

Transportation of products used for personal consumption will most likely be constrained. Railroads, as an essential component of industrial development, will need to expand. They will also have to modernize to accommodate an expanding coal and steel demand. However, rail shipments of automobiles and other consumer goods may decline. Such effects will translate into major geographical shifts in freight movement.

The effects on trucking can be analyzed by considering, separately, lightweight trucking and heavyweight trucking. Lightweight trucking, devoted mainly to transport of finished goods for the urban consumer market, should be constrained for the same reasons as for automobiles. Heavyweight trucking activities, on the other hand, might or might not decrease, depending on the availability of railroad services. Regardless, interstate heavyweight trucking may be expected to function under greatly improved operating procedures. For example, round-trip cargo hauling may be encouraged, whereas regulations often require one-way cargo hauling today.

It seems likely that the automobile will be the most readily constrained mode of transport. As people feel less affluent, they will be more readily disposed to car-pool. Automobiles will be lighter and more efficient. Long vacation trips will be restricted and average mileage per car reduced. Furthermore, urban mass transit systems will be better utilized. Even with all of these, it is unlikely that the rate of decline will level off as the pressures of economic contraction diminish and, when growth resumes, a newly structured automobile transportation system will grow in keeping with the economy as a whole. The driving habits of the public will never again be the same as now. The automobile will probably be used more for pleasure than for journey-to-work trips because the impetus of the depression decade will start a major growth of efficient public transportation.

These factors, taken all together, are assumed to transform into energy growth curves in the transportation sector as depicted in Figure 3.5. Air transportation component of this total energy is shown in Figure 3.6.

3.3.5 Air Transportation

Air transportation, as part of the overall transportation sector, may be viewed in two parts -- cargo and passengers. Cargo has been the most rapidly expanding component of the industry over the past 15 years. However, this has been on a much smaller base than passenger traffic. Because of this, it is a much less visible component of air traffic and, to some extent, has been accommodated by belly cargo on

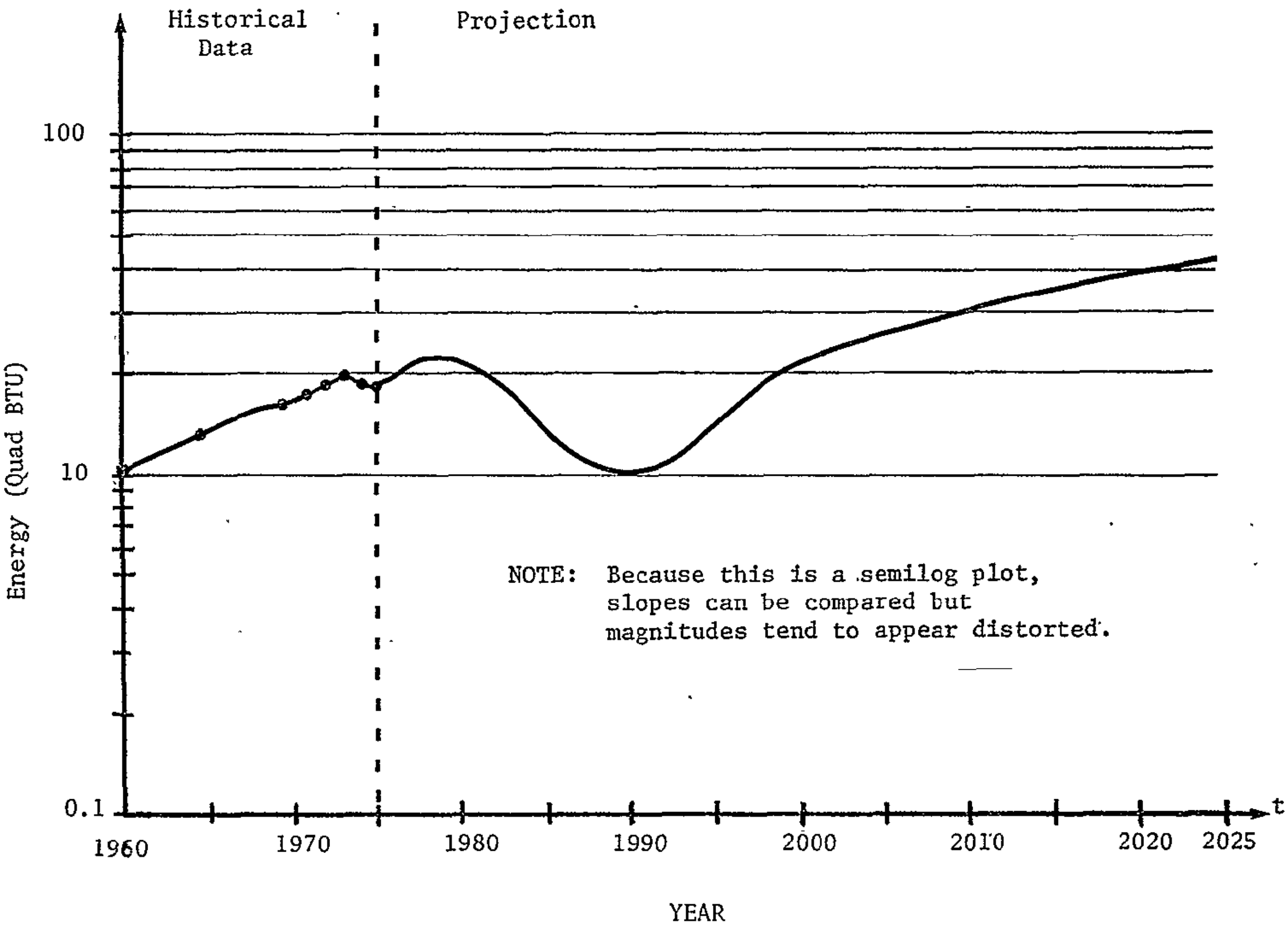


Figure 3.5: Total Transportation Energy Requirement

Source: Historical data based on A Time to Choose..., Ford Foundation, 1974.

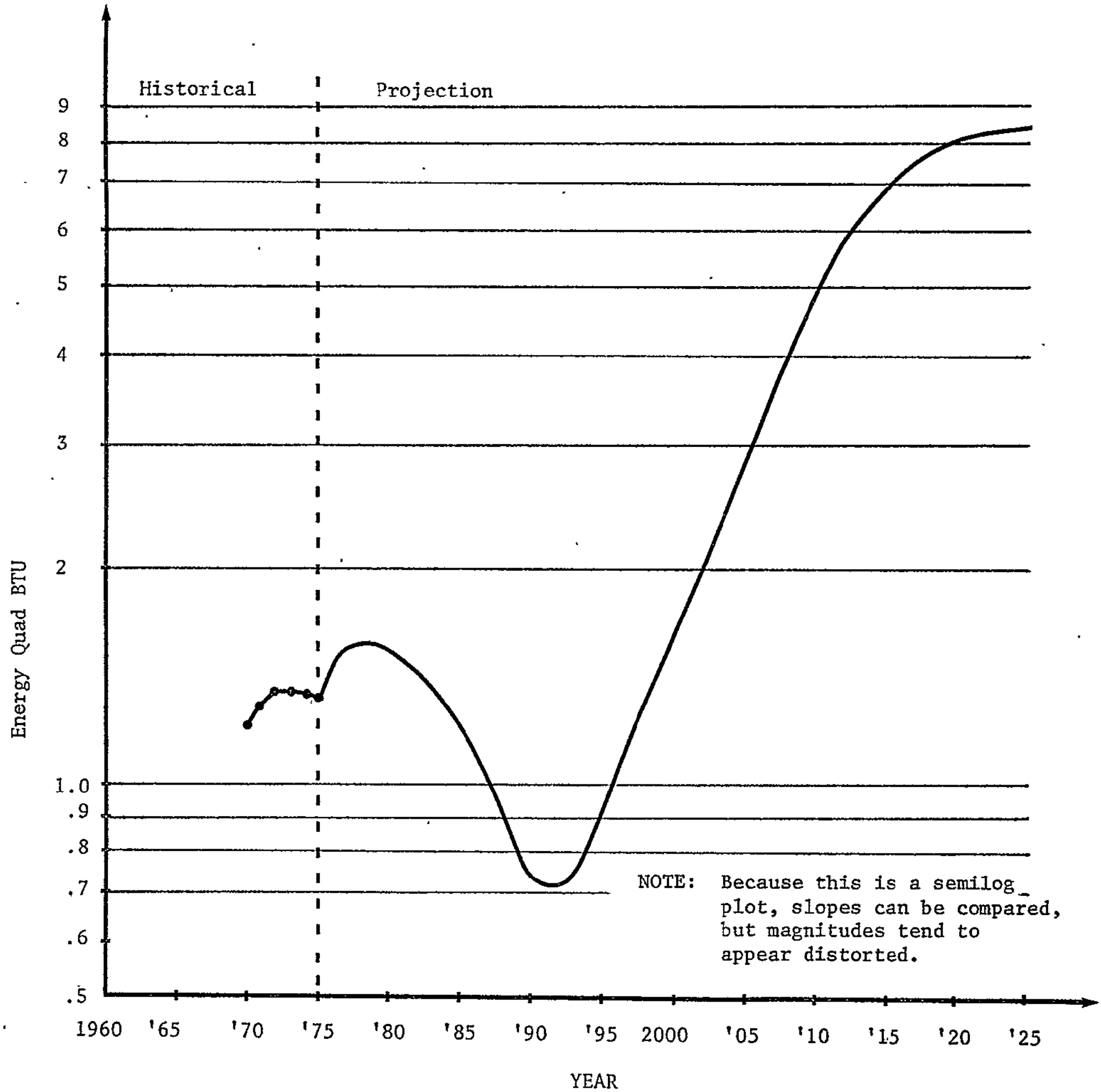


Figure 3.6: Air Transportation Energy Requirement

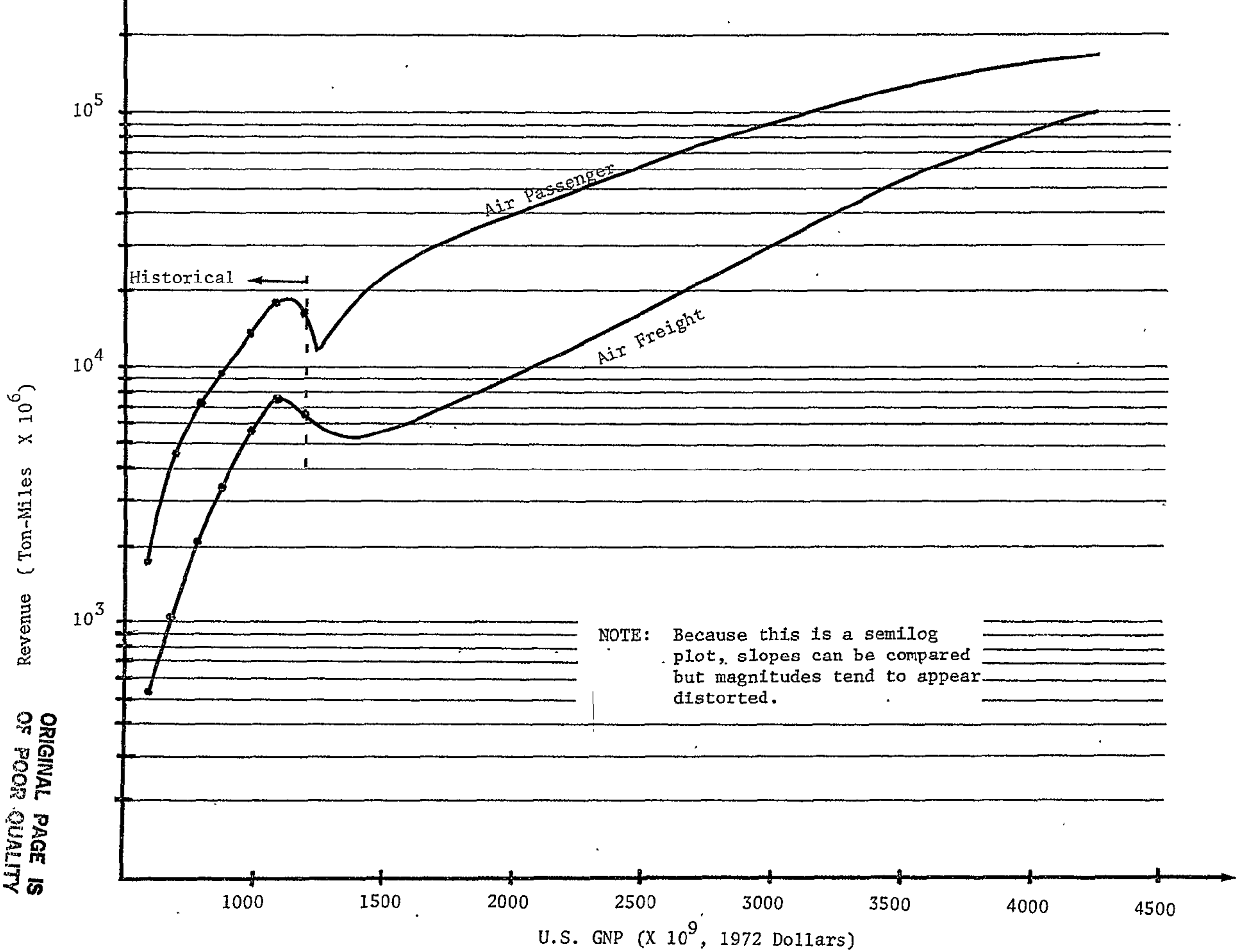
passenger jets. The type of freight suitable for air shipment has and will continue to be high-value, high-density merchandise. There is considerable potential for expansion of perishables, particularly exotic fruits. However, under the constrained economy, the realization of this potential may be slowed. Thus, while air cargo will be seriously affected by the decline in the economy, it can be expected to decline less than other transport sectors. Its rate of decrease is assumed to be 3% per year from 1978 to 1993. When economic resurgence occurs, air cargo may then be expected to exhibit even stronger growth than before.

Passenger traffic, on the other hand, has a bimodal characteristic. Business travel which is closely correlated with negotiation and planning of new programs will relate to capital expansion while pleasure and personal travel will contract. Since so much of business travel will be connected with solution of the energy problem, the main effect will be on long-haul, intercontinental flights to Europe, the Middle East, and Indonesia, as well as transcontinental U.S. route segments.

In the past, the breakdown of air transportation has been related to GNP, (Figure 3.7). Extrapolation of these trends as modified by the energy constraint and GNP is shown in Figure 3.7. While personal travel may be expected to decrease significantly, expansion of business travel will offset this decrease and so limit aggregate air travel to a decline at a 5% rate. As new energy resources become available, both air travel and freight will resurge. By the year 2025, growth of air transportation might only then tend to saturate at a 5% rate slightly

Source: Historical Data
Based on CAB 1975
& Business Week, 1977

Figure 3.7: Relation Between U.S. Air Traffic and GNP



in excess of GNP growth. Under the assumptions discussed above, the effects of these tendencies on air transportation are shown in figures 3.8 and 3.9 in terms of air passenger revenue ton-miles and air freight ton-miles, respectively.

3.3.6 Aircraft Technology and Fuel Efficiency

Within this scenario, the energy scarcity is forcing aviation fuel prices to increase more rapidly than other energy prices. Consequently, the concern for fuel conservation will increase. Furthermore, aircraft will be retained for longer service lives even though they will not be as efficient as potential new designs. Because of possible fuel allocation and savings policies, airlines will revise flight scheduling to decrease flight frequency and to increase load factor. With high load factors, energy intensity of air travel as measured by pounds of fuel per passenger mile, would undoubtedly improve. The availability of aviation fuel from petroleum may prove relatively greater than for other scenarios. This eventuality would produce the least pressure for changed fuel specifications. However, other industrial demands for intermediate weight petroleum fuels could intensify the competition for the same fuels needed by the aviation industry. The latter is felt to be the more likely outcome and therefore could necessitate a major change in fuel specifications. Thus, in the near future, aviation fuel would contain a higher percentage of aromatics and would have higher freezing points.

Because of high load factors and expected retirement of old airplanes, by 1985, the BTU/ton-mile required might decrease by as much as 10%.

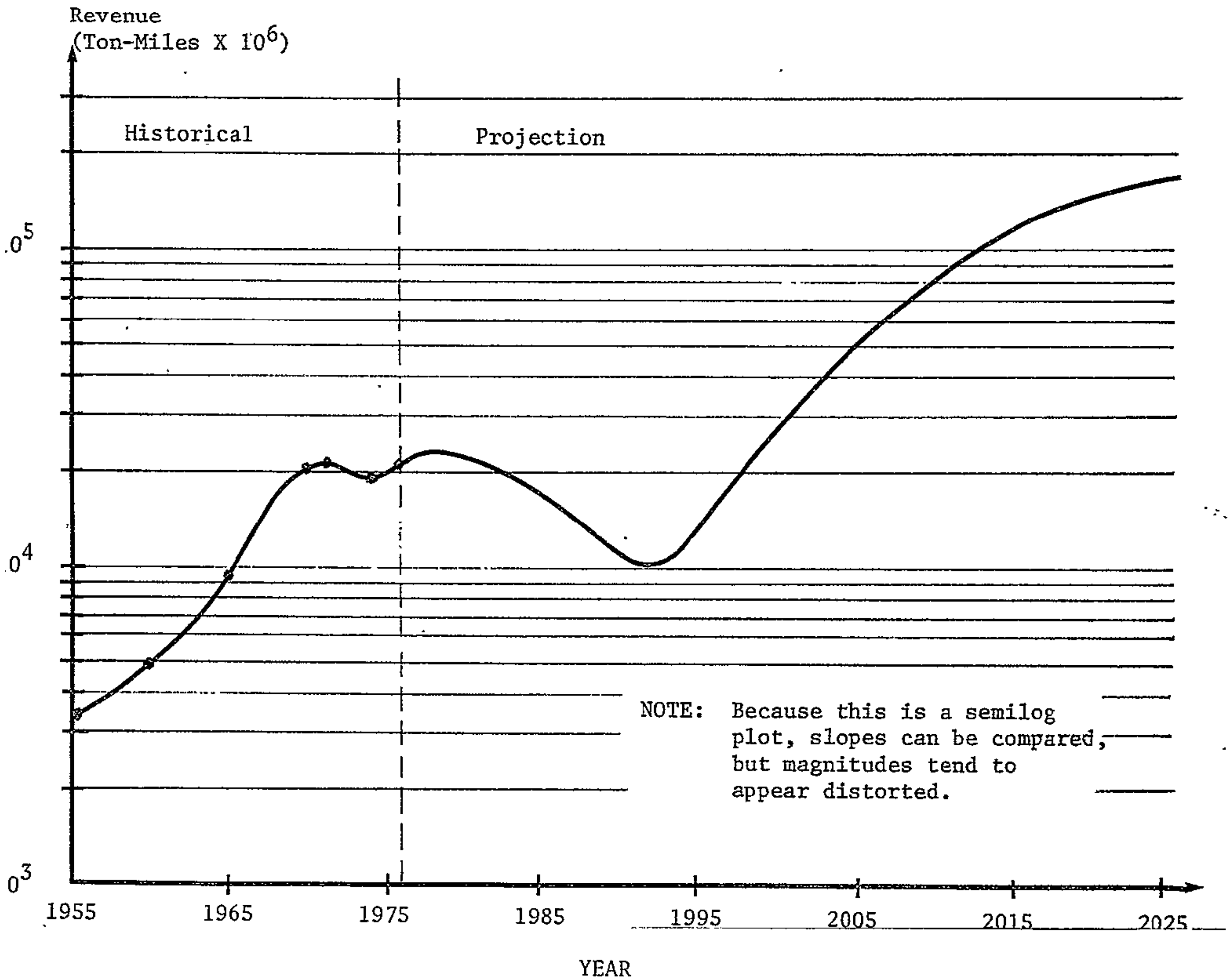


Figure 3.8: U.S. Air Passenger Revenue Ton-Miles

Source: Historical Data
Based on CAB 1975

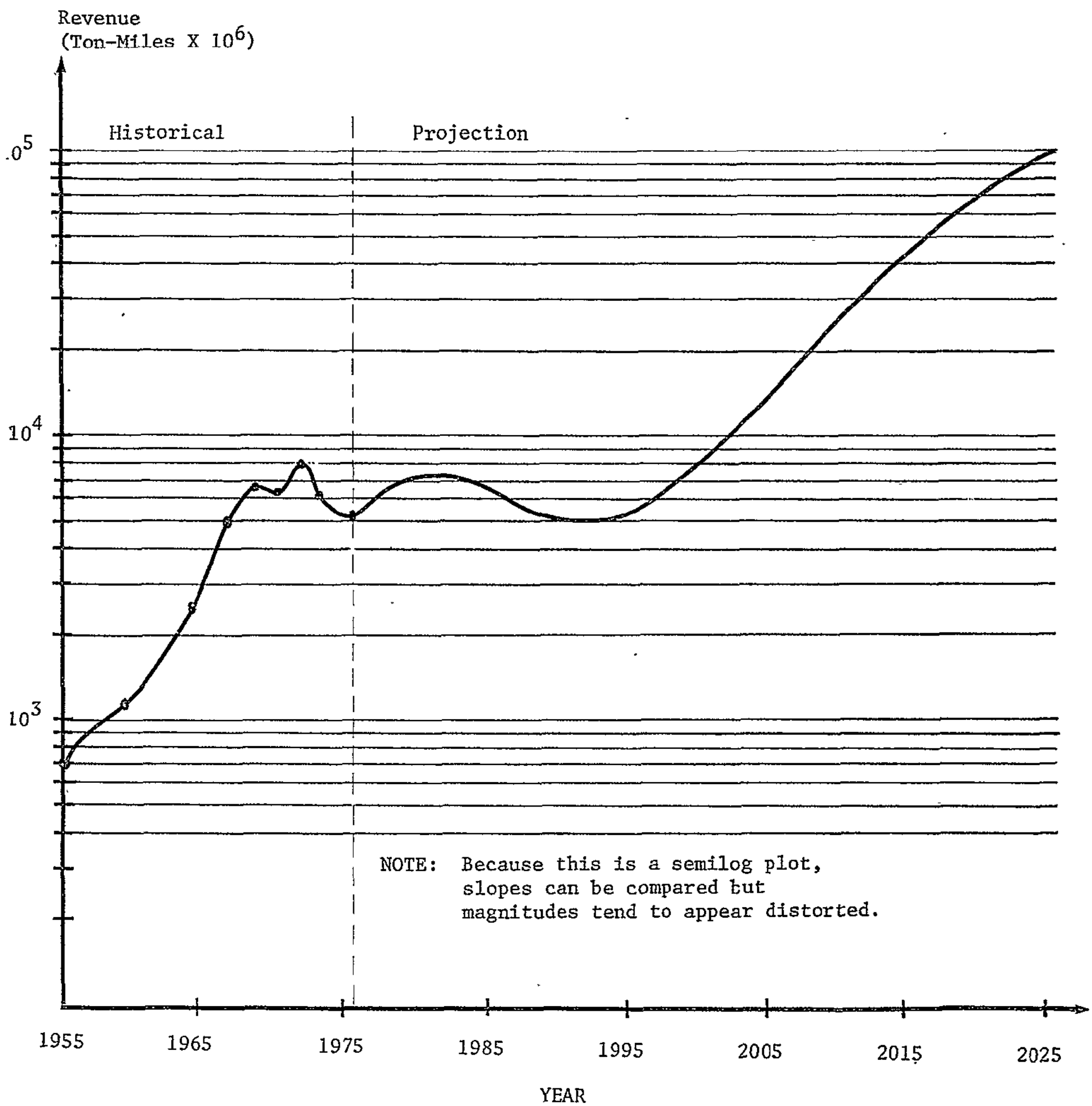


Figure 3.9: U.S. Air Freight Revenue Ton-Miles

Source: Historical Data
Based on CAB 1976

From 1990 onward, with economic conditions improving and air transportation demand rising, airlines will be retiring up to 60% of their older aircraft. At that time, aircraft with lighter structures, active control systems, more efficient engines, and better aerodynamic designs will be introduced into service. Advanced turbofan engines could also be a contributing factor for short and intermediate routes. By the year 2000, all necessary retirements of older models will have taken place and the entire air transport system will show markedly better fuel efficiency. Furthermore, synthetic fuels will begin to be a significant part of the total aviation fuel supply. Energy intensity (BTU/ton-mile) will be reduced by as much as 20% relative to 1975. Without taking into consideration the interrupted growth, a projection based on historical data coincides with this assertion, as illustrated in Figure 3.10.

With the economy recovering after 1990, there will be improved funding for research and development. Because of renewed impetus provided by this R & D, the following generation of aircraft will incorporate laminar flow control, active controls, advanced engines, and advanced composite structures. Noise and air pollution problems, although still of concern, will be less constraining. The pattern of development in technology and fuel, after the economic recovery, will parallel the uninterrupted growth scenario.

Finally, the experience with the Concorde will have determined whether or not an SST will be a factor in air transport. If the SST has proven viable, there will be a major component of passenger travel accommodated by this mode, especially for inter-continental routes.

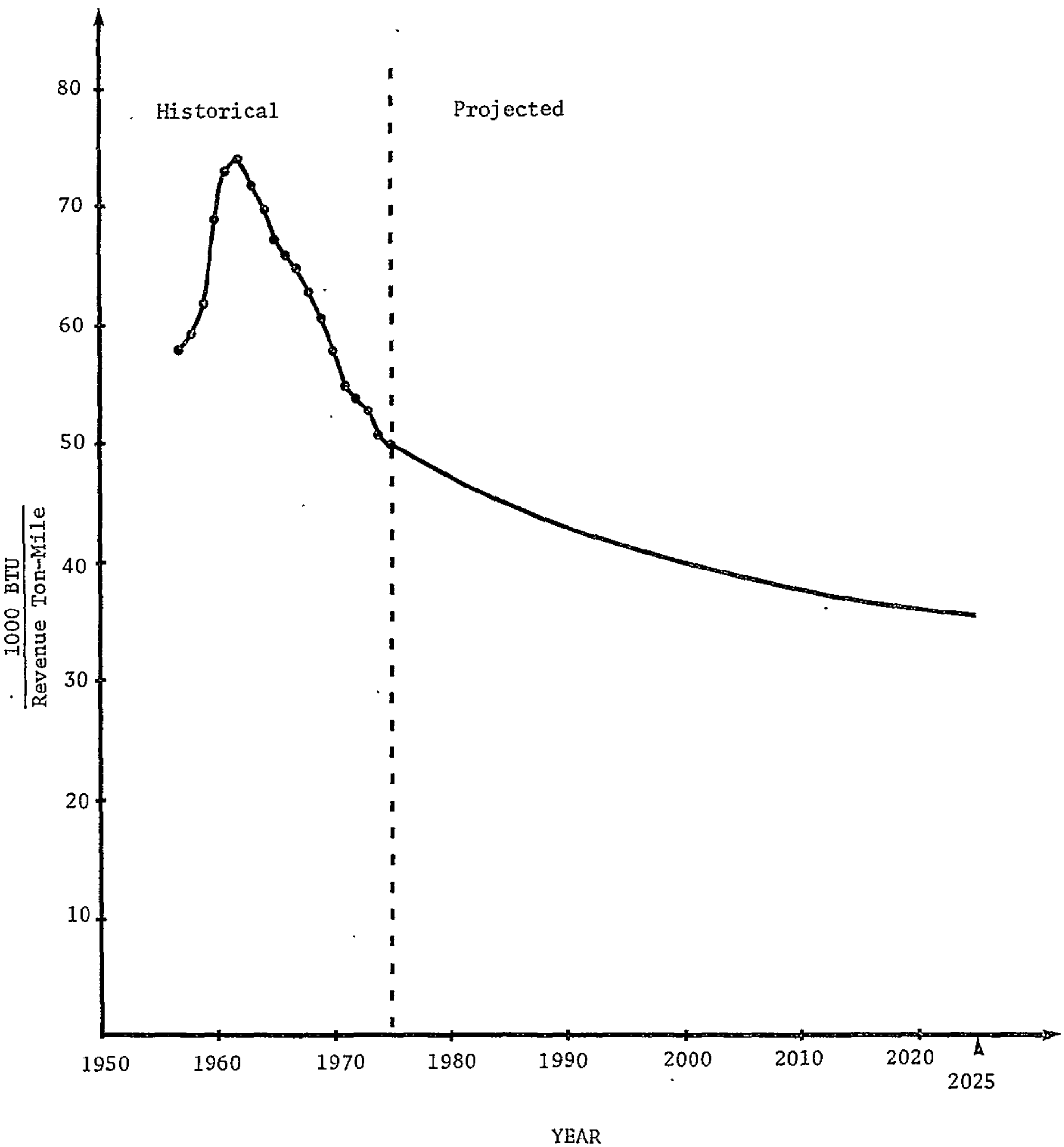


Figure 3.10: U.S. Fleet Fuel Efficiency
Certified U.S. Carriers

3.4 Uninterrupted Growth Scenario

In the uninterrupted growth scenario, it is assumed that the world economy will continue to grow as it has in the past. Although such a postulated growth may not be smooth, there will be no major interruption in the overall economic growth as was hypothesized in the interrupted growth scenario. As presented in the "Interrupted Growth Scenario", energy was assumed to be the key factor in determining GNP growth. In this scenario, however, energy is not considered to be the key factor in the determination of GNP growth even though it must be considered as one of the key factors supporting that growth. In order to maintain a steady growth in the world's economy, there must be, among other things, sufficient energy to support development programs which lead to economic growth. The case of the U.S. is discussed in the following section.

3.4.1 Economic Growth and Energy Consumption

Energy intensity of the U.S. economy, in terms of energy/GNP ratio, was shown to be declining in Section 3.3.1. This is primarily due to technological advancement, through which the economy can produce more with less and less energy input. This trend, repeated in Figure 3.11a is assumed to continue as pointed out earlier, but in addition, the economy will shift from an industrial society with its emphasis on consumption of physical goods to a post-industrial society with increasing demand for services. This historical trend will be acheived in the face of increasing energy intensities of certain sectors of the economy...notably in the extractive industries and transportation. At the same time, services, which have been growing steadily and can be expected to continue growing faster than the economy as a whole, are not energy intensive. Therefore, if the historical energy consumption/GNP ratio continues to decline at 1/2% per year, and the GNP grows at about 3.4% per year, energy demand will be expected to grow concomitantly with economic growth. Consequently, the amount of energy that the economy will require can be projected simply by multiplying the GNP and the energy consumption/GNP ration. This is depicted in Figure 3.11 (B).

To meet this energy demand and maintain a healthy uninterrupted growth, domestic production strategies and energy demand management are necessary. For instance, if the U.S. continues to import at present rates, it is likely that its economy will soon be disrupted by huge oil dollar deficits. Import quota systems may be necessary to control imports, while in other cases it may be necessary to impose conservation measures designed to moderately reduce consumption in the short run. The assumption in this scenario is that these measures will exist to prevent a decline in growth. At the same time, domestic production increases will be pressed. If oil exploratory activities continue at the same rate as in the past, it is improbable that any significant contribution to total energy will be seen. Therefore, coal, which the U.S. has in abundance (as shown in Table 2.7) will supply this energy-demand deficit needed to support the economy. Coal supply may not grow rapidly at first because of lack of expanded facilities. It will be expected to grow between 4% and 5% if domestic energy demand is to be met. Hydropower and geothermal energy will probably continue to grow at 3% per year but this is an insignificant contribution to total energy. Figure 3.12 shows the total energy supply under the following

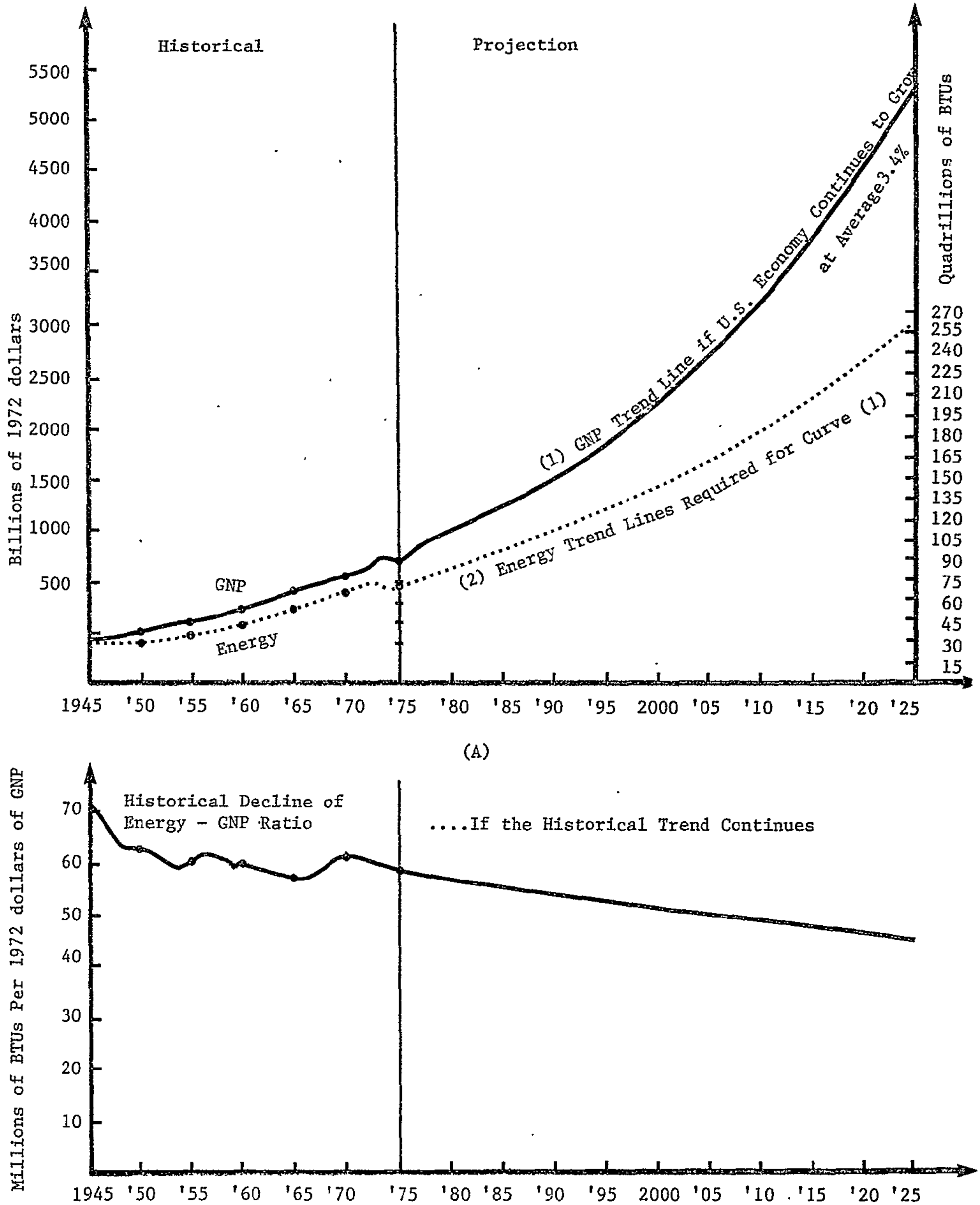


Figure 3.11: Energy and GNP Trend Lines (B)

Source: Historical Data
<u>Business Week</u>, 4/25/77

postulations.

1. Coal: 2% annual growth to 1978, 5% annual growth to 2000, and 7% annual growth to 2025.
2. Domestic oil and gas: 2.2% annual decline to 2025.
3. Hydro & geothermal: 3% annual growth to 2025.
4. Nuclear: 10% annual growth to 2010, 5% annual growth to 2025.

This energy trend is different from the case depicted for the interrupted growth scenario. There is no dip in total production around year 1990 as indicated in the interrupted growth scenario. Rather, energy growth is upward and smooth. Imports grow at rates sufficient to support the economy. Nuclear may not grow at the 17% per year rate projected by various studies but could grow between 5% and 10% per year. Total energy, as shown in Figure 3.12, will determine the shares that go to various sectors of the economy.

3.4.2 Energy Sharing

Energy-consuming sectors in the economy, namely, transportation, household, commercial and industrial, will be competing for this available energy. All sectors are expected to grow and, hence, energy to support this growth is also expected to increase. Conservation measures aimed at reducing energy consumption may, in the long run, increase consumption for the following reasons. Attempts to build more efficient small cars could result in families buying two small cars instead of one large sized car. In the industrial sector, attempts to replace more energy intensive materials with less energy intensive materials could result

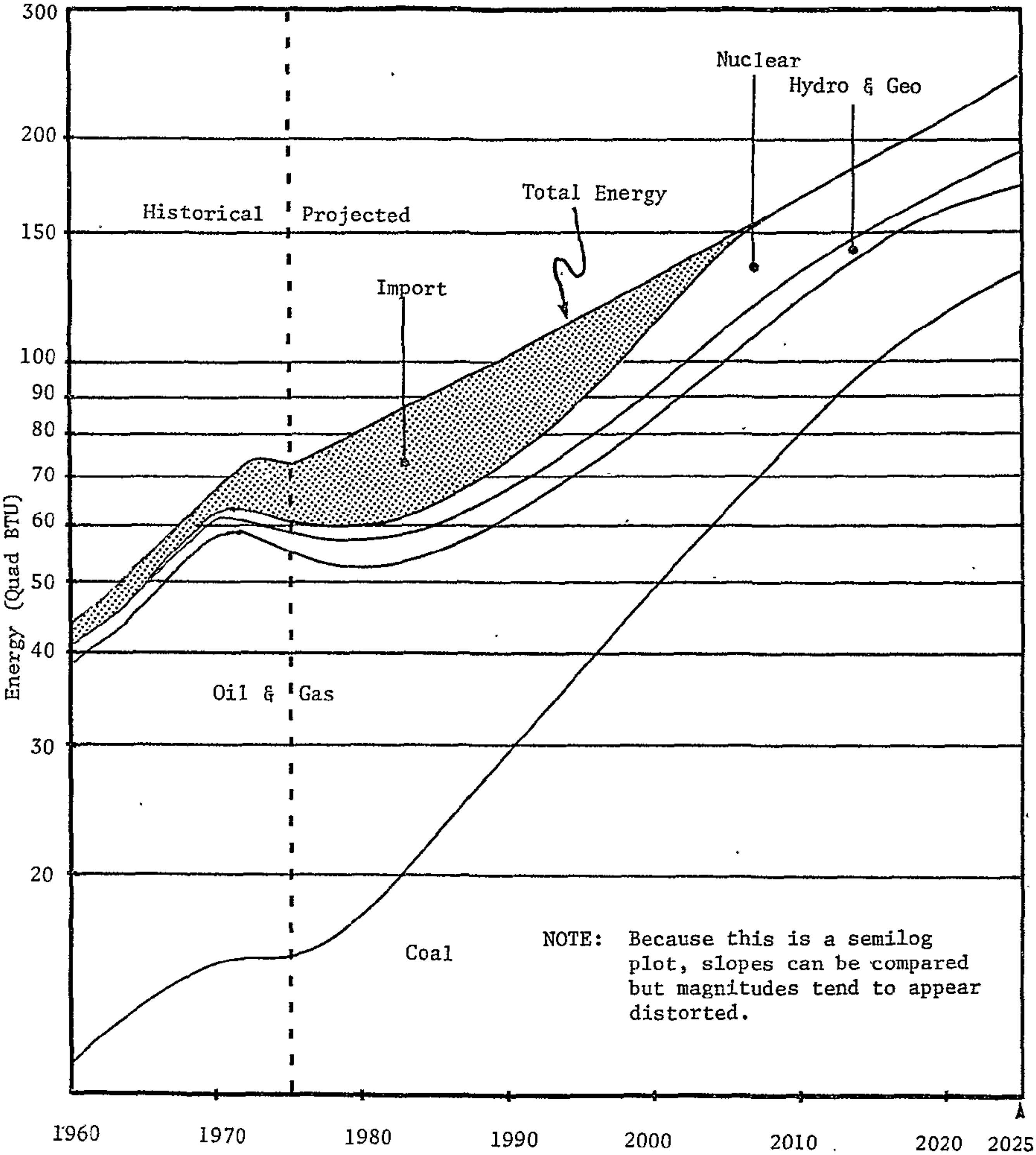


Figure 3.12: U.S. Energy Supply - Historical & Projected to 2025

in designing of inefficient operating equipments. The household and commercial sectors have a potential for decreasing energy consumption as efficient appliances replace old energy-consuming devices. Though such conservation measures could be implemented, their impact will depend on the extent of these masures. Sectorial energy consumption is estimated to follow the trend shown in Figure 3.13. This trend will be able to support the economy without any interruption.

3.4.3 World Effects

In the recent past, oil has contributed the greatest share of total energy consumption and OPEC nations have supplied the greatest share of oil. To continue supplying the consumers needs, producers will have to increase its production. OPEC is clearly not producing at capacity limits currently, as some of the OPEC countries have idle facilities. Demand for high energy intensive machines, equipments and luxury items by OPEC nations from the developed Western world means that OPEC will have to supply these countries with the necessary oil for industry. Therefore, for most countries to maintain uninterrupted growth, OPEC must produce to meet world energy demands. With limitations on the speed with which they can absorb oil revenues, OPEC may not produce enough to meet world demand. The assumption here, however, is that they will produce enough to support world economies in order to avoid interruption in growth.

Western Europe's new mines will probably be developed at rates equal to or greater than depletion rates of old mines. Hence, coal production

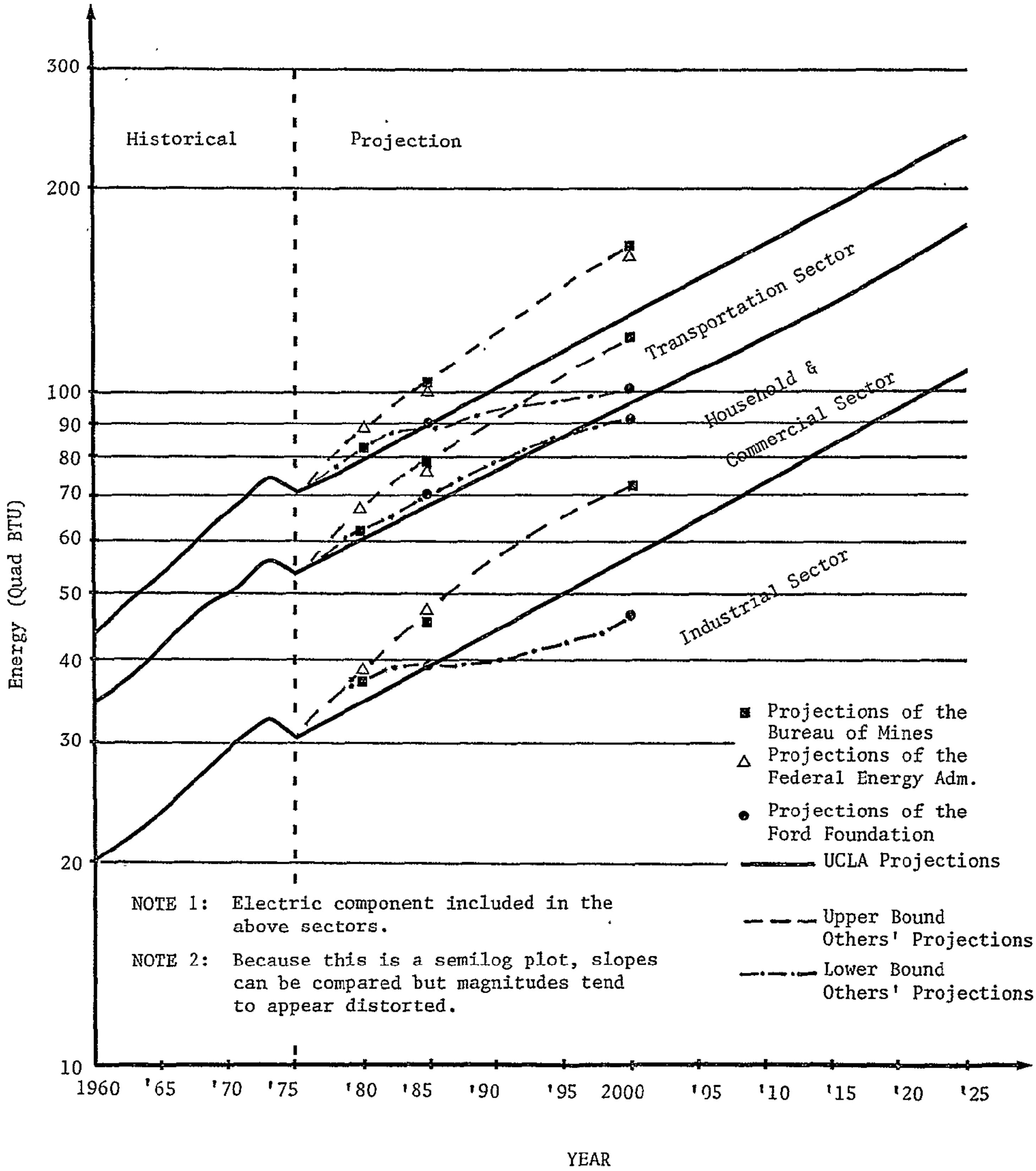


Figure 3.13: U.S. Sectorial Gross Energy Input

Source: Historical Data
Bureau of Mines, 1976

is expected to accelerate. It is anticipated that countries with heavy oil reserves such as Venezuela would develop their resources appropriately and in a timely manner. Nuclear energy's contribution to electricity is expected to increase. Though shale oil development has not, as yet, started on a commercial scale, it is expected to begin contributing to total energy just after the turn of the century. Therefore, it is believed that enough energy will be available in the economy to sustain an uninterrupted growth in world economies.

3.4.4 Transportation

Within the framework of the uninterrupted growth scenario, as in the other scenarios, the transportation sector depends on GNP and population growth rates, as well as on a shifting demand for transportation, relative to other goods and services. With the assumed GNP and population growth rates in the socio-economic environment (shown in scenario summary charts), the overall transportation activities would experience a low growth rate in the year 2025, although sectors such as air transportation, waterbound transportation (mainly international) and farming will continue to grow linearly. Slow growth rate in the year 2025 occurs mainly because of the saturation level which some of the ground modes of transportation will have reached (i.e., automobile and trucks for urban use). Automobile energy requirements and truck energy requirements, which still account for 61.34% of the total transportation energy requirements in the year 2025, will most likely begin to slow down by the year 2010. This slow-down could occur for the following reasons: 1) population growth may be limited; 2) if historical growth patterns continue, most of our cities could be experiencing such a high level of congestion that parking fees and travel time will be driven to such an unacceptable level that public modes of transportation would become a more economically feasible alternative; and finally, 3) as intercity modes of transportation such as high speed train and commercial airlines become more efficient and economically accessible to the society, they may replace private automobiles for intercity traveling. Concerning intercity ground cargo transportation activities, we can expect this sector to have a much higher growth rate than at present. Major transportation of bulk commodities such as grains and coal will be intensified. Recall that although the population growth in the U.S. remains fairly low, resulting in a total population of 280 million, world population could more than double (11 billion) by the year 2025. This implies that the U.S. could very well become one of the "food cellars" of the world. Not only would this intensify railroad and interstate trucking activities, but it would also undoubtedly intensify farming and water transportation activities. Coal, being one of the main sources of energy for the U.S., could also contribute to maintaining intensity of ground cargo transportation, as it will be shipped between mining sites and processing centers. The foregoing will probably transform into a total transportation energy requirement, as depicted in Figure 3.14.

Air transportation should continue to experience a linear to exponential growth within the time frame of this study (up to the year 2025). A detailed discussion of this sector is presented in the following section.

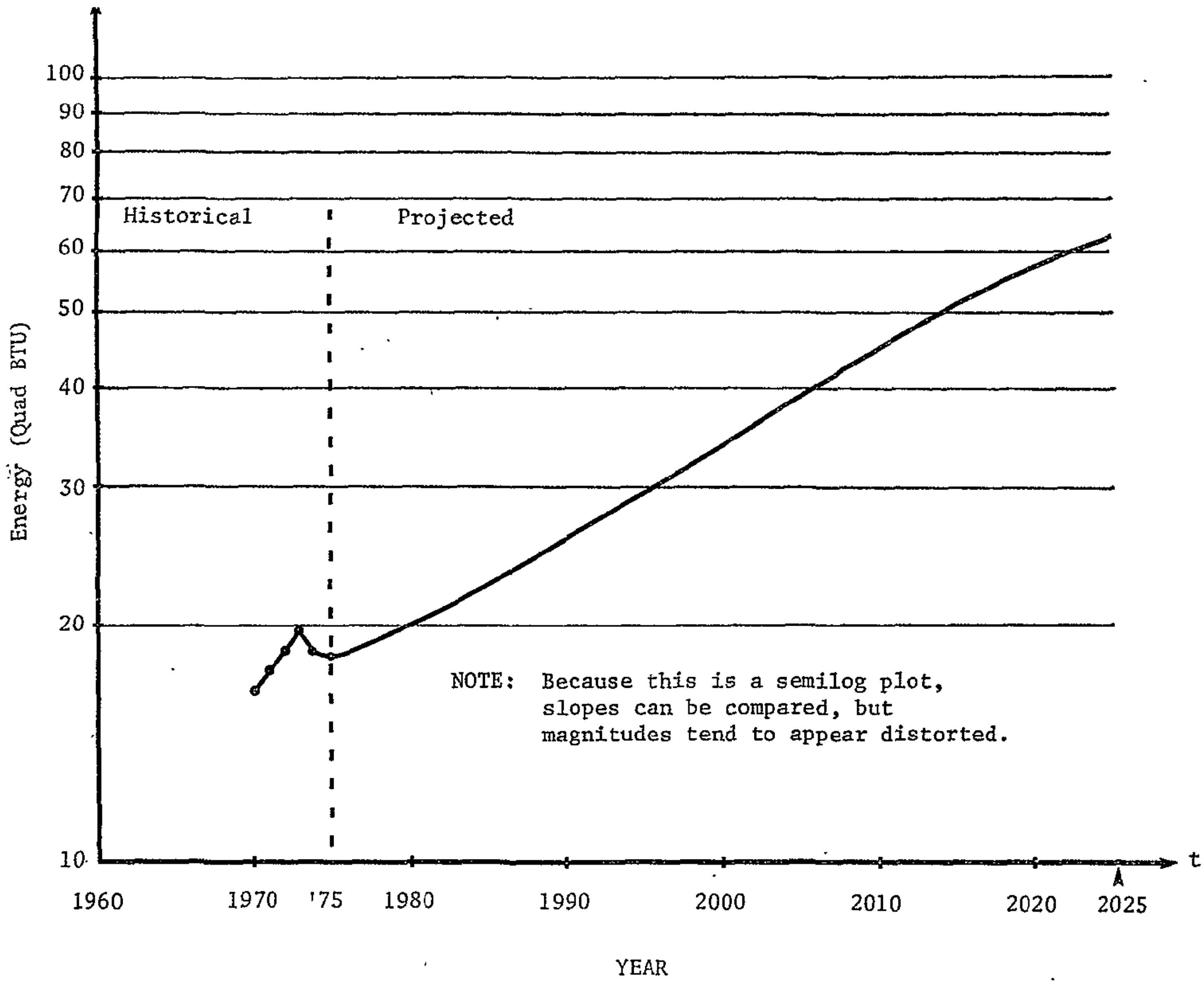


Figure 3.14: The U.S. Total Transportation Energy Requirement

3.4.5 Air Transportation

Since the assumption is made that the long-term general economy will continue to grow at a modest and steady rate, greater percentage of the population will become more affluent. This will provide an opportunity for expanding tourism. Business travel should grow with the long-term trends of the economy. It is likely that the industry will step into a modest and stabilized growth stage. Air transportation, being a component of total transportation, may follow the pattern of total transportation around year 1990 with a possible trend shown in Figure 3.15.

The air transportation industry will face the challenge of replacing an aging fleet within the next ten years. For each dollar of revenue, capital requirements for replacements require airline earnings of five to six cents (Steiner, Jan. 1977). This amounts to about $800 million per year (1975 dollars) for the next decade. Such capital investments, coupled with rising direct operating costs, may restrain growth of the industry, but not as severly as in the case shown for the interrupted growth scenario. In that scenario, growth temporarily slows and resurges again after about 1990. Energy demand may grow at 3.4% until after the year 2010 when it is expected to increase to slightly more than this. Air passenger traffic in the U.S. is expected to grow at a slower rate than at the present time. It is not anticipated that this rate will slow enough to cause an interruption in growth of the industry. Airlines may face problems as fuel suppliers continue to increase aviation fuel costs which, in turn, will increase overall operating costs.

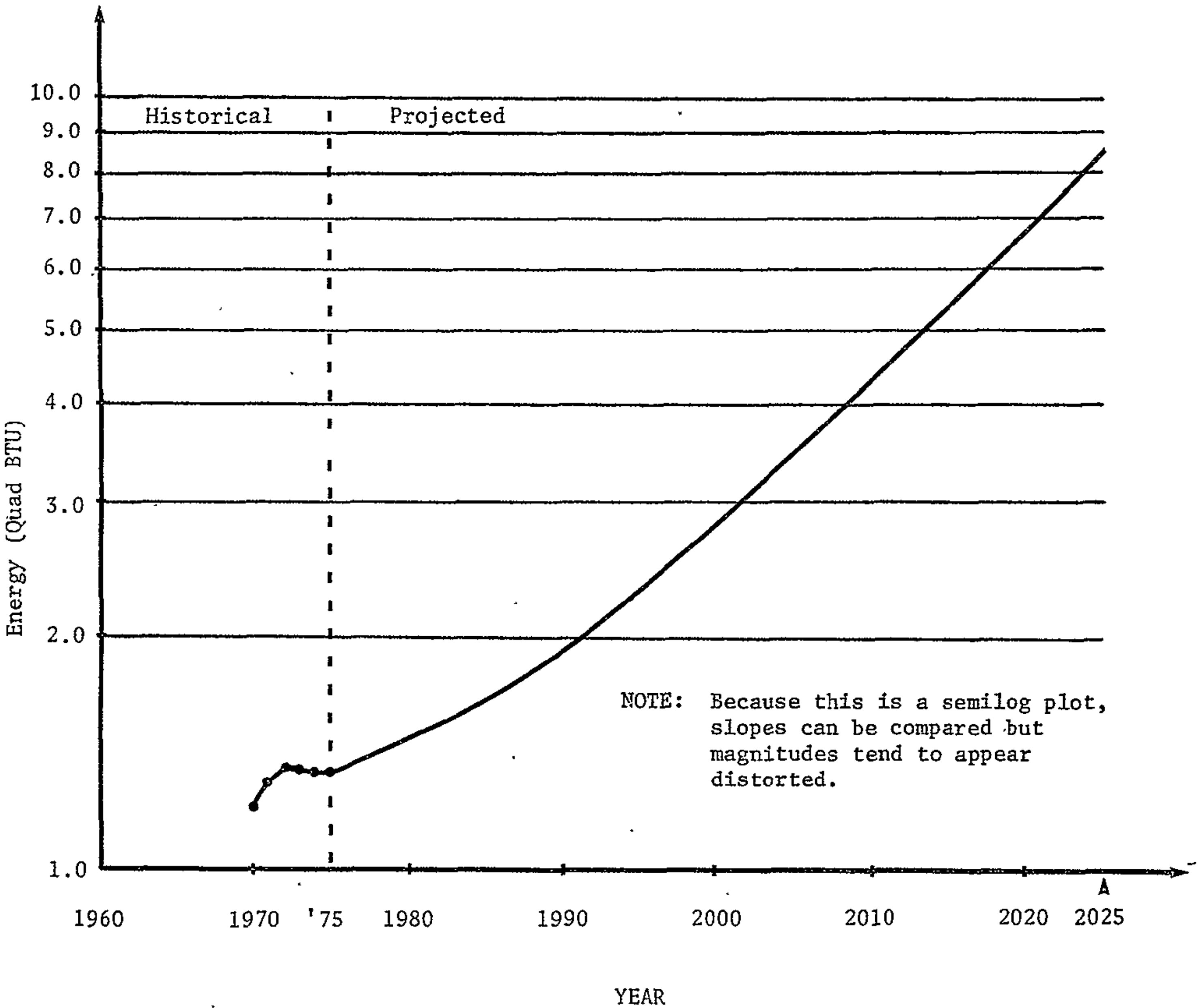


Figure 3.15: The U.S. Air Transportation Energy Requirement

However, efficient management coupled with increasing average load factors, could result in suppression of rising direct operating cost. Air fares will not rise in real dollars. Air passenger traffic is expected to have a 6.1% annual growth rate until 1990 and to follow the trend depicted in Figure 3.16. After the year 1990, it may continue to grow with a 8.1% annual growth rate because of introduction of more efficient aircraft and correspondingly lower fares. Growth of U.S. air freight may follow patterns similar to those of air passenger traffic, but with slightly higher growth rate, as shown in Figure 3.17. As GNP continues to grow, there will be more time-valuable goods for shipping in the market. Before the year 1990, the growth of air freight is expected to be 8.4% annually with a 10.2% rate after 1990.

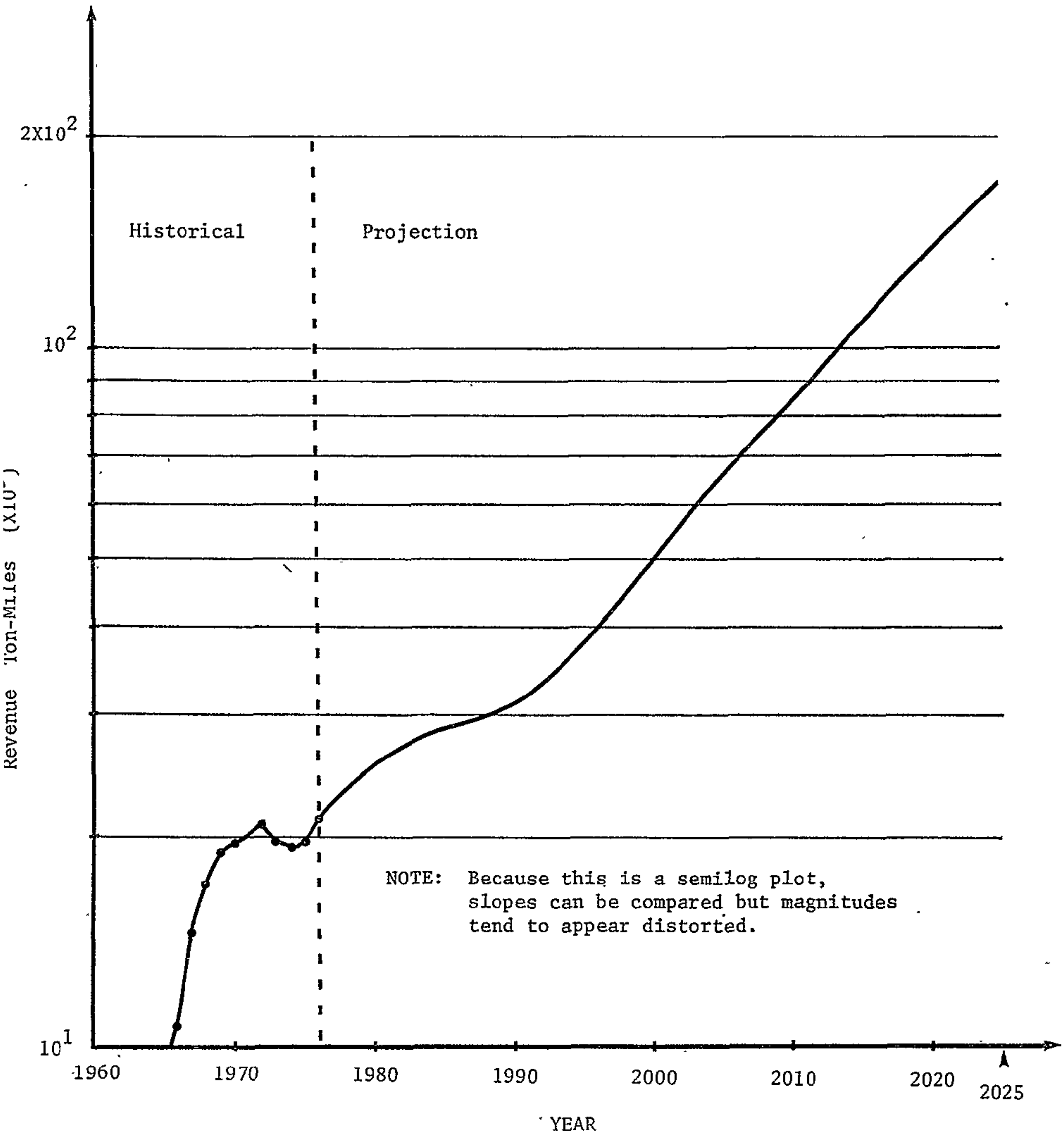


Figure 3.16: U.S. Air Passenger Revenue Ton-Miles

Source: Historical Data
Based on CAB 1975

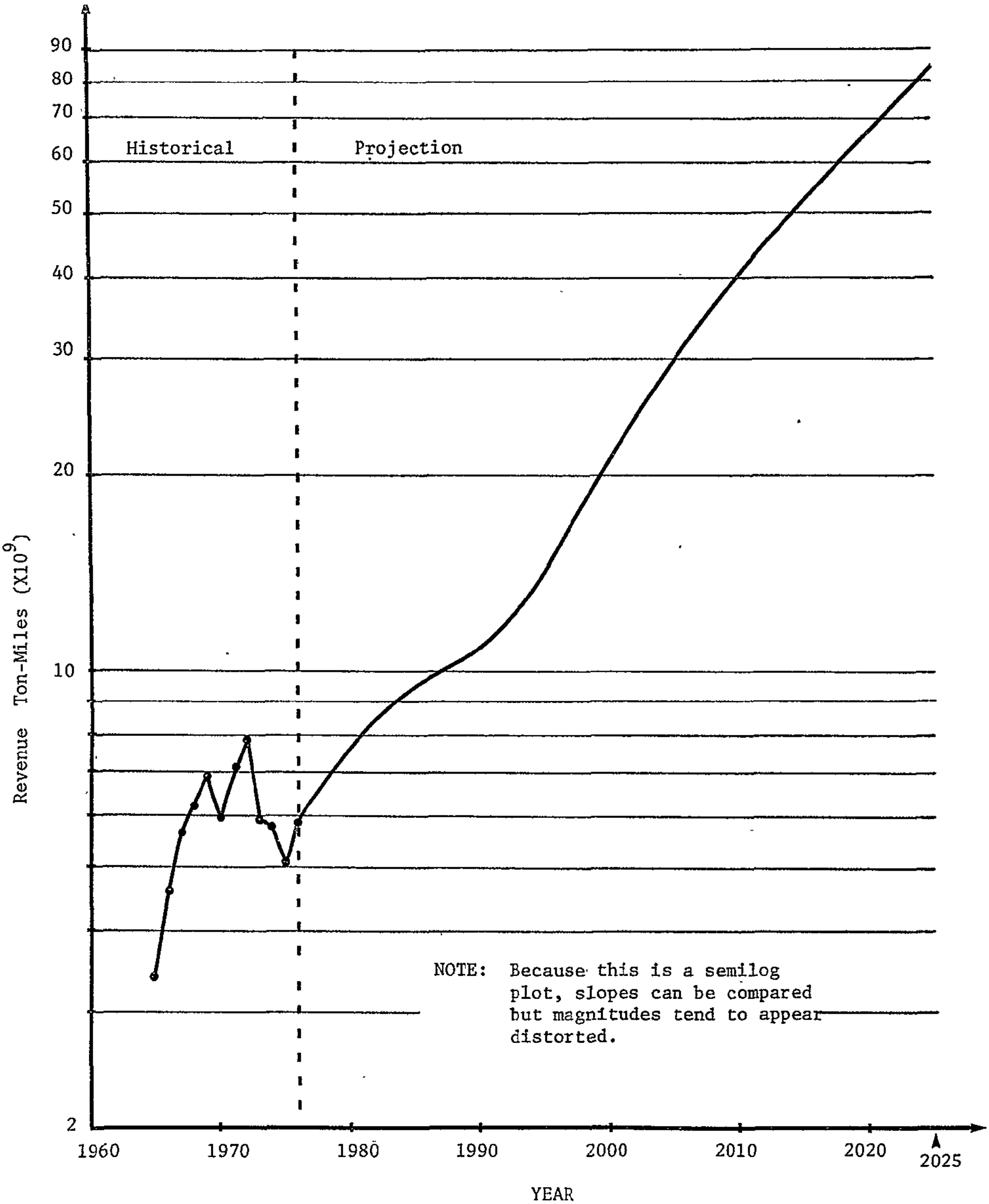


Figure 3.17: U.S. Air Freight Revenue Ton-Miles

Source: Historical Data
Based on CAB 1975

3.4.6 Aircraft Technology and Fuel Efficiency

In recent years, the world airline traffic grew steadily, while the U.S. airline traffic grew modestly. It is assumed in this scenario that the U.S. air transportation demand continues to grow every year. Also, more than half of the U.S. airlines' aircraft should be replaced by 1985 (Figure 3.18). So in less than ten years, the U.S. airlines should phase in new aircraft and provide enough seat miles for growing air transportation demand. By and large, airlines are expected to be able to finance the purchase of these new airplanes.

Currently, research is continuing in aircraft structure, aerodynamics, propulsion and active control technology. In this scenario, economic conditions are sound enough to fund these research programs modestly. New aircraft will have modifications such as more efficient configurations, structures and engines. They will employ composite materials in secondary structure, employ super-critical airfoils, winglets and, to some extent, will use active control technology. Also, these aircraft will employ high by-pass ratio turbofan engines, probably with lowered operating costs. By 1985, around 60% of the fleets are assumed to utilize the improved technology, so that the saving in commercial aviation fuel is expected to be about 15%.

Within the Uninterrupted Growth Scenario, there will be sufficient hydrocarbon aviation fuel supply to avoid any major problems for the air transportation industry. Also, engine improvement has allowed the relaxation of jet fuel specifications so as to increase aviation fuel availability. As a result, aviation fuel price will increase moderately. With better management and overall fuel efficiencies, air fares might not increase, in real terms, which will lead to a greater air travel demand. As a result, such demand grow-

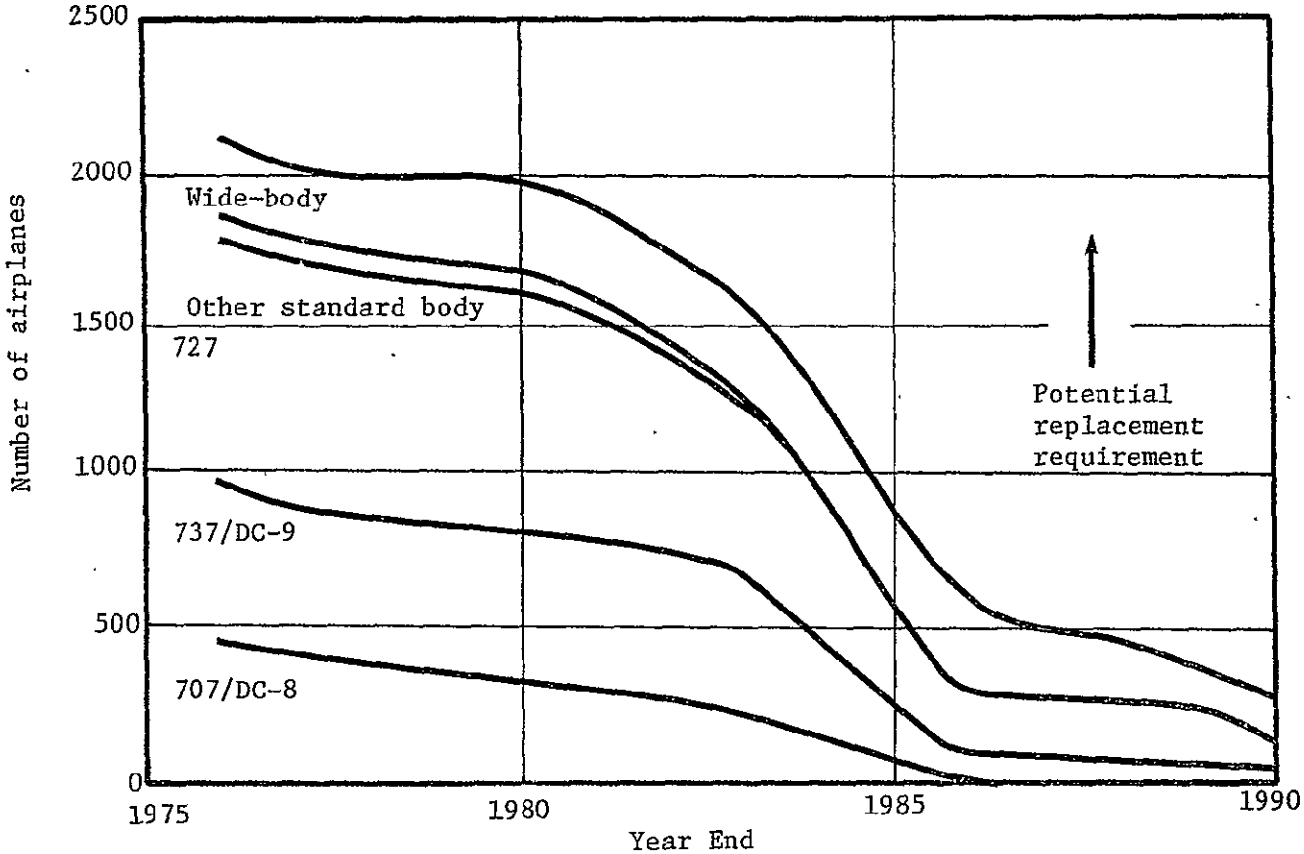


Figure 3.18: U.S. Airlines Potential Replacement Requirement. It is assumed that there is a 16-year life for standard body and an 18-year life for wide-body aircraft.

Source: Steiner, AIAA (October 1977)

growth will increase the load factor, and thus the passenger/miles. In this case, in spite of having more advanced technology, and higher load factor, total aviation fuel consumption would lead to increase resulting in a higher price for aviation fuel. However, higher load factors, and more efficient aircraft and operations are assumed to neutralize the effect of any increase in fuel cost.

By 1985, technology of laminar flow control, active control and advanced composite material might be available. And technology of advanced turboprop, for short and intermediate routes will also have been developed. Due to growth of air transportation demand, reasonably good economic conditions of airlines, and profitability of more efficient aircraft will encourage airlines to phase in new technology by that time. If so, all present-generation aircraft might be replaced by the year 2000, and airlines will have fuel-efficient turboprop and turbofan engines in service. In all, commercial air transportation system by the year 2000 are assumed to be 25% more fuel-efficient than now.

Several research centers have already begun research on the feasibility of deriving aviation fuels from shale oil and coal. This research will be continued and it is assumed that the objectives will be met around 1995 and aircraft could use syncrude aviation fuel in the year 2000. Development of this technology is assumed to increase petroleum-based aviation fuel availability due to substitution in ground transport modes. Plentiful syncrude supplies may also prevent drastic increases in the price of fuel. After the year 2000, the air transportation demand will be still growing. Airline industries will be prospering, and aircraft manufacturers will be producing fuel efficient SST's. By the year 2010, SST's will be in service on long-range flights, especially intercontinental routes. Also, it is not unreasonable to anticipate hydrogen-fueled SST's. After year 2010 the number of supersonic aircraft is expected to increase its share in airline fleets and air transportation will begin a new stage in its development with the appearance of SST or hydrogen SST. Also up-to-date electronic developments in aircraft control systems and air traffic operation will have a sensible effect on aviation fuel consumption. About 40% fuel saving is forecasted for the year 2025. This conjecture coincides with the historical prediction given in Figure 3.10 (Interrupted Growth Scenario).

3.5 Optimistic Growth Scenario

This is the most optimistic scenario in the realm of feasibility (see Scenario Summary, Tables 3.1 and 3.2). It is based on the assumption that the learning capacity of man is always increasing and that he will be able to use energy and materials more conservatively and with increasing efficiency. It is also assumed that the growth of efficiency arising from man's ingenuity will always exceed the rate of consumption of energy and other natural resources. The technological level will be such that energy input per unit of product output for energy-dependent processes will continue to decrease. Overall, there will be possibilities of substituting more energy-intensive materials with those that are less energy-intensive and thus save energy. Improved efficiency in all sectors of the economy and displacement of manual labor with automation in highly sophisticated forms will also allow man to better conserve the existing natural resources.

The major characteristics of this optimistic growth scenario, for the world and for North America, are shown in Scenario Summary Charts (see Tables 3.2 and 3.2).

3.5.1 Energy Supply and Demand

Due to the level of technology available for increasing efficiency of energy consumption in all sectors of the economy, and for the development of new, safe, and clean energy sources (i.e., solar, nuclear, synthetic fuel), society will have practically an unlimited energy supply. Heating and electricity for all sectors of the economy will be provided mainly by sources such as hydroelectric, solar, nuclear, and geothermal. Beyond 1995, energy resources such as petroleum, coal, and natural gas will cease to be meaningful candidates for electricity production, as society comes to accept solar and nuclear energy as economically feasible and safe new sources for electricity generation. Energy from shale oil and coal will be reserved for industrial and transportation sectors. For the 1977-1985 period, nuclear energy and synthetic fuels from shale, tar sand, and coal will contribute little to overall energy needs because petroleum will again become abundant and relatively cheaper than at present.

A lower rate of population growth, implicit in the socio-economic environment, together with relatively high energy supply will result in increasing energy output per capita, particularly for the less developed countries. As pointed out in the interrupted growth scenario, energy supply is a function of the level of technology and rate of recovery of energy resources. The assumption in this scenario, of a high level of technology means that more energy could be recovered than in the other scenarios. The assertion of low pollution implies that production processes will be improved to minimize waste. Outstanding solutions to energy problems could be provided by economics and technology and sudden large price fluctuations will tend to be self-correcting. Communication systems will provide a capability for rapid economic adjustment whenever changes are required.

Although feasible supplies of energy will not be limiting, there may be less demand for energy in the developed world because society will be changing its lifestyle towards a lower energy-intense economy.

This scenario, like scenarios 1 and 2, remains to be developed in detail. However, it is somewhat more complete than are the scenarios for 1 and 2.

3.5.2 Transportation Technology

Although most modes of transportation in use at the present time are dependent, either directly or indirectly, on petroleum and related products as energy sources, under the optimistic growth scenario, modes in operation in the year 2025 would have almost totally different propulsion systems from those of today, especially in ground transportation.

Some of the major characteristics of this scenario, concerning the transportation sector (see key factors affecting transportation in Chapter 2 and Scenario Summary Tables 3.1 and 3.2) are: High economic growth, abundance of energy resources and exponential growth in technological advancement. It is, therefore, feasible to conclude that new propulsion systems will be available to all modes of transportation. Propulsion systems such as linear induction motors, linear synchronous motors, and gas turbines will be in use in most of the ground transportation modes. At the same time, for air transportation, new engines of the variable thermodynamic cycle type will have replaced the conventional engines in use today. A variable cycle engine uses different optimized thermodynamic cycles for taking off, cruising and landing for improved efficiency. Advanced electronic control systems will also be used in engine and navigation systems. In aircraft body technology (Chapter 2), laminar flow control systems and composite structure materials will have been developed, and therefore aircraft bodies will be better designed. Summarizing, more than 40% fuel saving can be gained as compared to the present aircraft. Finally, many designs and propulsion systems developed for the air transportation sector will also enhance the water transportation modes, since both types of transportation have similar flow environment characteristics.

3.5.3 Transportation Scenario

Modes in operation in the year 2025 will be quite different from the existing modes of today. Transportation sector activities will have reached saturation levels in most parts of the world. Highly sophisticated audio, visual and data communication systems will have eliminated most unnecessary trips for such activities as banking, conventional mail, etc. Most transportation modes will be highly automated through the use of advanced computers. Home-to-work (and vice-versa) journeys will be increased in distance because of urban growth patterns which will tend to separate residential areas and commercial areas from the industrial areas. However, urban transportation saturation levels will also decrease slightly because of the possibility of fewer working days (four working days per week). Therefore, more time will be spent either at home or at educational and recreational centers. Inter-city traffic will consist mainly of freight transportation and leisure travel by the public, and should be more intensive than urban traffic. The individual modes that are in service in the year 2025 are described as follows:

Ground Transportation

Most ground modes of transportation, private and public, will be of multi-mode types, which are, in general, electric vehicles that are self-propelled for urban uses but also operable on electrically powered guideways for intercity travel. Intercity traveling will be done either by advanced high-speed trains (for both passenger and cargo freight) or on automated highways and guideways (mainly passenger). Mass transit systems in operation for both urban and intercity traveling are very economical and efficient. Electric multi-mode trucks will be used only for urban freight transportation, moving goods between separated residential, commercial and industrial zones.

Air Transportation

With continued average annual growth rate of around 14.1%, air transportation will have reached saturation level in all developed regions, while in the remaining regions (developing and underdeveloped) it will continue to be moderate to high. Long range commercial air transport fleets will be composed mainly of supersonic and hypersonic aircraft, while giant subsonics will be used mainly for short range to medium range passenger freight and for all cargo freight.

Water Transportation

Water transportation modes will show continued growth, however, still dictated by the GNP growth rate. Due to new technology and intensive capital investment in all transportation sectors, in use in the year 2025 water modes in operation in the year 2025 will be mainly composed of high-speed hydrofoils and air cushions, while improved barges and ships continue to play an important role only for freight transportation.

Conclusion

Although GNP per capita, under this scenario, would be high, (indicating a much higher intensity level in transportation activities compared to today), the transportation sector should experience, in the year 2025, a very low growth in developed regions and moderate to high growth in under-developed and developing regions. This low growth rate in developed regions is related to sophisticated and advanced telecommunication systems, low population rates, and the saturation level which the transportation sector would have reached.

For instance, in urban regions, because of efficient city planning and sophisticated communication systems, in the year 2025 the public will not need to leave home or neighborhood to do banking, obtain information from the libraries, or to obtain elementary and secondary level education. Therefore, urban travel might even decline.

On the other hand, in under-developed and developing regions, the transportation sector will experience a moderate to high growth rate. The reasons are: population and GNP growth are constantly increasing, standard of living is rapidly improving, and transportation activities are still inadequate.

3.5.4 Air Transportation Scenario

Social economic conditions and technology breakthroughs provide the most favorable environment for the development of air transportation. There will be more alternatives for fuel supply. Aircraft engines will use fuel more efficiently. Aspects of the air transportation scenario can be depicted as follows:

- By the year 2025, the growth of air transportation will reach its saturation point in the developed regions of the world while in the underdeveloped regions this growth will continue to be moderate to high.

- Advanced SST will see extensive service for medium and long range routes. Advanced engine design will reduce environmental impacts to a minimum.

- The integrated air cargo system will appear. The system will provide fast and economical service due to efficient ground-support systems. These systems would be fully mechanized and computer controlled with emphasis on high volume, high-speed processing.

REFERENCES

1. Basile, Paul S. (ed.), "Energy Demand Studies: Major Consuming Countries," First Technical Report on the Workshop on Alternative Energy Strategies (WAES), The MIT Press, 1976.

2. Brewer, Daniel G., "Hydrogen-Fuel for Commercial Transport Aircraft," Lockheed Report, 1976.

3. Bureau of Mines, "Energy Prospects," U.S. Department of Interior, Washington D.C., Part I, 1975.

4. Bureau of Mines, "Energy Prospects," U.S. Department of Interior, Washington D.C., Part II, 1976.

5. Bureau of Mines, "United States Energy Through Year 2000 (revised)," U.S. Department of Interior, Washington D.C., December 1975.

6. Clark, Colin, "Do Population and Freedom Grow Together?" Fortune, pp. 136-139, December 1960.

7. Clark, Colin, "Population Growth and Living Standards," International Labor Review, pp. 99-117, August 1953.

8. Cole, H. et al., Models of Doom, New York, 1973.

9. Davis, R., "The History of the World's Air Lines," Oxford University Press, London, 1964.

10. Energy Policy Project of the Ford Foundation, "A Time to Choose America's Energy Future," Ballinger Publishing Co., Cambridge, Mass., 1974.

11. Forrester, Jay W., "World Dynamics," Wright Allen Press, Cambridge, Mass., 1974.

12. Federal Energy Administration (FEA), "Project Independence Report," U.S. Government Printing Office, Washington D.C., November 1974 (Stock Number 4118-00029).

13. Federal Energy Administration (FEA), "1976 National Executive Summary Outlook," U.S. Government Printing Office, Washington D.C., 1976.

14. Fisher, J.C., "Energy Crisis in Perspective," John Wiley & Sons, New York, 1974.

15. Gleason,C.C. and Bahr, "Experimental Clean Combustor Program, Alternate Fuels Addendum," NASA CR-134972.

16. Grey, Jerry (ed.), "Aircraft Fuel Conservation: An AIAA View," Proceedings of a Workshop Conference, Reston, Virginia, American Institute of Aeronautics and Astronautics, 1974.

17. Hudson Institute, "The Business Environment in 1975-1985," Volume I & 2, New York, 1974.

18. International Civil Aviation Organization (ICAO), ICAO Bulletin, Montreal, Canada, 1972-1975.

19. Jacoby, N.H., "Multinational Oil," MacMillan Co., New York, 1974.

20. Kahn, Brown and Martel, "The Next 200 Years," Morrow, New York, 1976.

21. Kenward, Michael, "Potential Energy," Cambridge University Press, Boston, Mass., 1976.

22. Longwell, J.P., "Alternative Fuel for Aviation," Testimony Before the Senate Subcommittee, September, 1976.

23. Malthus, Thomas, "An Essay on the Principle of Propulsion," Ward, Lock & Co., New York, 1890.

24. Meadows, Denis and Donella, "The Limit to Growth," University Books, New York, 1972.

25. Morris, Bruce R., "Economic Growth & Development," Pitman Publishing Corp., New York, 1967.

26. National Aeronautics and Space Administration - Lewis Research Center, "Alternative Fuels Panel X," NASA Aircraft Engine Emission Conference, May 1977.

27. National Aeronautics and Space Administration - Office of Aeronautics and Space Technology, "Aircraft Fuel Conservation Technology," NASA Task Force Report, September 1975.

28. O'Toole, James, "Energy and Social Changes," The MIT Press, 1976.

29. Pearce, D.W. (ed.), "The Economics of Natural Resources Depletion," John Wiley & Sons, New York, 1975.

30. Pinkel, Irving I., "Future Fuels for Aviation," AGARD Advisory Report # 93, North Atlantic Treaty Organization (NATO), January 1976.

31. Steiner, J. E., "The Future of Air Transportation - Technical Review," AIAA Annual Meeting, Washington D.C., American Institute of Aeronautics and Astronautics, January 1977.

32. Steiner, J.E., "The Timing of Technology for Commercial Transport Aircraft," Astronautics & Aeronautics, AIAA, October 1977.

33. The Scientific Panel on Propulsion Effluents (CIAP), Propulsion Effluents in the Stratosphere," CIAP Program - Department of Transportation, Washington D.C., 1974.

34. Technology Assessment Team (Peat, Marwick, Mitchell & Co., et al), "Technology Assessment of Future Intercity Passenger Transportation Systems," Workshop Proceedings, March, 1976.

35. United Nations, U.N. Total Population Estimate for World Regions and Countries, Population Division, ESA/P/WP, 34, 1970.

36. United Nations, U.N. Yearbook of National Account Statistics, Vol, III, International Tables, New York, 1975.

37. U.S. Department of Commerce - Bureau of the Census, Historical Statistics of the U.S. from Colonial Times to 1970, Washington D.C., 1970.

38. U.S. Department of Commerce - Bureau of the Census, Statistical Abstracts of the U.S., Washington D.C., 1975.

39. Wilson, Carroll L. (Project Director), "Energy: Global Prospects 1985-2000," Report of the Workshop on Alternative Energy Strategies (WAES), McGraw-Hill Book Co., New York, 1977.

40. World Bank - International Bank for Reconstruction and Development, World Bank Atlas: Population Per Capita Product and Growth Rates, Washington D.C., 1974.