320
4-2-80

Sh. 1011

DSE-4230-T1(Vol.1)

A STUDY OF CAPITAL REQUIREMENTS FOR SOLAR ENERGY

Final Report: Volume 1

An Analysis of the Macroeconomic Effects of Increased Solar Energy Market Penetration

By
Christopher J. Pleatsikas
Edward A. Hudson
David C. O'Connor
Douglas H. Funkhouser

MASTER

July 19, 1979

Work Performed Under Contract No. EM-78-C-01-4230

Urban Systems Research & Engineering, Inc.
Cambridge, Massachusetts

and

Dale W. Jorgenson Associates
Cambridge, Massachusetts

U.S. Department of Energy

Solar Energy

DISCLAIMER

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Paper Copy $12.00
Microfiche $3.50

DSE-4230-T1(Vol.1)
Distribution Category UC-59

A STUDY OF CAPITAL REQUIREMENTS FOR SOLAR ENERGY

FINAL REPORT: VOLUME 1

An Analysis of the Macroeconomic Effects of Increased Solar Energy Market Penetration

Christopher J. Pleatsikas
Edward A. Hudson
David C. O'Connor

Assisted by:

Douglas H. Funkhouser

July 19, 1979

CONTRACT NUMBER EM-78-C-01-4230

Prepared for:

Department of Energy
20 Massachusetts Avenue
Washington, DC 20545

Prepared by:

Urban Systems Research & Engineering, Inc.
36 Boylston Street
Cambridge, MA 02138

and

Dale W. Jorgenson Associates
P. O. Box 276
Cambridge, MA 02138

DISCLAIMER

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (continued)

VOLUME 1

LIST OF TABLES

LIST OF TABLES

LIST OF TABLES

LIST OF TABLES

LIST OF TABLES

LIST OF TABLES

PART I

CHAPTER 1

INTRODUCTION AND EXECUTIVE SUMMARY

1.0 INTRODUCTION

This report defines the analytical framework for, and presents the results of, a study to determine the macroeconomic effects of increased market penetration of solar energy technologies* over the 1977-2000 time period. This research has been undertaken in support of the National Plan to Accelerate Commercialization (NPAC) of Solar Energy. The capital and operating requirements for three market penetration levels are first determined; the effects of these requirements on economic performance are then estimated using the Hudson-Jorgenson Energy/Economic Model.

1.1 Organization Of This Report

This report is organized into three major parts. Part I includes this introductory chapter and concludes with the "Executive Summary" (Section 1.2). Part II includes Chapters 2-5 and defines in detail the analytical design, computational methods, data sources, assumptions and scenario configurations for this analysis. Part III, comprising Chapters 6-11, presents the results of the analysis of the economic impact of

---

*For the purposes of this document, solar technologies are defined as wind, photovoltaics, ocean thermal electric (OTEC), small-scale (non-utility) hydroelectric and all solar active and passive thermal technologies.

solar energy. The implications of these results are also discussed in Part III.

In addition, two appendices are included. Appendix A explains the methodology for transforming investment to capital stocks. Appendix B, which is provided in a separate volume, describes the Hudson-Jorgenson Model in greater detail.

All economic information is reported in terms of constant dollars. Nineteen hundred and seventy-two (1972) dollars are used for all macroeconomic output and input information. Unit energy costs (price per 10^6 Btu, or, for crude oil, per barrel) are reported in 1976 dollars to conform to NPAC1 scenario specifications.

As an aid to textual clarity, all tables for each chapter are placed at the end of that chapter.

1.2 Executive Summary

1.2.1 Methodology/Scenario Specifications

This analysis began with the specification of three different levels of solar energy market penetration over the 1977-2000 period. Within each level of market penetration, a different mix of solar technologies was specified. Cost and performance parameters, both current and future (to the year 2000), were also defined for each of the solar technologies.

This information was then used to structure five aggregate energy supply scenarios for analysis. These scenarios are shown in Table 1-1. These scenarios covered five of the six possible combinations of outcomes from two sets of events:

- o the degree of utilization of solar technologies (low, medium, or high); and
- o the world price of oil (lower or higher).

By assumption, these scenarios were structured so that increased solar market penetration was achieved mainly through displacement of imported oil.

In order to develop comparisons of economic performance among the scenarios, a reference point or "Base Case" was necessary. The Base Case designated for this study was the low solar, lower oil price scenario. Given the energy and economic assumptions defined for this scenario, GNP growth for the forecast period averaged just over 3% per annum.

The other scenarios were analyzed as deviations from this Base Case. There were two key differences between the Base Case and the medium and high solar market penetration scenarios at the lower oil price.

- o the new solar energy supply programs divert capital and other economic inputs from the rest of the economy to construct and operate the new solar capacity;
- o because new solar capacity displaces conventional fuels, demand for these fuels is reduced, thereby reducing the inputs needed to deliver these fuels.

The analysis was structured so that differences in economic structure and performance between the Base Case and the two alternative (higher) solar market penetration scenarios at the lower oil price was entirely caused by the direct and indirect effects of the change in energy supply conditions. Thus, the analysis of these differences permits the macroeconomic consequences of increasing solar market penetration levels to be assessed.

Similarly, between the two cases involving higher oil prices, the only causal difference was the different level of solar market penetration and the reallocation of investment this required. However, between the lower and higher oil price cases for a particular level of solar market penetration, both oil prices and the mix of conventional technologies changed, rendering comparisons across oil prices somewhat more complicated.

1.2.2 Scenario Assumptions

The quantity of energy available from solar technologies is displayed in Table 1-2. For the low solar market penetration scenarios these technologies contribute 2.0 Quads of energy* in the year 2000, for the medium solar scenario about 7.3 Quads in 2000, and for the high solar scenarios about 16.3 Quads in 2000 (about 1.7%, 6.4% and 14.4%, respectively, of total energy used, under conditions of lower oil prices). To place these solar energy contributions into perspective, under the medium solar scenario, solar technologies in the year 2000 would be an important source of energy supply, but would still rank behind coal, oil, gas or nuclear power in terms of their contribution to U.S. energy needs. Under the high solar scenario, solar technologies would supply approximately as much energy as nuclear power or natural gas, but still less than either coal or petroleum. Oil imports in the year 2000 for the five scenarios range from 13.84 Quads to 6.68 Quads (i.e., from 7 to 3.4 billion bbl/day).**

Table 1-3 displays the assumptions concerning oil and natural gas prices and domestic oil and gas production. Both domestic oil and gas prices are assumed to be fully decontrolled and at world levels by 1985. Under the lower oil price assumptions, the world price for crude oil increases by the year 2000 to approximately $25/bbl in 1976 dollars.*** The higher price path for oil results in a crude oil price of approximately $35/bbl in 2000 (in 1976$).**** In each case, the price of

---

*All energy stated in terms of primary energy equivalents.

**Currently, oil imports are 8-8.5 million bbl/day.

***This is equivalent to $30/bbl in 1979$ (1st Quarter).

****This is equivalent to $42/bbl in 1979$ (1st Quarter).

gas, by 2000, is approximately equal to that of oil in terms of energy content. Domestic production of petroleum and natural gas is assumed to be fairly price inelastic due to a lack of economically exploitable resources. Any slack between domestic supply and domestic demand for these energy sources is made up by imports, which are assumed to be available in any desired quantity at the world oil price.

Considerable effort was directed to developing estimates of the costs for various types of new energy supply technologies, including:

- o solar technologies;
- o biomass technologies (both direct use and synthetic fuels conversion);
- o coal-based synthetic fuel technologies;
- o new electric technologies which use fossil fuels.

For all of these technologies, current and projected capital and operating costs were defined and estimates of aggregate new technology capital investment requirements for each scenario developed (Chapters 4 and 5 present the results of the cost analyses).

1.2.3 Results*

Some of the principal results of this analysis of the macroeconomic effects of increasing solar technology market penetration are summarized in Tables 1-4 and 1-5. Increased solar penetration requires considerable quantities of additional economic inputs, in particular inputs of capital.** Even when

---

*This summary discussion refers to results obtained under conditions of lower oil prices, although similar results were obtained under conditions of higher oil prices (see Table 1-5 and Chapter 8).

**In this document "capital stock" and "depreciated capital" are used to refer to total depreciated value of in-place account is taken of the net capital requirements, i.e., after allowing for conventional energy capital displaced by increased solar supply, the proportion of <u>total</u> U.S. capital stock in 2000 devoted to solar and other new technology energy sources is 0.8%, 1.6% and 2.8%, for the low, medium and high penetration cases respectively. This represents an addition to the already large capital requirements of the conventional fuel components of the energy sector.

These capital changes are brought about by redirection of investment within the economy. Total gross investment in the new technology supply sources during the forecast period, i.e., both 1980s and 1990s, averages 1.3%, 3.3% and 7.0%, for the three levels of penetration respectively, of total investment in the economy. When allowance is made for the conventional energy investment displaced, the net investment requirements are still substantial -- 2.7% of total investment in the medium solar case and 5.1% in the high penetration case. Further, the investment requirements peak in the 1990s. During this decade, new technology investments average $4 billion (1972$) annually in the low penetration case, $17 bn* (1972$) in the medium case and $35 bn (1972$) for high solar penetration. These gross investment requirements correspond to 5.0% of total investment in the 1990s in the medium penetration case and 9.9% in the high case. It is possible that such requirements can be accommodated within the capital markets. However, they are sufficiently large--and may be compounded by heavy investment

---

capital stock. "Capital investment," "investment" or "capital costs" refer to current flows and are defined as the value (non-depreciated) of capital investment made in any particular year. Chapters 4, 5 and 10 deal with capital investment (current flows). Chapter 9 deals with capital stocks, while Chapters 6-8 and 11 discuss both capital investment and capital stocks. See Appendix A for the methodology and assumptions used to convert solar capital investment to capital stocks.

*bn = billion.

requirements elsewhere in the energy system--that they will certainly bid up interest rates and divert substantial volumes of investment away from the nonenergy part of the economy.

Increased solar penetration also has significant impacts on the level and growth of economic activity. The increased capital and other inputs directed towards the energy system result in reduced inputs being available to the nonenergy part of the economy. This, in turn, results in slower growth of capacity and productivity. Therefore, real GNP growth in the medium and high solar penetration cases is slower than in the low solar Base Case. Correspondingly, real income and output is, in future years, lower than it would have been in the absence of increased use of solar energy.

These impacts are, in relative terms, sustainable in the sense that economic growth continues and material living standards continue to increase substantially from current levels, even in the case of high solar market penetration. Real GNP growth in the medium solar penetration case is not affected prior to 1990. Then, in the 1990s, growth is slowed by only 0.1 percentage points annually, from 2.8% in the Base Case to 2.7%. In the high penetration case the slowdown is more noticeable, being 0.1 percentage points in the 1980s and 0.2 points (from 2.8% to 2.6%) in the 1990s. By 2000, these correspond to real GNP levels 0.9% lower than the Base Case for medium penetration and 2.9% lower for high penetration.

These relative GNP reductions are quite large when viewed in terms of absolute magnitude. The total real GNP loss between 1980 and 2000 amounts to $86 bn (1972$) for the medium case, and $413 bn (1972$) in the high penetration case. The present value (to 1980 at a 5% real discount rate) of these losses are $37 bn (1972$) and $202 bn (1972$), respectively. These correspond to lump sum taxes of $667 and $3,648, in the medium and high penetration cases, for every household in the

U. S. in 1980. Using any of these measures, the aggregate economic costs of a new technology energy program will be large.

Furthermore, the economic costs of solar energy seem to be non-linear. Thus, the real GNP loss per million Btu supplied by solar increases as the scale of the solar program increases. This fact is discussed in more detail in Chapter 11.

The economic conclusions are that a large scale solar energy program will have noticeable, and adverse, effects on the economy in terms of slower growth of incomes and output. Also, the effect of solar investment on capital markets may be severe. Thus, the absolute magnitude of the costs imposed by increased solar market penetration is substantial. However, living standards as measured by GNP per capita will increase from current levels even with a large scale solar program. This implies that a large scale solar program may be sustainable but that it still involves significant economic costs. From a policy point of view, these costs must be weighed against the benefits that solar energy may provide--such as reduced oil imports, greater security in energy supply and (possibly) reduced environmental and health damage caused by decreased production and use of fossil and nuclear fuels--in evaluating the overall attractiveness of a major solar energy program.

TABLE 1-1

SCENARIO CONFIGURATION

Energy Supply Scenario / Oil Price Scenario	Scenario A	Scenario B	Scenario C
Oil Price 1	High Imported Oil Low Solar	Medium Imported Oil Medium Solar	Low Imported Oil High Solar
Oil Price 2	High Imported Oil Low Solar	Medium Imported Oil Medium Solar	

Note: By assumption, (Oil Price 2) > (Oil Price 1)

TABLE 1-2

SOLAR MARKET PENETRATION AND ASSOCIATED OIL IMPORTS*

(Quadrillion BTU per year)

Solar Energy Market Penetration	Oil Price Level	Contribution of Solar Technologies 1977	1985	1990	2000	Oil Imports 2000 **
Low	Lower Price	0.0	0.10	0.50	2.00	13.84
	Higher Price	0.0	0.10	0.50	2.00	9.91
Medium	Lower Price	0.0	0.36	1.30	7.27	10.33
	Higher Price	0.0	0.36	1.30	7.27	6.68
High	Lower Price	0.0	0.99	3.82	16.30	6.68

*Total energy input in primary equivalents.

**Oil Imports in 1977 were 17.25 Quads.

TABLE 1-3

OIL AND GAS PRICE AND PRODUCTION

	FUEL	OIL PRICE LEVEL	1977	1985	1990	2000
Fuel Prices $\$10^6$ Btu (1975\$)	Crude Oil	Higher	1.74	3.03	4.46	6.43 (1)
		Lower	1.74	2.35	3.01	4.63 (2)
	Crude Gas	Higher	0.43	2.04	3.00	6.49
		Lower	0.43	2.00	2.42	4.32
Domestic Production (Quadrillion Btu) (3)	Oil	Higher	19.75	22.27	21.48	19.71 (4)
		Lower	19.75	21.09	20.30	19.31
	Gas	Higher	20.60	18.80	18.15	17.60
		Lower	20.60	18.70	18.15	17.60

(1) This is equivalent to \$34.97/bbl in 1976\$, assuming 5.4×10^6 Btu/bbl.

(2) This is eqiuvalent to \$25.00/bbl in 1976\$, assuming 5.4×10^6 Btu/bbl.

(3) Estimates derived from BNL BESOM model.

(4) This is equivalent to 10.0 million barrels per day.

TABLE 1-4

REAL GNP IMPACTS OF SOLAR AND NEW ENERGY TECHNOLOGIES IN LOWER OIL PRICE CONDITIONS

	1985	1990	2000
Real GNP, Billion 1972$			
Base Case (Low solar)	1773.3	2060.2	2721.7
Medium Solar	1773.3	2060.2	2697.3
High Solar	1769.4	2044.3	2643.6
Difference from Base Case, Billion 1972$			
Medium Solar	0	0	-24.4
High Solar	-3.9	-15.9	-78.1
Difference from Base Case, %			
Medium Solar	0	0	-0.9
High Solar	-0.2	-0.8	-2.9
Real GNP Growth Rates (1)			
Base Case	3.64	3.05	2.82
Medium Solar	3.64	3.05	2.73
High Solar	3.61	2.93	2.60

(1) Average percent per annum.

TABLE 1-5

REAL GNP IMPACTS OF SOLAR AND NEW ENERGY TECHNOLOGIES IN HIGHER OIL PRICE CONDITIONS

	1985	1990	2000
Real GNP, Billion 1972$			
Reference Case (Low Solar)	1761.5	2036.1	2669.9
Medium Solar	1761.5	2036.1	2643.9
Difference from Reference Case			
Billion 1972$	0	0	-26.0
Percent	0	0	-1.0
Real GNP Growth Rates (1)			
Reference Case	3.55	2.94	2.75
Medium Solar	3.55	2.94	2.65

(1) Average percent per annum

PART II

ANALYTICAL DESIGN AND SCENARIO PARAMETERS

CHAPTER 2

ANALYTICAL METHODOLOGY

2.0 INTRODUCTION

Two subjects will be discussed in this chapter. The research design which has been developed for this study is presented in Section 2.1. The analytical tool which will be used for the economic analysis--the Hudson-Jorgenson Energy/ Economic Model--is described in Section 2.2.

2.1 Research Design

The purported high cost and capital intensity of solar energy technologies are the most common arguments used to support the thesis that large scale application of this energy source may have unacceptable economic consequences. However, this issue has never received proper study. The major objective of this research is to determine the implications for the U.S. economy over the next 20 years of a large scale solar energy investment program. To properly investigate this question, two related issues must also be considered:

- How do the economic implications change as the market penetration of solar energy changes?

- How do the economic implications change as the prices of alternative energy sources change?

To accomplish this objective, it was necessary that the capital requirements analysis be structured in multidimensional form so that the effect of changing energy price and solar market penetrations could be analyzed. (i.e., at least a 2x2 matrix was necessary, with price along one dimension and solar market penetration along the other).

Therefore, the major analytical problem faced in this study, beyond establishing the cost of various energy technologies, was to construct a sensitivity analysis which would effectively consider these interrelated issues in a consistent format.

An additional constraint placed upon the research methodology was a cost constraint which limited the number of scenarios that could be analyzed to five. The practical implications of this cost constraint cannot be overemphasized. In reality, the choice between a "solar energy future" and a "non-solar energy future" involves choices among numerous possible supply mixes (e.g., high solar market penetrations could replace or complement large-scale development of nuclear power, or large scale development of synthetic fuels). In short, to determine an optimum energy supply future from an economic standpoint, numerous configurations of energy supply should be considered and their economic implications evaluated. Since four scenarios would be required just to investigate changing price and market size assumptions (see above), specifying markedly different overall supply/demand mixes across five scenarios would result in a less than satisfactory analysis. This is true because one would be forced to draw comparisons among scenarios whose underlying supply assumptions were inconsistent by definition (since they have been so specified).

The most effective way to circumvent this problem is to design the scenarios so that only one major alternative to solar energy is specified. In such a system, solar energy would, in the main, substitute for, and be substituted by one energy source. An obvious choice as the alternative to solar energy is imported oil. It is the energy source now most widely used to bridge the gap between domestic energy supply and domestic energy demand. The economic problems often associated with the huge dollar outflows to purchase this oil are a source of political and economic concern, and national energy goals are seldom set without concentrating, in part, on decreasing our dependence on imported oil.

In addition, imported oil requires no capital input from U.S. sources but entails a continuous export payment. In this sense it provides an effective and sharp economic contrast to solar energy, which requires large domestic capital investments but little or no export of funds from the U.S. to foreign producers. Thus, although solar energy is not necessarily the only or the most effective alternative to imported oil, this paradigm provides a timely and interesting economic comparison.

Table 2-1 presents the analytical design outlined above for investigating the interrelated issues of the effect of changing solar market penetrations and energy prices on the national economy. It is a modified 2x2 matrix. (The additional scenario--a very high solar penetration scenario at one oil price--has been added to provide greater breadth in the analysis of changing market penetration impacts.*) It involves evaluating the economic implications of solar vs. an alternative energy source at different market penetration levels at two oil price levels. Note that the scenarios have been purposely defined so that there exists an inverse relationship exists between solar and imported oil market penetrations. While direct comparisons of the same market penetration scenario (e.g., Scenario A, the low solar, high imported oil scenario) at different oil prices may be interesting, for the purposes of this analysis it is the paired comparison of the two different market penetration

*An investigation of Scenario C at the higher oil price is not possible due to cost constraints.

scenarios at different oil prices (i.e., a comparison of scenarios A and B at the lower oil price with A and B at the higher oil price) which will be most important. This comparison will be useful in identifying the changes in economic impact of solar capital requirements as the price of competing energy sources change.

Finally, four points should be emphasized before the precise specification of scenarios is discussed (in Chapter 3):

- The scenarios which have been designed for this analysis have been specified, to the extent possible, to reveal a consistent comparison between solar energy and imported oil. As such, only one alternative to solar energy has been evaluated, although there are many possible alternatives;

- The scenarios which have been developed for this analysis have been designed for the purposes of conducting a sensitivity analysis. Thus, although they have been derived, in part, from market analysis research, they should not be construed to represent prescriptive definitions of future energy supply mix alternatives. Numerous possible combinations of future energy supply mixes exist; the scenarios developed for this analysis merely represent selected feasible alternatives;

- The full capital costs for achieving the energy utilization patterns specified in the scenarios have been allocated, to the extent possible to the appropriate energy sectors;

- Energy utilization in all scenarios is reported in <u>primary energy equivalents.</u>* To convert to delivered energy services

*I.e., the value of energy resources actually extracted, not the value of energy delivered or utilized at the end-use. Solar energy technologies, under this scheme, are valued at the primary energy which they replace.

required information on link efficiencies for each sector and fuel type. Generalized link efficiency data are presented in Chapter 3.

2.2 The Hudson-Jorgenson Energy/Economic Model

2.2.1 Description of the Model

The Hudson-Jorgenson Energy/Economic Model (also referred to as the Long Term Interindustry Transaction Model--LITM) will be used to evaluate the economic implications of the scenarios developed for this analysis. It is a model of economic structure and economic growth. As it is a purely national model, no sub-national spatial detail is reported or input. Prices and costs in the model are reported in 1972 dollars, as they are in this report.

The model's sectoral specification is oriented towards energy so that the model provides a framework for the analysis of interdependencies within the energy system as well as of the interdependence between energy and the rest of the economy. In addition, the model provides a comprehensive basis for medium and long term economic and energy forecasting and for the analysis of economic growth and structural change.

The model separates economic activity into several components. Included in these components are 10 domestic producing sectors, six of which cover energy extraction and processing and four of which cover the main nonenergy producing sectors (see Table 2-2). In addition, other non-conventional energy sectors (such as solar energy) can be modeled exogenously and their economic parameters used as inputs to the appropriate sectors in the model. In this manner, their economic impacts, such as the effects of their capital and labor requirements on production, are captured.

Each producing sector is modeled in terms of price determination and input patterns. Final demand is separated into consumption, investment, government, and exports. Consumption expenditure is based on a model of household behavior in which labor supply, consumption, and savings are all determined in a consistent manner. These final demands drive the production side of the model with an input-output system used to take account of the complex input requirements and interindustry flows required to sustain the final output of the economy. This whole production process is also subject to the limitations imposed by the availability of primary inputs, in particular capital and labor. Over time, labor supply changes as a result of population and participation rate changes, while capital supply increases by investment net of depreciation. The Hudson-Jorgenson system places all these components within a comprehensive framework and produces a dynamic, general equilibrium model of the U.S. economy.

Two of the model's principal features are the flexible coefficient, input-output models of producer behavior and the comprehensive, operational, general equilibrium system that this permits. The producer behavior models incorporate both price and quantity aspects of production in a comprehensive framework. This permits the determination of output prices, the determination the output quantities, and the determination of input patterns (the flexible input-output coefficients) to be accomplished on a uniform basis. In addition, household and other final demand behavior is incorporated, input constraints and input price determination are included and balance in inter-industry transactions and input and output markets is enforced to derive a consistent, general equilibrium system.

The model is set up in simulation form. This permits two types of solutions to be performed directly. The first is the development of base case forecasts in which likely values of the exogenous variables are inserted and the model then solved to yield the corresponding path and structure of economic and energy growth. The second type of solution concerns the alteration of assumptions about exogenous variables, with the model being solved to yield alternative forecasts and to estimate the effects of the stipulated changes in conditions.

2.2.2 Treatment of Capital Investment in the Hudson-Jorgenson Model

This study is concerned mainly with the impact of the capital requirements for solar energy on U.S. economic performance. In particular, it is the change in capital investment required to achieve a specified level of solar market penetration that is of interest. Therefore, it is useful to discuss the treatment of capital investment in the Hudson-Jorgenson Model so that the reader may better understand what scenario inputs must be developed for the model and how these inputs are utilized within the model.

The Hudson-Jorgenson Energy/Economic Model determines sectoral capital inputs on the basis of capital flows information collected for the period which was used to calibrate the parameters in the model (1947-71). Input of capital services* are calculated for each of the ten sectors in the model for forecast years (the total depreciated value of in-place capital stock can be estimated for any forecast year on the basis of this information). Thus, the model does not directly utilize capital/output ratios for any sector.**

*The services (output) provided by capital including a normal rate of return and an allowance for depreciation.

**Direct capital/output ratios (in the form of $/kW) can be utilized in the electric/utility sector since the H-J model includes a detailed submodel for this sector.

However, the input of capital services to the energy sectors is directly responsive to the outputs specified for those sectors. For example, by exogenously specifying a level of output for the energy extraction sectors in the model (i.e., coal, oil, gas) the model will respond by diverting to those sectors the volume of capital services required to sustain the stipulated output. Energy price levels also affect capital and other requirements. In particular, a rising real price for energy is an indication that greater factor inputs are required to elicit the continued supply of energy resources. For these reasons, the exogenous specification of energy supply and prices that will be used for runs of the Hudson-Jorgenson system replicates the exploitation of increasing marginal cost energy resources.*

The Hudson-Jorgenson model does not distinguish between energy using capital services and other "productive" capital services for the residential/commercial transportation and industrial sectors. In this manner, the demand for capital services in these sectors is more a function of output and prices than of energy use (producers--both household and otherwise--are free to utilize the mix of capital services which may best achieve output objectives). In this sense, the model is more flexible and realistic than if energy use in all energy consuming sectors were tied in fixed relationship to output, since, in the long run, labor and/or capital may be substituted for energy.

---

*Since no resource extraction curves which separate capital investments from operating expenses could be obtained for this research, defining capital services inputs to the oil, gas and coal sectors on the basis of output and resource price represents the best possible alternatives to simulating the effect of such a curve.

Therefore, in order to determine the economic impact of the capital requirements for solar energy (or any other supply mix), deviations from the value of depreciated capital stocks from some base value must be developed. This requires that capital investment information be input to the model in an appropriate format (except for the electric sector where the submodel which interacts with the larger model can accept as inputs normal capital/output ratios). To review then the form in which capital requirements will be specified for the scenarios:

- For energy extraction sectors capital requirements will be determined endogenously in the model using exogenous specifications of output and price;

- For the gas utility sector capital requirements will be specified endogenously based on capital flow trends. Capital services input to this sector is not expected to differ significantly across the different scenarios;

- For the electric utility sector, the submodel may be used to specify investment requirements for conventional technologies. These requirements can be generated using traditional capital/output relationships ($/kw). Similar information will be generated exogenously for non-conventional technologies. Since transmissions and distribution investment is not expected to vary significantly across similar oil price scenarios, these costs will be calculated endogenously within the model;

- For the petroleum refining sector, the model will determine capital service inputs endogenously based on the general assumption that 50% of all imported oil and all of the domestically-produced oil is refined in the U.S. Thus, refining capacity will implicitly vary based on domestic output and input requirements;

- For all other sectors, the effect of solar and other capital investment must be input to the model in the form of deviations in depreciated capital stock from a norm (e.g., no solar market penetrations). The total capital investment requirements developed in this report will be transformed into the appropriate format for input to the model. Non-fuel operating costs can also be treated as deviations from some norm.

2.2.3 Treatment of Multiple-Use Transportation Modes and Conservation Capital Requirements

Finally, two types of energy-related capital requirements have not been considered. These are non-single-use energy transportation modes* and conservation expenditures.

Non-single-use energy transportation capital requirements have not been considered because:

- The Hudson-Jorgenson model currently specifies a relationship between energy outputs by sector and the transportation sector (which includes all multiple use modes). If this relationship is retained, the energy sectors will continue to demand inputs from the transportation sector. The transportation sector, in turn, will demand capital inputs to construct sufficient capacity. By retaining this relationship, the analysis would implicitly assume that, during the forecast period, the pattern for transportation of fuels will be similar to the pattern during the period during which the model was calculated (or will change based on rates of change observed during the calibration period). Thus, transportation inputs to energy sectors would be included in our analysis.

- All multiple use modes used to transport energy--such as rail, barge or truck--can be used to transport other commodities by definition. Determining the marginal indirect capital investment requirements for each mode for each scenario in order to ship fuels would be extremely difficult under any circumstances and is inappropriate to the level of detail necessary for this study.

- Varying fuel transportation relationships across different scenarios would be equivalent to shifting the spatial distribution of fuel providers and users across different

---

*E.g., truck, rail and barge transport facilities.

scenarios. However, since the Hudson-Jorgenson model is a national model which provides no detail at the sub-national level, it is inappropriate to use the model in this manner.

For these reasons, current transportation/energy relationships will be retained for this study. Retention also carries the additional advantage of eliminating a major source of variation in the inputs for the scenarios which will be analyzed. Given the dynamic and interactive structure of the Hudson-Jorgenson model such variation would render the attribution of interscenario parameter differences problematic. Since the goal of this study is to determine the macroeconomic effects of variation in the energy supply system, retaining current transportation/energy relationships across all scenarios is the preferred approach.

Conservation device capital expenditures and their macroeconomic impact will also not be factored into the analysis for this study. At each oil price level, all energy supply scenarios that will be analyzed will utilize the same energy demand path. Thus, it is reasonable to assume that conservation device expenditures will not vary significantly among these scenarios. Furthermore, since the value of conservation devices is small relative to the total output of the manufacturing sector (where they are produced in the model) and the output of the construction sector (where they are installed), the Hudson-Jorgenson model is much too gross a tool to determine the impact of additional capital expenditures for conservative devices on macroeconomic variables. Finally, it should be noted that expenditures of conservation devices have occurred during the period for which the model was calibrated. Thus, some level of such expenditures is inherent in the model's economic outputs (albeit dwarfed by the much larger sectoral output for those sectors within which conservation device expenditures are subsumed).

TABLE 2-1

SCENARIO CONFIGURATION

Oil Price Scenario \ Energy Supply Scenario	Scenario A	Scenario B	Scenario C
Oil Price 1	High Imported Oil Low Solar	Medium Imported Oil Medium Solar	Low Imported Oil High Solar
Oil Price 2	High Imported Oil Low Solar	Medium Imported Oil Medium Solar	X

Note: By assumption, (Oil Price 2) > (Oil Price 1)

TABLE 2-2

SECTORS IN THE HUDSON-JORGENSON MODEL

- coal mining
- petroleum extraction
- natural gas extraction
- crude oil refining
- gas utilities
- electric utilities
- construction, agriculture, and non-fuels mining (including uranium mining)
- manufacturing
- transportation
- services

CHAPTER 3

SPECIFICATION OF SCENARIOS FOR ANALYSIS

3.1 Identification of Scenarios

Two major sources were used to develop scenarios for sectoral energy by fuel for the analysis.

- Toward a National Plan for the Commercialization of Solar Energy and other unpublished material developed for the National Plan to Accelerate Commercialization of Solar Energy (NPAC)*

- A Comparative Assessment of Energy-Economy Interactions by the Economic Analysis Division of the Brookhaven National Laboratory and Dale W. Jorgenson Associates (BNL/DJA)

The Department of Energy has developed information on energy demand by sector for two year 2000 oil prices ($25.00 and $32.00 per barrel, 1976 dollars) for the following fuels (electric vs. non-electric):

- oil
- gas
- coal
- nuclear

---

*NPAC1 scenario information was used to enhance the compatability of this analysis with other NPAC research.

- o hydro
- o solar*
- o biomass (including synthetic fuels)
- o geothermal
- o coal-based synthetic fuels

At each oil price, two scenarios--the NPAC1** Reference Scenario (which corresponds to a medium solar, medium imported oil scenario) and the NPAC1 Option III (representing maximum technically feasible market penetration for solar and low imported oil)--were presented. These scenarios posited different levels of solar market penetration based on an analysis of the effect of market incentives for solar technologies. Finally, for each scenario, solar penetrations were further classified by technology (see Tables 3-14 through 3-16).

These scenarios formed the basis for the medium and high solar market penetration scenarios developed for this analysis. The modifications made to them are discussed in Section 3.3. These modifications were necessary to:

- o obtain the most consistent set of scenarios possible;
- o enhance the comparison between solar and imported oil as alternative energy sources;
- o eliminate variations in solar market penetration data developed for NPAC1; and

---

*Includes wind, photovoltaics, ocean thermal electric (OTEC), small scale (non-utility) hydroelectric and all solar thermal applications. This definition of solar will pertain throughout this document.

**NPAC1 = National Plan to Accelerate Commercialization of Solar Energy--1979 Scenarios.

- o simplify the sensitivity analysis.

Work performed by the Brookhaven National Laboratory and Dale W. Jorgenson Associates (BNL/DJA) was used to define solar market penetrations for the low solar, high imported oil scenario. The BNL/DJA study defined a scenario where the market penetration of solar technologies resulted in the displacement of 2.0 Quads (10^{15} BTU) of primary energy in the year 2000 as opposed to 6.9-7.3 Quads for the NPAC1 Reference Scenario and 16.3 Quads for the NPAC1 Option III Scenario. In addition, the BNL/DJA work was used to define economic growth targets for use in the analysis (representing a moderate growth trend for most economic parameters), and domestic oil and gas production at different energy price levels (see Section 3.2). Both the NPAC1 and the BNL/DJA studies were used to assist in developing a growth path for overall energy use for 1985, 1990, and 2000, the key years for the analysis. Finally, NPAC1 specification of solar market penetration by technology was specified for the Reference and Option III scenarios for 1985, 1990, and 2000, and these were used as the basis for defining solar market penetrations for all scenarios.

3.2 Definition of General Energy/Economic Targets

The analysis of the economic impacts of different energy supply mixes during the forecast period (1978-2000) requires that a general scenario for key economic and energy parameters be specified. The Brookhaven/Jorgenson work was especially relevant to this task since it defined, for three different oil price levels, for 1977, 1985, 1990, and 2000:

- o GNP growth
- o Government GNP component
- o unemployment rate
- o energy prices

- o factor productivity growth
- o domestic oil and gas production
- o GNP price inflation
- o total energy use

All three BNL/DJA scenarios represent moderate GNP growth paths and incorporate only a relatively small amount of solar market penetration. Also, all three scenarios assume substantial deregulation of domestic oil and gas prices by 1985.

Since the middle oil price (c. $25/bbl in 1976$) and the higher oil price in the BNL/DJA scenarios (c. $35/bbl) corresponds very well with the prices used to develop the NPAC1 scenarios, the BNL/DJA specification of key economic and energy parameters was accepted for this analysis.* The values for these parameters for several forecast years are noted in Tables 3-1 (for the Lower Oil Price) and 3-2 (for the Higher Oil Price). It is important to note that in some cases (e.g., domestic oil and gas production, labor and capital productivity and government GNP component), these parameter values are exogenously specified, and will therefore be automatically achieved. In other cases, such as GNP growth rate and GNP prices, the targets define a path which may or may not be replicated as a result of the interactions among several economic and energy factors (e.g., energy prices, energy use, capital requirements, etc.). Since the Low Solar (High Imported Oil) Scenario developed for this analysis corresponds in many aspects to the BNL/DJA Scenario for which the economic and energy parameter values were developed, the Low Solar Scenario energy/economic results should track these values quite closely.

---

*Total energy use for the two sources also coincided quite closely at similar oil price levels.

Finally, it should be noted that the domestic oil and gas production values specified at each energy price are derived from outputs of the BNL BESOM Model (Brookhaven Energy System Optimization Model) and were calculated as part of the BNL/DJA scenario research. Thus, the economic (especially energy price) and domestic oil/gas production values specified are internally consistent. Furthermore, the BESOM results have been compared with several other forecasts and are in substantial agreement with many, including the 1977 AAR, Mid-Supply Forecasts.

3.3 Formulation of Energy Scenarios

Table 3-3 shows information provided by the Department of Energy on energy use for the year 2000 for three scenarios:

- o NPAC1 Reference Option, Mid-Oil Price ($25.00/bbl, 1976$)*
- o NPAC1 Reference Option, High Oil Price ($32.00/bbl, 1976$)**
- o NPAC1 Option III, Mid-Oil Price ($25.00/bbl).

In addition, estimated energy use information was provided for the Reference Option, Mid-Oil Price for 1990 and for market penetration by specific solar technologies for 1985, 1990, and 2000. This information was used as the initial basis for designing five energy supply scenarios which would satisfy the requirements for the sensitivity analysis outlined in Chapter 2. The Low Solar scenarios were formulated using the basic assumption that total solar market penetration (in primary energy equivalents) by the year 2000 would be 2.0 Quads of energy, as specified in the BNL/DJA research.

From this starting point several steps were utilized to develop the energy supply scenarios into their final form:

---

*Corresponds to the Lower Oil Price ($25.00/bbl, 1976$, in the year 2000) in this analysis.

**Corresponds to the Higher Oil Price ($34.97/bbl, 1976$, in the year 2000) in this analysis.

- First, efforts were made to reconcile differences in NPAC1 aggregate data on solar market penetrations, with NPAC1 disaggregate (technology and sector specific) data on solar market penetrations. This resulted in the increase in the solar market penetrations for the year 2000 for the Reference Scenario at the $25/bbl oil price from 6.9 Quads to 7.3 Quads. This results in the following year 2000 solar market penetrations for the different scenarios:

  -- 2.0 Quads for the Low Solar (High Imported Oil) Scenario (BNL/DJA "Base Case")

  -- 7.3 Quads for the Medium Solar (Medium Imported Oil) Scenario (NPAC1 Reference Option)

  -- 16.3 Quads for the High Solar (Low Imported Oil) Scenario (NPAC1 Option III).

- To simplify the problem of capital requirements estimation and to increase commonality and comparability between similar market penetration scenarios, total solar market penetrations (as measured in Quads) are assumed to be equivalent at different oil prices for each scenario. Thus, solar market penetrations as measured by percent of total energy use will increase slightly at the higher oil price (since total energy use will decrease). This is consistent with NPAC1's assumptions.

- The growth path for total energy use at each oil price represents a compromise between assumptions used by NPAC1 and BNL/DJA. This path is represented in Table 3-4.

- To develop a Low Solar Scenario which is, to the greatest extent possible, consistent with the specification of the Medium Solar Scenario, the following information was necessary:

  (1) data on the type of fuels displaced by each solar device. This information was supplied by NPAC1 and appears in Table 3-5.

(2) data on the relative efficiencies of various fuels. This information was developed from data gathered in Task 1 of this research effort and is presented in Table 3-6.*

The data in Table 3-5 can be used to derive the conventional fuels mix which would replace 5.3 Quads of solar in proceeding from the Medium Solar Scenario to the Low Solar Scenario.

- Because this sensitivity analysis posits the replacement of solar by imported oil, the efficiency information (Table 3-6) was necessary to derive the oil equivalent to the conventional fuels mix which replaced solar. Using imported oil to replace solar as opposed to a mix of fuels has two advantages.

  --it enhances the comparison between solar and imported oil as energy alternatives.

- Solar electric generation was replaced by conventional electric generation**, while end-use of Solar was replaced by end-use of imported oil. Although many analysts assume that solar end-use devices will replace electricity utilized at the end-use for a solar vs. an imported oil future, this will not necessarily hold. Furthermore, this assumption avoids increasing the already high electrification use inherent in the NPAC1 scenarios.

  The resulting total primary energy demands across scenarios may thus differ slightly based on the

---

*Note that this information specified current efficiencies. These efficiencies will change over time, but as a simplifying assumption, we assumed that their relative values would be constant.

**Note that some portion of solar electric energy is replaced by coal and nuclear electric generation in the Low Solar Scenario (vs. the Medium Solar Scenario). This was done so as to constrain oil electric generation to approximately its current capacity, since current federal regulations (which are expected to continue) discourage the construction of new oil-fired electric capacity. Coal and nuclear fuels were substituted because domestic supply for these two sources is relatively unconstrained.

different efficiency factors for using different fuels.

- Energy use, by fuel, by sector was determined by defining linear growth trends for the Medium Solar Scenario based on the NPAC1 Reference Scenario information for 1977, 1990, and 2000 and the BNL/DJA fuels distribution information. Adjustments to this derived distribution were then made to this scenario based on the higher solar market penetrations of the High Solar Scenario, by replacing conventional fuels with solar according to the information supplied by NPAC1. The Low Solar Scenario was derived in the opposite manner. Thus, all three scenarios are internally consistent according to the efficiency and solar factor replacement information presented in Tables 3-5 and 3-6.

Several other relatively minor adjustments were made to the scenarios, both to enhance the solar versus imported oil comparisons and to develop the most consistent set of scenarios possible. These included:

- <u>Residential biomass fuel use was ignored.</u> Data on residential biomass fuel use (including historical trends, current use and forecasts of future use) is not based on accurate information at this time. For this reason and since residential biomass use is such a small part of total residential fuel use throughout the forecast period, its use has been ignored for the purposes of this analysis.

- <u>Industrial and synthetic biomass fuel use has been equalized across all scenarios</u> for simplicity for the purposes of enhancing the comparison between solar and imported oil. The additional Industrial biomass present in the High Solar Scenario has been replaced by gas and oil, according to the factors in Table 3-5.

  It has been assumed for the purposes of this analysis (because no reliable data is available to support or refute this assumption) that the resulting trend for industrial biomass fuel use represents a simple extension of the historical growth rate. Synthetic fuel primary energy use (which is the same for all market penetration scenarios at the same oil price) is assumed to replicate the NPAC1 Reference Option to eliminate the movement from coal-based to biomass-based synthetic fuels as a possible source of variation in economic impacts.

- Some conventional end-use fuel use has been reallocated in the NPAC1 Option III Scenario from oil to natural gas in the year 2000, so that domestic demand for natural gas equals domestic supply. This results in a slight reduction in total primary energy use due to the greater efficiency in the direct use of gas than oil.

3.4 Final Specification of Scenarios

Table 3-7 provides base year (1977) energy demand/supply information by sector and fuel. The energy demand/supply scenarios developed according to the assumptions and guidelines specified in Chapter 2 and this chapter are summarized in Table 3-8. Tables 3-9 through 3-13 present more detailed information for each of these scenarios, and Tables 3-14 through 3-16 present more detailed categorization of solar market penetrations by technology for 1985, 1990, and 2000. As noted above, the market penetrations for the Medium Solar and High Solar scenarios are based on information supplied by the Department of Energy. The market penetrations for the Low Solar Scenario have been derived through the following process:

(1) Overall solar market penetrations for the residential/commercial, industrial and electric utility sectors were determined for the Low

Solar Scenario. It was assumed that the proportional reduction in solar electric utility penetration would be greater than for residential/commercial or industrial, which is consistent with NPAC1's implicit assumption that solar electric applications would occur later than residential/commercial and industrial applications.*

(2) Technology specific solar market penetrations were calculated for each sector based on the proportional downward adjustment of total solar market penetration in that sector from the level specified for the Medium Solar Scenario. For those technologies for which this downward adjustment resulted in a market penetration of less than .02 Quads, these market penetrations were set to zero.

*Thus, the Low Solar Scenario may be considered, in part, a scenario where solar market penetration has been temporally slowed.

TABLE 3-1

DEFINITION OF SCENARIO ECONOMIC/ENERGY TARGETS--LOWER OIL PRICE

	1977	1985	1990	2000	Units
GNP	1332.7	1773.3	2060.2	2721.7	Billions of 1972$
Government	269.2	344.4	408.0	553.0	Billions of 1972$
Unemployment rate	7.0	5.0	4.8	4.8	per cent
Domestic oil[1] production	19.75	21.09	20.30	19.31	Quads per year
Domestic gas[1] production	20.6	18.7	18.15	17.6	Quads per year
Crude oil price	1.74	2.35	3.01	4.63[2]	in (1976$)/$10^6$ BTU
Crude, natural gas price (domestic)	0.43	2.00	2.42	4.32	in (1976$)/$10^6$ BTU
Coal price (minemouth)	0.63	1.34	1.41	1.50	in (1976$)/$10^6$ BTU

Annual Growth Rate Rates (% per year)

	1977-1985	1985-1990	1990-2000
Real GNP	3.64	3.05	2.82
GNP Prices	6.0	5.0	4.8
Labor Force	1.70	1.23	1.08
Civilian Employment	2.01	1.30	1.09
Gross Labor Productivity	1.60	1.72	1.71

[1]Estimates derived from BNL BESOM Model.

[2]This is equivalent to $25.00/bbl (1976$).

TABLE 3-2

DEFINITION OF SELECTED SCENARIO ENERGY/ECONOMIC TARGETS -- HIGHER OIL PRICE

	1977	1985	1990	2000	
Crude oil price	1.74	3.03	4.46	6.43[1]	
Crude natural gas price	0.43	2.04	3.00	6.49	1976$/$10^6$ BTU
Coal price (minemouth)	0.63	1.34	1.41	1.51	
Domestic oil[2] production	19.75	22.27	21.48	19.71	Quads per year
Domestic gas[2] production	20.6	18.8	18.15	17.6	Quads per year

[1]Equivalent to $34.97/bbl (1976$).

[2]Estimates derived from BNL BESOM Model.

TABLE 3-3

ENERGY DEMAND/SUPPLY INFORMATION FROM NPAC1

(Year 2000, Quadrillion BTU's in Primary Energy Equivalents)

FUELS	Mid Price-Reference Option				Mid Price-Option III				High Price-Reference Option			
	End-Uses	Electric Utility	Synthetic Fuel	Total	End-Uses	Electric Utility	Synthetic Fuel	Total	End-Uses	Electric Utility	Synthetic Fuel	Total
PRIMARY												
Oil	27.2	2.0	--	29.2	25.9	1.5	--	27.4	23.7	1.5	--	25.2
Gas	17.7	0.5	--	18.2	14.3	0.3	--	14.6	16.8	0.3	--	17.1
Coal	9.6	25.6	3.8	39.0	9.1	20.2	3.2	32.5	7.2	23.1	4.8	35.1
Nuclear	--	15.0	--	15.0	--	14.2	--	14.2	--	13.0	--	13.0
Hydro	--	3.4	--	3.4	--	4.0	--	4.0	--	3.5	--	3.5
Solar	4.4	2.5	--	6.9	9.8	6.5	--	16.3	4.3	2.5	--	6.8
Geothermal	--	0.5	--	0.5	--	0.5	--	0.5	--	0.6	--	0.6
Biomass*	2.2*	--	0.6	2.8	4.0*	0.3	1.2	5.5	2.4*	0.1	1.2	3.7
INTERMEDIATE												
Electricity	49.5	49.5			47.5	47.5			44.6	44.6		
Synthetic Fuels	4.4		4.4		4.4		4.4		6.0		6.0	
TOTAL				115.0				115.0				105.0

*Industrial Process Heat Only

TABLE 3-4

GROWTH RATES FOR ENERGY USE

Year 2000 Oil Price (1976$)	Growth Rates (% per year)		
	1977-1985	1985-1990	1990-2000
$25.00/bbl	2.30	1.67	1.30
$34.97/bbl	1.72	1.25	1.03

TABLE 3-5

FACTORS USED TO CONVERT SOLAR ENERGY TO
PRIMARY ENERGY EQUIVALENTS

Sector	Conventional Fuel	% Displaced by Solar
Residential/Commercial (Solar)	Electricity	.57
	Gas	.32
	Oil	.11
Industrial (Biomass)	Gas	.70
	Oil	.30
Industrial (Solar)	Electricity	.17
	Gas	.48
	Oil	.18
	Coal	.17
Electricity (Solar baseload)	Nuclear Electric	.26
	Coal Electric	.74
Electricity (Solar intermediate)	Coal Electric	.88
	Oil and Gas Electric	.12
Electricity (Solar fuel savers)	Coal Electric	.73
	Oil and Gas Electric	.27

SOURCE: NPAC1 data.

TABLE 3-6

CURRENT EFFICIENCIES FOR PRIMARY FUEL USE

Sector	Transportation	Conversion	Transmission & Distribution	End-Use	Total
Oil Electric	.995	.93[1], .3456[2]	.91	1.00	.291
Natural Gas Electric	.954[3]	.33[4]	.91	1.00	.286
Coal Electric	.98	.3456[2]	.91	1.00	.308
Nuclear Electric	--	.96[5], .312[6]	.91	1.00	.273
Oil Direct	.995	.93[1]	.98	.55	.499
Coal Direct	.98	--	.98	.65	.624
Natural Gas Direct	.954[3]	--	.98	.70	.654

[1]Refining efficiency.

[2]Conversion to electricity.

[3]Domestic pipeline efficiency.

[4]Conversion to electricity, lower efficiency than other fossil fuels reflects greater use of natural gas for peaking production.

[5]Enrichment efficiency.

[6]Conversion at 10,500 BTU/kWh.

TABLE 3-7

U.S. ENERGY DEMAND DATA FOR THE YEAR 1977
QUADS - PRIMARY FUEL

USES / FUELS	END-USES			INTERMEDIATE USES		GROSS ENERGY USE	PERCENT
	Residential and Commercial	Industrial	Transportation	Electric Utility	Synthetic Fuels		
PRIMARY							
Oil	7.1	7.0	19.1	3.8	---	37.0	47
Gas	7.5	8.3	0.6	3.2	---	19.6	25
Coal	0.2	3.7	---	10.4	---	14.3	19
Nuclear	---	---	---	2.7	---	2.7	4
Hydro	---	---	---	2.4	---	2.4	3
Solar	---	---	---	---	---	---	---
Geothermal	---	---	---	---	---	---	---
Biomass	---	1.6	---	---	---	1.6	2
INTERMEDIATE							
Electricity	13.3	9.0	0.2	22.5			
Synthetic Fuels	---	---	---		0.0		
TOTAL	28.1	29.6	19.9			77.6	100

Source: NPAC1 information

TABLE 3-8

SUMMARY OF ENERGY SCENARIOS DEVELOPED FOR ANALYSIS

Scenario	Oil Price	Year	Total Energy Use (in Quads)	Solar Market Penetration (in Quads)	Oil Imports (in Quads)
Low Solar	Lower Price	1985	92.98	0.10	18.87
		1990	100.96	0.50	18.25
		2000	114.84	2.00	13.84
Medium Solar	Lower Price	1985	93.00	.36	18.65
		1990	101.00	1.30	17.58
		2000	115.00	7.27	9.82
High Solar	Lower Price	1985	93.00	0.99	18.57
		1990	101.00	3.82	17.07
		2000	114.46	16.30	6.35
Low Solar	Higher Price	1985	89.01	0.10	15.03
		1990	94.68	0.50	13.60
		2000	104.84	2.00	9.89
Medium Solar	Higher Price	1985	89.00	.36	14.77
		1990	94.70	1.30	12.92
		2000	105.00	7.27	5.89

TABLE 3-9

LOW SOLAR SCENARIO, LOWER OIL PRICE ($25.00/bbl)

U.S. ENERGY DEMAND DATA
QUADS -- PRIMARY FUEL

FUELS	1985				1990				2000			
	End-Uses	Electric Utility	Synthetic Fuel	Total	End-Uses	Electric Utility	Synthetic Fuel	Total	End-Uses	Electric Utility	Synthetic Fuel	Total
PRIMARY												
Oil	36.26	3.5	--	39.76	35.18	3.37	--	38.55	29.75	3.40	--	33.15
Gas	18.4	2.2	--	20.60	18.80	1.04	--	19.84	17.50	0.50	--	18.00
Coal	5.12	15.05	0.30	20.47	5.99	19.64	1.50	27.13	9.76	26.00	3.80	39.56
Nuclear	--	7.00	--	7.00	--	9.54	--	9.54	--	15.03	--	15.03
Hydro	--	3.20	--	3.20	--	3.30	--	3.30	--	3.80	--	3.80
Solar	0.10	--	--	0.10	0.50	--	--	0.50	1.80	0.20	--	2.00
Geothermal	--	0.05	--	0.05	--	0.10	--	0.10	--	0.50	--	0.50
Biomass	1.80*	--	--	1.80	2.00*	--	--	2.00	2.20*	--	0.60	2.80
INTERMEDIATE												
Electricity	31.00	31.00			36.99	36.99			49.43	49.43		
Synthetic Fuels	0.30		0.30		1.50		1.50		4.40		4.40	
TOTAL				92.98				100.96				114.84

*Industrial Process Heat Only

TABLE 3-10

MEDIUM SOLAR SCENARIO, LOWER OIL PRICE ($25.00/bbl)

U.S. ENERGY DEMAND DATA

QUADS -- PRIMARY FUEL

FUELS	1985				1990				2000			
	End-Uses	Electric Utility	Synthetic Fuel	Total	End-Uses	Electric Utility	Synthetic Fuel	Total	End-Uses	Electric Utility	Synthetic Fuel	Total
PRIMARY												
Oil	36.04	3.5	--	39.54	34.67	3.21	--	37.88	27.13	2.00	--	29.13
Gas	18.4	2.2	--	20.6	18.8	1.0	--	19.80	17.50	0.50	--	18.00
Coal	5.1	15.05	0.3	20.45	5.94	19.64	1.5	27.08	9.54	25.25	3.80	38.59
Nuclear	--	7.0	--	7.0	--	9.54	--	9.54	--	14.88	--	14.88
Hydro	--	3.2	--	3.2	--	3.3	--	3.30	--	3.80	--	3.80
Solar	.36	--	--	.36	1.1	0.2	--	1.30	4.8	2.47	--	7.27
Geothermal	--	.05	--	.05	--	0.1	--	0.10	--	0.50	--	0.50
Biomass	1.8*	--	--	1.8	2.0*	--	--	2.00	2.2*	0.03	0.60	2.83
INTERMEDIATE												
Electricity	31.0	31.0			36.99	36.99			49.43	49.43		
Synthetic Fuels	0.3		0.3		1.5		1.5		4.4		4.4	
TOTAL				93.0				101.00				115.00

*Industrial Process Heat Only

TABLE 3-11

HIGH SOLAR SCENARIO, LOWER OIL PRICE ($25.00/bbl)

U.S ENERGY DEMAND DATE

QUADS - PRIMARY FUEL

FUELS	1985				1990				2000			
	End-Uses	Electric Utility	Synthetic Fuel	Total	End-Uses	Electric Utility	Synthetic Fuel	Total	End-Uses	Electric Utility	Synthetic Fuel	Total
PRIMARY												
Oil	35.96	3.50	--	39.46	34.17	3.20	--	37.37	24.16	1.50	--	25.66
Gas	18.17	2.20	--	20.37	18.42	1.00	--	19.42	17.30	0.30	--	17.60
Coal	5.07	14.77	0.3	20.14	5.81	18.12	1.50	25.44	9.10	20.20	3.80	33.10
Nuclear	--	6.90	--	6.90	--	8.86	--	8.86	--	14.20	--	14.20
Hydro	--	3.20	--	3.20	--	3.80	--	3.80	--	4.00	--	4.00
Solar	0.99	--	--	0.99	2.40	1.42	--	3.82	9.80	6.50	--	16.30
Geothermal	--	0.05	--	0.05	--	0.10	--	0.10	--	0.50	--	0.50
Biomass	1.8*	0.09	--	2.39	2.0*	0.20	--	2.20	2.20*	0.30	0.60	3.10
INTERMEDIATE												
Electricity	30.71	30.71			36.70	36.70			47.50	47.50		
Synthetic Fuels	0.3		0.3		1.50		1.50		4.40		4.40	
TOTAL				93.0				101.00				114.46

*Industrial Process Heat Only

TABLE 3-12

LOW SOLAR SCENARIO, HIGHER OIL PRICE
($34.97/bbl)

U.S. ENERGY DEMAND DATA
QUADS -- PRIMARY FUEL

FUELS	1985				1990				2000			
	End-Uses	Electric Utility	Synthetic Fuel	Total	End-Uses	Electric Utility	Synthetic Fuel	Total	End-Uses	Electric Utility	Synthetic Fuel	Total
PRIMARY												
Oil	34.00	3.30	--	37.30	32.13	2.95	--	35.08	26.60	3.00	--	29.60
Gas	17.70	2.20	--	19.90	18.10	1.00	--	19.10	16.80	0.30	--	17.10
Coal	5.11	14.60	0.30	20.01	5.45	18.65	1.50	25.60	7.44	23.70	4.80	35.94
Nuclear	--	6.65	--	6.65	--	9.00	--	9.00	--	13.00	--	13.00
Hydro	--	3.20	--	3.20	--	3.30	--	3.30	--	3.80	--	3.80
Solar	0.10	--	--	0.10	0.50	--	--	0.50	1.80	0.20	--	2.00
Geothermal	--	0.05	--	0.05	--	0.10	--	0.10	--	0.60	--	0.60
Biomass*	1.8*	--	--	1.80	2.00*	--	--	2.00	2.00*	--	0.60	2.80
INTERMEDIATE												
Electricity	30.00	30.00			35.00	35.00			44.60	44.60		
Synthetic Fuels	0.30		0.30		1.50		1.50		5.40		5.40	
TOTAL				89.01				94.68				104.84

*Industrial Process Heat Only

TABLE 3-13

MODERATE SOLAR SCENARIO, HIGHER OIL PRICE
($34.97/bbl)

U.S. ENERGY DEMAND DATA
QUADS -- PRIMARY FUEL

FUELS	1985				1990				2000			
	End-Uses	Electric Utility	Synthetic Fuel	Total	End-Uses	Electric Utility	Synthetic Fuel	Total	End-Uses	Electric Utility	Synthetic Fuel	Total
PRIMARY												
Oil	33.74	3.30	--	37.04	31.60	2.80	--	34.40	24.0	1.60	--	25.60
Gas	17.70	2.20	--	19.90	18.10	1.00	--	19.10	16.80	0.30	--	17.10
Coal	5.10	14.60	0.30	20.00	5.40	18.60	1.50	25.50	7.20	22.90	4.80	34.90
Nuclear	--	6.65	--	6.65	--	9.00	--	9.00	--	12.90	--	12.90
Hydro	--	3.20	--	3.20	--	3.30	--	3.30	--	3.80	--	3.80
Solar	0.36	--	--	0.36	1.10	0.20	--	1.30	4.80	2.47	--	7.27
Geothermal	--	0.05	--	0.05	--	0.10	--	0.10	--	0.60	--	0.60
Biomass*	1.80*	--	--	1.80	2.00*	--	--	2.00	2.2*	0.03	0.60	2.83
INTERMEDIATE												
Electricity	30.00	30.00			35.00	35.00			44.60	44.60		
Synthetic Fuels	0.30		0.30		1.50		1.50		5.40	--	5.40	
TOTAL				89.0				94.70				105.00

*Industrial Process Heat Only.

TABLE 3-14

CONTRIBUTION OF SOLAR, HYDRO AND BIOMASS TECHNOLOGIES (IN QUADS) IN 1985

(Normalized from detailed NPAC1 figures to obtain consistency with scenario definitions)

	Medium Solar	High Solar	Low Solar
Residential			
Thermal	.13	.37	.05
Passive	.01	.02	
WECS			
Photovoltaics			
Commercial			
Thermal	.12	.31	.05
Passive		.01	
WECS			
Photovoltaics			
Industrial			
Solar Thermal	.10	.28	
Biomass	1.80	1.80	1.80
Photovoltaics			
WECS			
S.T. Electric			
STES			
S.S. Hydro			
Electric Utility			
WECS			
Solar Thermal			
Photovoltaics			
OTEC			
Biomass Elec.		.09	
Hydro	3.2	3.2	3.2
Biomass Synthetic Fuels			

TABLE 3-15

CONTRIBUTION OF SOLAR, HYDRO AND BIOMASS TECHNOLOGIES (IN QUADS) IN 1990

(Normalized from detailed NPAC1 figures to obtain consistency with scenario definitions)

	Medium Solar	High Solar	Low Solar
Residential			
Thermal	.30	.85	.15
Passive	.04	.08	.01
WECS			
Photovoltaics			
Commercial			
Thermal	.25	.52	.14
Passive	.01	.01	
WECS			
Photovoltaics			
Industrial			
Solar Thermal	.50	.95	.20
Biomass	2.00	2.0	2.0
Photovoltaics			
WECS			
S.T. Electric			
STES			
S.S. Hydro			
Electric Utility			
WECS	.15	.67	
Solar Thermal	.05	.66	
Photovoltaics		.09	
OTEC			
Biomass Elec.	.01	.20	
Hydro	3.3	3.8	3.3
Biomass Synthetic Fuels			

TABLE 3-16

CONTRIBUTION OF SOLAR, HYDRO AND BIOMASS TECHNOLOGIES (IN QUADS) IN 2000

(Normalized from detailed NPAC1 figures to obtain consistency with scenario definitions)

	Medium Solar	High Solar	Low Solar
Residential			
Thermal	1.24	2.90	.48
Passive	.23	.53	.10
WECS	.02	.03	
Photovoltaics	.04	.05	.02
Commercial			
Thermal	.77	1.33	.30
Passive	.02	.04	
WECS	.17	.31	.08
Photovoltaics	.07	.01	.02
Industrial			
Solar Thermal	1.87	3.73	.68
Biomass	2.2	2.2	2.2
Photovoltaics			
WECS	.18	.37	.06
S.T. Electric	.02	.02	
STES	.01	.18	
S.S. Hydro	.12	.30	.06
Electric Utility			
WECS	1.36	2.99	.12
Solar Thermal	.99	2.40	.08
Photovoltaics	.01	.67	
OTEC	.11	.44	
Biomass Elec.	.03	.3	
Hydro	3.80	4.0	3.80
Biomass Synthetic Fuels	.6	.6	.6

CHAPTER 4

CURRENT AND FUTURE CAPITAL COSTS FOR SELECTED TECHNOLOGIES

4.0 INTRODUCTION

In this chapter current and future (to the year 2000) capital costs for selected energy technologies are defined, as well as certain information on operating costs. The technologies considered in this chapter include energy technologies not explicitly or implicitly modeled in the Hudson-Jorgenson system:

- solar thermal (active and passive, producing heat for direct use and electric production);
- small scale industrial hydroelectric;
- wind electric technologies (for residential/ commercial, industrial and electric utility applications);
- ocean thermal electric;
- biomass electric;
- biomass-based synthetic fuels;
- photovoltaics;
- coal-based synthetic fuels.

In addition, capital and operating costs estimates have been developed for electric sector "conventional"* technologies (including new conventional technologies), since costs per unit size or output for these technologies can be explicitly considered in the Hudson-Jorgenson model through the detailed electric sector submodel. Finally, costs for the nuclear fuel cycle are also included since costs for expansions in current capacity will also be necessary.

The current and future costs which have been defined are presented in Tables 4-2 through 4-4 (at the end of this chapter). These costs will be used in Chapter 5 of this report to develop estimates of total capital investment requirements for each scenario for the electric sector and those technologies which must be modelled exogenously. The assumptions and sources used to develop these estimates are explained in the following sections.

4.1 Sources for Cost Estimates

For most of those energy technologies currently commercially available (although not necessarily economically viable), the Draft Task 1 Report for this project, Identification of Capital Cost Estimates for Energy Supply and End-Use Sectors, was used to define capital costs. That document defines capital costs using the following assumptions:

- all costs are reported in 1972 dollars (for compatibility with the Hudson-Jorgenson model inputs);
- a uniform real inflation rate across all technologies for escalation during construction equal to 2.3%;

---

*Conventional is here used to designate nuclear, fossil, hydroelectric, and geothermal technologies (i.e., non-solar and non-biomass).

- a uniform real interest rate for interest during construction across all technologies of 2.5%;

- cost for 1977 (in 1972 dollars) are for a facility whose construction is begun in 1977.

For several energy technologies not currently commercially available, several sources were identified to define current costs (where applicable), future costs (in constant dollars) and experience curve effects (if any). These additional sources are referenced in Tables 4-2, 4-3, and 4-4.

4.2 Derivation of Adjusted Current and Future Cost Estimates: Initial Stage

In order to present the most realistic and useful estimates of capital costs, the 1977 cost estimates for the Task 1 report had to be adjusted over the forecast period to reflect some sectoral or technology specific real inflation rate. Since no absolutely reliable forecasts exist for sectoral/technology specific inflation rates, it was decided to base these rates on recent past performance. These historical rates are presented in Table 4-1, as well as projections for these rates over the forecast period, which are assumed to be one-half of the 1972-77 rates.

The costs for 1977 included in the Task 1 report were also adjusted so that the 1977 costs contained in this report refer to a facility which was completed in 1977. The adjustment was accomplished by considering both length of construction period and sectoral/technology inflation rate. Thus, data are presented which can be used to determine costs for facilities completed and brought on line during the entire forecast period.

Finally, the costs presented in this document were adjusted to reflect an 8-9% actual cost of capital during construction. This is compatible with capital costs determined endogenously within the Hudson-Jorgenson model.

4.3 Derivation of Adjusted Current and Future Cost Estimates: Final Stage

The capital costs reported in most sources, including the Task 1 document for this study, are reported in terms of either:

- o cost (either total or annualized) per unit energy output, or
- o cost (either total or annualized) per unit energy input.

Neither of these two forms is entirely satisfactory for this analysis because energy use has been reported in primary energy equivalents. This requires, for example, that an active solar heating system not be valued at the energy it delivers but at the primary energy it replaces. If the solar system delivers one million BTUs per year to the user and replaces electric energy, which has an average primary energy efficiency of approximately .295 (see Table 3-6), the solar system in this study would replace not one million but 3.39 million (one million divided by .295) BTUs of primary energy.

Thus, all capital (and operating) costs, except for electric utility technologies,* must be adjusted to reflect costs per quadrillion BTUs of primary energy equivalent. The information in Tables 3-5 and 3-6 can be used to develop adjustment factors for the residential/commercial and industrial sectors, since information is provided on primary efficiencies and fuels replaced by solar for those two sectors.**

---

*The Hudson-Jorgenson detailed electric utility submodel requires capital costs be defined in terms of $/kW and operating costs in mills/kWh.

**The resulting adjustment factors for the residential/commercial and industrial sectors are .432 and .560, respectively, (i.e., capital costs per quadrillion BTUs output of solar and small-scale hydro technologies for each sector should be multiplied by these factors to derive capital costs per quad primary energy equivalent).

For the coal-based synthetic fuels sector, output efficiencies were derived from Bechtel Corp. (Resource Requirements Impacts, and Potential Constraints Associated with Various Energy Futures, August, 1978) and Bhagat (Bhagat, et al, Draft Evaluation of Technical Data in the DFI and PIES Models). Since it was unclear whether the biomass-based synthetic fuels should be valued at their primary input or their output (which for SNG and SynCrude, the major elements of this sector's outputs, is equivalent to primary fuel output), they were valued at their input. In this manner, they are treated consistently with coal-based synthetic fuels.

4.4 Treatment of Experience Curves and Solar Capital Costs

Two final issues must be explained to define the derivation of capital costs for this study. First, it is unclear whether and to what extent experience curves for several new technologies will be based on cumulative production or time (specifically, the interaction of time and R&D activities). Certainly, the federal government's photovoltaics program assumes that experience curves for this technology will be, to a great extent, dependent upon research activities, not production experience. In this analysis, for simplicity, it has been assumed that most new technology experience curve effects are time-based. The two major exceptions to this are OTEC and Solar Thermal Electric technologies, for which cumulative cost schedules for each modular system were developed by MITRE Corporation and are used here.

Second, the capital cost estimates for non-utility solar applications (except photovoltaic) were developed in a very specialized form by the consultant for these technologies, David White. The capital costs presented are for the solar technologies, including collectors, storage systems and heat transfer from collectors to storage (where applicable) but excluding backup systems and internal heat utilization systems (e.g., piping or ducting to transfer heat within a house to radiators or registers). Thus, they represent the capital cost of the solar device or system over and above any expenditures for those heat utilization components that would have to be installed whether or not the solar system was installed. To the extent that certain components of the conventional backup systems can be down-sized or eliminated (rather unlikely), the non-utility solar capital costs presented here may tend to overstate total capital investment when added to the conventional investment requirements generated endogenously within the Hudson-Jorgenson model. However, this bias, if it exists, is probably very slight.*

---

*The bias may originate most specifically from the fact that heating elements in the backup system may be somewhat smaller for a solar-assisted system than an equivalent (in heat output) totally conventional system in some cases. However, since the heating element would be a rather small portion of total capital costs of the heating system, this resulting bias would be small.

In fact, if the backup system were designed for peak, rather than average loads, the size of a backup heat element for a solar system would be essentially the same as that for a totally conventional system.

TABLE 4-1

PROPOSED FORECAST FOR SECTORAL INFLATION FOR PROJECTING ENERGY SUPPLY CAPITAL COSTS

	% Per Annum	
Sector	Real Inflation Rate (1972-1977)	Forecast of Real Inflation Rate (1977-2000)[1]
Pipeline Const. Cost	3.0%	1.5%
Refinery Cost	0.0%	0.0%
Non-Nuclear Electric Power Plant Index	4.0%	2.0%
Nuclear Electric Power Plant Index	4.36%	2.18%
BEA Residential Fixed Equip.	2.4%	1.2%
Hydroelectric	NA[2]	1.5%[3]
BEA Non-Residential Fixed Equip.	0.7%	0.35%

[1]Equal to one-half the 1972-1977 per annum rate.

[2]Not available.

[3]Inflation for Hydroelectric facilities is projected to be less than that for fossil plants in Forecasts of Cost, Duration, and Manual Man-Hour Requirements for Construction of Electric Generating Plants: 1977-1981, a report prepared for the Construction Manpower Demand System.

TABLE 4-2

COST INFORMATION FOR CURRENT ELECTRIC TECHNOLOGIES[1]

Technology	Year				Capital Cost Materials Fraction[2]	Non-Fuel O&M[4] (1977$)	Capacity Factor	Construction Time (in years)
	1977	1985	1990	2000				
Nuclear Electric	577	662	738	915	.687-.758	0.71	.60-.70	7-8
Coal-Fired w/FGD	450	525	580	710	.725-.763	1.50	.60-.65	6
Oil-Fired w/o FGD	310	362	400	488	.70	0.30	.50-.60	6
Oil-Fired w/FGD	412	483	532	650	.70	0.30[5]	.50-.60	6
Gas-Fired (Baseload)	322	376	415	508	.70	0.30	.50-.60	4
Combined Cycle Oil/Gas	200	233	258	315	.76	1.27-1.93	.50-.60	4
Hydroelectric[3]	533	600	647	751	.62	2.63	.50-.60	5
Pumped Storage[3]	320	360	388	451	.65		.10-.15	6
Geothermal	560	655	722	883	.90	1.50	.70-.80	4
Peaking - Gas/Oil	135	158	174	213	.84	2.04-3.90	.08-.15	1.5-2

[1]All costs in 1972$ in $/kW. Source for information, unless otherwise noted, is Draft Task 1 Report "Identification of Capital Cost Estimates for Energy Supply and End-Use Sectors", 12/29/78, by USR&E. Real inflation is included. Interest during construction at 8-9%. These costs are for facilities completed in the year noted.

[2]From Bechtel Corp., Resource Requirements, Impacts and Potential Constraints Associated with Various Energy Futures, prepared for the U.S. Department of Energy, August, 1978 and United Engineers and Constructors, Commercial Electric Power Costs Studies (several Volumes), unless otherwise noted.

[3]Costs inflated @ 1.5%/yr. Historically, according to the Construction Manpower Demand System Data, hydroelectric capital investment costs have risen less sharply than other non-nuclear electric generation capital investment costs.

[4]Variable Costs only in 1977$, mills/kWh. Source: EPRI, Technical Assessment Guide, June, 1978.

[5]Does not include $12/kW or approximately 2-3 mill/kWh for FGD.

TABLE 4-3

COST INFORMATION FOR NEW ELECTRIC TECHNOLOGIES[1]

Technology	Year				Capital Cost[2] Materials Fraction	Cap. Factor	Const. Time (in years)	Non-Fuel O&M Costs (1977$)	
	1977	1985	1990	2000				Fixed ($/kW/yr)	Variable (mills/kWh)
Peaking-Coal[3]	NA	NA	330	405	.75[11]	.08-.15	6	4.00[18]	3.0-4.0[3]
AFB-Coal, Baseload[24]	NA	NA	477	583	.75[11]	.70	5-6	10.99[19]	1.20-2.20[19]
LMFBR[25]	NA	NA	1207	1497	.70[12]	.70	7-8	3.43[19]	0.86-1.84[19]
Coal Gasification/Elect. Generation--Combined Cycle[22]	NA	604	667	817	.70[13]	.70	5	14.39[19]	1.58-2.70[19]
Photovoltaics w/storage	NA	NA	1550[5]	1300[5]	.84[14]	.30	2	20-41[20]	---[21]
Photovoltaics w/o storage	10750 (NA)	NA	1025[5]	750[5]	.84[14]	.26	2	20-41[20]	---[21]
OTEC[17]	NA	NA	2475[5,6]	1600[5]	.70[15]	.60	5	37[20]	---[21]
Wind (Electric Utility)	1136	1241[7]	820[7]	940[23]	.84[14]	.48	2-3	18-30[20]	---[21]
Solar Thermal w/storage	NA	NA	2330[4]	1730[4]	.70[15]	.50	2-3	15-21[20]	1.59[19]
Solar Thermal w/o storage	3400[5,8]	2100[5]	---[9]	1075[5]	.70[15]	.36	2	12-13[20]	1.50[18]
Biomass Electric	934[5,10]	1031[5]	1139[5]	1388[5]	.84[14]	.50-.70	2	50-82[20]	---[21]

[1]All costs in 1972$ in $/kW. Source for information, unless otherwise noted, is Draft Task 1 Report, "Identification of Capital Cost Estimates for Energy Supply and End-Use Sectors," 12/29/78 by USR&E. Real inflation is included. Interest during construction at 8-9%. These costs are for facilities completed in the year noted.

[2]From Bechtel Corp., Resource Requirements, Impacts and Potential Constraints Associated with Various Energy Futures, prepared for the U.S. Department of Energy, August, 1978, unless otherwise noted.

[3]Based on information from MITRE Corp. (Systems Description and Engineering Costs for Solar Related Technologies: Volume 1, Summary), which gives cost of coal peaking plant at 1.575 times gas/oil peaking plant. The longer construction time for the coal plant yields an additional 20% premium for a total factor of 1.89.

[4]Based on a multiple (of coal steam w/FGD) of .83 from BNL and MITRE.

[5]From MITRE (Solar Energy: A Comparative Analysis to the Year 2020)

[6]For 1993.

[7]From JBF Scientific. Based on $900/kW (1990 cost in 1977$, before inflation). Source: T. R. Kornreich.

[8]For 1981.

[9]Dependent on market penetration.

[10]For 1980.

[11]Assumed equivalent to coal baseload facility. Source: Bechtel Corp.

[12]Assumed equivalent to LWR baseload facility. Source: Bechtel Corp.

[13]Assumed equivalent to average for all coal gasification plants. Source: Bechtel Corp.

[14]Assumed equivalent to oil/gas peaking facility. Source: Bechtel Corp.

[15]Source: MITRE Corp., Systems Descriptions and Engineering Costs for Solar Related Technologies: Vol. VII, Ocean Thermal Electric Conversion.

[16]Source: MITRE Corp., Systems Descriptions and Engineering Costs for Solar Related Technologies: Vol. V, Solar Thermal Electric Systems.

[17]Not including $47-151/kW additional transmission costs (in 1977$).

[18]Estimated based on similar facilities.

[19]Source: EPRI, Technical Assessment Guide, June, 1978.

[20]Source: MITRE Corp., "Market Sector: Utility Total Market," Preliminary Draft.

[21]All costs are included under fixed costs.

[22]Based on 15% cost premium over coal steam w/ FGD. (From information by SRI, MITRE, EPRI, BNL, Bechtel, and Fluor Corp.)

[23]From Solar Energy: A Comparative Analysis to the Year 2020 and T. R. Kornreich, JBF Scientific. Based on $760/kW (1976 $, before inflation).

[24]AFB = Atmospheric Fluidized Bed.

[25]LMFBR = Liquid Metal Fast Breeder Reactor

TABLE 4-4

COST INFORMATION FOR REFINING AND NEW TECHNOLOGIES[1]

TECHNOLOGY	1977	1985	1990	2000	Capital Cost Material Fraction	Capacity Factor	Const. Time (in years)	Non-Fuel O&M Costs	Units for O&M Costs
Refining	1.27	1.27	1.27	1.27	.62	.8	4	.10 - .12	$\$/10^6$ BTU
Solar Thermal (Res/Com)[2]	31.54	23.76[3]	21.99[24]	23.81	.65	NC[10]	< 1[3]	.01 - .02	%/capital cost
Solar Thermal Industrial Low Temp[2]	51.80	33.60[3]	28.33[25]	29.34	.63	NC	< 1[3]	.02 - .165	"
Solar Thermal Industrial High Temp[2]	73.75	40.66[3]	31.02	25.25[26]	.63	NC	< 1-2[3]	.020-.054	"
WECS Residential[5]	39.79	30.93	32.95[27]	39.79	.90[3]	.4	< 1[3]	.03[23]	"
WECS Commercial[5]	--	41.60	32.95[27]	34.36	.90[3]	.4	< 1[3]	.03[23]	"
WECS Industrial[5,6]	--	48.50	32.04[28]	36.73	.84[4]	.48	1-2[3]	.03[23]	"
Passive Solar Res/Com[7]	23.67	17.84	16.49	17.86	.65[7]	NC	< 1[3]	.02[23]	"
Photovoltaics Res/Com w/Storage[8]	--	--	112.14	94.05	.90[3]	.3	< 1[3]	.03	"
Solar Thermal Electric, Industrial[2]	--	--	28.28[29]	29.29	.70[9]	NC	1-2[3]	.01 - .02	"
Solar Total Energy Systems (STES)[2]	--	--	22.51[30]	23.30	.70[9]	NC	1-3[3]	.01 - .02	"
Small Scale Hydro, Industrial[11]	26.57	29.98	32.36	37.47	.75[3]	.55	1-2[3]	.02	"
Coal Gasification, High BTU[12,13]	6.37	7.23	7.58	9.25	.66	.8	4	.42	$\$/10^6$ BTU
Coal Gasification, Medium BTU[12,14]	5.28	6.02	6.49	7.92	.68	.8	4	.42	"
Coal Gasification, Methanol[12,15]	7.04	8.25	9.10	11.10	.75	.8	5	.41	"
Coal Liquefaction[12,16]	4.96	5.81	6.42	7.83	.73	.8	5	.46	"
Coal Liquids Refinery[17]	1.44	1.44	1.44	1.44	.65	.8	4	.14	"
Methanol from Biomass[12,18,19]	6.45	7.54	8.32	10.17	.70[22]	.8	4[22]	1.15	"
SNG from Biomass[12,18,20]	2.40	2.81	3.10	3.79	.70[22]	.8	4[22]	.56	"
Syncrude from Biomass[12,21,18] (excludes refinery)	3.81	4.46	4.92	6.02	.70[22]	.8	4[22]	.97	"
Ammonia from Biomass[12,18,20]	6.29	7.36	8.11	9.92	.70[22]	.8	4[22]	1.19	"
Uranium Fuel Cycle	1.12	1.33	1.48	1.84	.65	.8 - .9	8	.06	"

[1]All costs in 1972$. ($ Billion/Quad Primary Energy Equivalent). Source for information, unless otherwise noted is Draft Task 1 Report, "Identification of Capital Cost Estimates for Energy Supply and End-Use Sectors", 12/29/78, by USR&E. Real inflation is included. Interest during construction at 8%. These costs are for facilities completed in the year noted.

[2]Source: David White and OTA Solar Study. Industrial Low Temp information based on avg. from 140°F and ≥ 180° F collectors. This represents the cost of collection and storage only.

[3]Estimated.

[4]Estimated based on peaking technologies.

[5]From T. R. Kornreich, JBF Scientific Corporation. Inflation factor at 2% per year (equal to inflation for electric utility systems).

[6]From MITRE Corp., Solar Energy: A Comparative Analysis to the Year 2020.

[7]Based on 75% of the cost of solar active systems for optimal passive design. From D. White and W. Whiddon, Booz Allen Corp.

[8]Based on 50% cost premium over utility systems.

[9]Based on solar thermal electric utility technology.

[10]NC = Not Calculated.

[11]Based on avg. $1000-1200 (1977$) from D. Smith (USR&E consultant), Eugene O'Brien (TAMS) and MITRE Corp. Information for dam in place.

[12]Inflation factor at 2.0% year. Does not include investment for coal extraction or end-use utilization.

[13]Current conversion efficiency 64.0%. Efficiency for 1990 = 69.5%. From Bhagat et al, Draft Evaluation of Technical Data in the DEI and PIES Models.

[14]Current conversion efficiency 76.0%. Efficiency for 1990 = 80.0%. From Bhagat, et al.

[15]Conversion efficiency = 51%. From Bhagat et al.

[16]Not including refining. Conversion efficiency 70%. From Bhagat et al.

[17]Conversion efficiency 90.1%. From Bechtel.

[18]Billion $ per quadrillion BTU input. Does not include investment for biomass cultivation, collection or end-use utilization.

[19]Conversion efficiency 45.3%. From MITRE Corp.

[20]Conversion efficiency 66.0%. From MITRE Corp.

[21]Conversion efficiency 61.3%. From MITRE Corp.

[22]Estimated, based on coal synthetic fuels conversion facilities.

[23]Source: James T. Yen, "Wind Energy: Potential Problems and Possible Solutions," paper to be presented to the ASCE Spring Convention, April, 1979.

[24]Based on ultimate cost (1990) of $\$65/10^6$ BTU delivered (1977$, before inflation). 0.8% inflation rate per year (average for residential and non-residential sectors).

[25]Based on ultimate cost (1990) of $\$85/10^6$ BTU delivered (1977$, before inflation) for ≥ 180° F. system and $\$52/10^6$ BTU delivered (1977$, before inflation) for 140° F. system. (Lower temp price reflects res/com thermal price, less 20% discount for industrial buyers. Discount for volume purchases and purchases dire from manufacturer.)

[26]Based on ultimate cost (1995) of $\$60/10^6$ BTU delivered (1977$, before inflation).

[27]Based on $1000/kW (1990 cost in 1977$, before inflation) for residential systems and $850/kW (2000 cost in 1977$, before inflation) for commercial systems.

[28]Cost equal to those for electric utility systems.

[29]Based on ultimate cost (1990) of $\$68.30/10^6$ BTU delivered (1977$, before inflation).

[30]Based on ultimate cost (1990) of $\$54.40/10^6$ BTU delivered (1977$, before inflation).

CHAPTER 5

CAPITAL INVESTMENT REQUIREMENTS FOR EACH SCENARIO

In this chapter the total capital investment requirements for each scenario for selected technology groups are presented. The three technology groups are:

- o residential, commercial, and industrial on-site solar technologies (including small scale hydro)
- o all electric utility technologies, including both fossil, nuclear, hydro, geothermal, biomass electric and solar
- o synthetic fuels, including biomass-based and coal-based synthetic fuels.

For each technology group, capital investment requirements for each scenario are presented for 1977-85, 1985-90, and 1990-2000, as well as the total for 1977-2000. Investment costs per Quad for each technology within each of the 1977-85, 1985-90, and 1990-2000 periods were calculated using the simple average for costs for the years at the beginning and end of each period*, except where noted otherwise. The costs presented here are in the form of billions of 1972 dollars which must be invested, in total, to achieve the market penetrations specified in each scenario. To input this data to the Hudson-Jorgenson model, one further change must be made -- the investment costs must be transformed into the equivalent depreciated capital stock for key years during the forecast. This will be done for Task 3 of this study.

---

*See Tables 4-2 through 4-4.

5.1 Investment for On-Site Solar Technologies

Investment requirements for each scenario for solar on-site technologies were developed using the following process.

- o First, incremental solar market penetrations for 1978-85, 1986-90, and 1991-2000 were developed for each scenario from Tables 3-14 through 3-16. Note that market penetrations do not vary for the Moderate Solar Scenario between the higher and lower oil price. The same is true for the Low Solar Scenario.

- o Second, average cost per Quad (primary energy equivalent) for each of the three periods during the forecast were calculated from Tables 4-2 through 4-4.

- o Multiplying average cost per Quad by market penetration in Quads gives total investment requirements for each of the three time periods.

The results of these calculations are presented in Tables 5-1 through 5-3. An implicit assumption in these calculations is that no replacement of any on-site solar devices is required over the forecast period as a result of their long assumed average life-times (20 years or greater). In reality, even with such a long design life, certain components (e.g., pumps and motors) would have to be replaced at some interim point during the device lifetime. However, the costs for these components constitute a relative minor proportion of the total system cost for solar devices and these costs will, to some extent, be captured by the O&M costs assumed for this study. Also, even with a 20-30 years assumed lifetime, this represents only an average lifetime. Thus, some devices will be replaced prior to this assumed age and some will last far beyond it. We decided not to attempt to replicate a replacement function in this study for two reasons:

- o the precise form and specification of this replacement function is unknown at this time;

- since the forecast period includes only a part of the first replacement cycle for solar devices, early replacement of some percentage of these devices to replicate "real" circumstances would tend to overstate the capital inputs for solar over the 1977-2000 study period.

5.2 Investment for Electric Utility Generating Capacity

Determining investment in electric utility generating capacity required a more complex calculation process than for on-site solar technology investment.

(1) Generating capacity in the base year had to be defined. Estimates of base year generating capacity are presented in Table 5-4. The NERC estimates, however, are not directly comparable with the others, since NERC defines generating capacity on a different basis than most other sources, which use "nameplate" rating. Given the close agreement from most sources, the base year capacity used here is 550,000-560,000 MW.

(2) Electric primary energy requirements for 1985, 1990 and 2000 for each fuel had to be converted to kilowatt-hours per year generated at the plant. This was accomplished by:

--multiplying fuel-specific electric primary energy use as specified in Tables 3-9 through 3-13 by the fuel-specific electric efficiency factors in Table 5-5 (excluding transmission and distribution efficiency losses, because the focus is generation at the plant

--dividing the resulting BUT output at the plant by 3412 BTU/kWh, which is the conversion factor from BTUs to kilowatt-hours.

(3) Capacity factors were defined by fuel type for each fuel used for electric generation. These are presented in Table 5-6. Using these factors, the number of kilowatt-hours per year generated per kilowatt capacity for each fuel type could be determined for each forecast year.

(4) Total kilowatts of capacity by fuel type for 1985, 1990, and 2000 for each scenario was determined by dividing total kilowatts generated by kilowatt-hours generated per kilowatt of capacity.

5.2.1 Retirements

In order to convert this generating capacity information to capital investment, a further factor had to be included -- retirements of existing capacity. Using retirements and generating capacity information we could calculate gross additions by fuel type for each scenario.

Several sources were available which project retirements of electrical generating capacity over the next five to ten years. Both the EIA (Energy Data Reports: Power Production Consumption, and Capacity, 1977) and the electric utilities project that only 2% of total 1977 generating capacity will be retired during the next ten years. The percentage of total 1977 capacity to be retired by type is as follows:

o Fossil steam	2.4%
o Combustion turbine	3.6%
o Diesel	1.3%
o Combined cycle	1.0%
o Hydro	.05%

Although the EIA retirement rate is quite low, it was accepted here as essentially accurate because it seemed to reflect a desire by the utilities to stretch existing capacity in the face of financial, regulatory and legislative uncertainties. Acknowledging that the EIA and the utilities may be somewhat conservative in their estimates, however, deratings have been added to retirements in this report to calculate total retirements.

Retirements from 1985 to 2000 are based on information provided by Dale Jorgenson Associates. These retirements also show variation by fuel type and range from 0% for hydro to 1.4%* for coal. The average for all capacity is about 1.2% per year over the period.

In some cases, oil and gas retirements have been accelerated beyond those predicted by DJA. This reflects a large decrease in oil or gas-fired capacity in a particular scenario. Retirement information by fuel type is presented in Table 5-7, including information on accelerated retirements for each scenario, where these were required to replicate scenario fuel use parameters.

Gross additions to capacity for 1985, 1990, and 2000 are given in Tables 5-8 to 5-12, and have been calculated using the information on installed capacity and retirements. Please note that both cumulative additions and additions for each of the three time periods considered separately are provided.

5.2.2 Capital Costs

Capital costs per unit capacity are presented in Table 5-13 for all technologies which are expected to contribute to electric utility generation over the next 22 years. 'NA' indicates that the technology is not available for a given year. WECS, photovoltaics, OTEC, and Solar Thermal are subject to learning curves, technological advances, and economies of scale, as evidenced by declining capital costs. Solar Thermal and OTEC costs vary slightly by scenario, and are dependent upon market penetration.

Capital costs for coal represent weighted capital costs.

---

*This represents percentage of the capacity existing at the beginning of any given year that is retired in that year.

From 1986 to 1990 additional coal capacity is assumed to be 80% coal steam (w/ FGD) and 20% combined cycle. After 1990 additional capacity is assumed to be:

- o 10% coal peaking
- o 90% coal baseload -- 40% combined cycle
  50% atmospheric fluidized bed

Oil costs for the period 1985-1990 are weighted as follows:

- o 50% combined cycle oil
- o 50% peaking oil.

For the period 1991 to 2000 this same weighting holds for the High Solar and Medium Solar scenarios. However, because of larger additions of oil in the imported oil scenarios, some of which will probably be baseload, the following weights were used:

- o 17% oil with FGD
- o 17% oil without FGD
- o 33% combined cycle oil
- o 33% peaking oil

Gas costs reflect only gas peaking capacity.

5.2.3 Total Capital Investment

Total capital investments for electric generating capacity are presented in Tables 5-14 to 5-18 for 1985, 1990, 2000, and for all the periods combined. The totals are as follows, in billions of dollars:

Medium Solar Scenario, Lower-Price	526.0
Medium Solar Scenario, Higher-Price	472.2
Low Solar Scenario, Lower-Price	492.6
Low Solar Scenario, Higher-Price	438.9
High Solar Scenario, Lower-Price	586.6

The lower capital investments of the high-price cases relative to the respective mid-price cases is not surpirsing, given that primary fuel demand by electric utilities is about 5 Quads less under the higher oil price scenarios. The High Solar Scenario entails by far the highest capital investment, which is consistent with its reliance upon newer and more expensive technologies.

5.3 Synthetic Fuels

Only two synthetic fuels scenarios have actually been developed -- one at the lower oil price and one at the higher oil price -- since the solar market penetration scenarios at each oil price have been designed to eliminate variation in synthetic fuels investment. Capital investment requirements for synthetic fuels have been calculated in much the same manner as on-site solar technologies, namely:

- o incremental market penetrations were determined for 1978-85, 1986-90, and 1991-2000 for each scenario;
- o average cost per Quad (primary energy equivalent) for each period was developed;
- o total investment requirements were determined by multiplying incremental market penetration in each period by cost per Quad for that period. The results are presented in Table 5-19.

The technology mix within the biomass synthetic fuels sector was derived from a draft NPAC1 market sector analysis document. The NPAC1 "Reference Scenario, Mid-Price" mix was used to specify the scenario mixes. The technology mix within the coal-based synthetic fuels was arbitrarily specified.

5.4 Summary

Table 5-20 summarizes the total capital investment requirements for selected sectors for all five scenarios.

TABLE 5-1

GROSS CAPITAL INVESTMENT REQUIREMENTS FOR SOLAR TECHNOLOGIES
LOW SOLAR SCENARIO -- BOTH OIL PRICES (in billions of 1972$)

Sector	Technology	1978-85	1986-90	1991-2000	Total
Residential	Thermal	1.38	2.29	7.56	11.23
	Passive		.17	1.55	1.72
	WECS				
	Photovoltaics			2.06	2.06
Commercial	Thermal	1.38	2.06	3.67	7.11
	Passive				
	WECS			2.69	2.69
	Photovoltaics			2.06	2.06
Industrial	Thermal[1]		5.68	13.67	19.35
	Photovoltaics				
	WECS			2.06	2.06
	S.T. Electric				
	STES				
	S.S. Hydro			2.09	2.09
Total		2.76	10.20	37.41	50.37

[1]Divided equally between low temperature and high temperature.

TABLE 5-2

GROSS CAPITAL INVESTMENT REQUIREMENTS FOR SOLAR TECHNOLOGIES
MEDIUM SOLAR SCENARIO -- BOTH OIL PRICES (in billions of 1972$)

Sector	Technology	1978-85	1986-90	1991-2000	Total
Residential	Thermal	3.59	3.89	21.52	29.00
	Passive	.21	.05	3.27	3.53
	WECS			.72	.72
	Photovoltaics			4.12	4.12
Commercial	Thermal	3.32	2.97	11.90	18.19
	Passive		.17	.17	.34
	WECS			5.72	5.72
	Photovoltaics			7.22	7.22
Industrial	Thermal[1]	4.50[2]	11.35	39.03	54.88
	Photovoltaics				
	WECS			6.19	6.19
	S.T. Electric			.58	.58
	STES			.23	.23
	S.S. Hydro			4.19	4.19
Total		11.62	18.43	104.86	134.91

[1]Divided equally between low and high temperature.

[2]Costs set at $45.0 Billion/Quad.

TABLE 5-3

GROSS CAPITAL INVESTMENT REQUIREMENTS FOR SOLAR TECHNOLOGIES
HIGH SOLAR SCENARIO (in billions of 1972$)

Sector	Technology	1978-85	1986-90	1991-2000	Total
Residential	Thermal	10.23	10.98	46.95	68.16
	Passive	.42	1.03	7.74	9.19
	WECS			1.09	1.09
	Photovoltaics			5.15	5.15
Commercial	Thermal	8.57	4.81	18.55	31.93
	Passive	.21		.52	.73
	WECS			10.43	10.43
	Photovoltaics			1.03	1.03
Industrial	Thermal[1]	12.60[2]	19.01	79.19	110.80
	Photovoltaics				
	WECS			12.72	12.72
	S.T. Electric			.58	.58
	STES			4.12	4.12
	S.S. Hydro			10.47	10.47
Total		32.03	35.83	198.54	266.40

[1]Divided equally between low temperature and high temperature.

[2]Costs set at $45.0 Billion/Quad.

TABLE 5-4

ELECTRIC GENERATING CAPACITY ESTIMATES
12/77

Source	Capacity (000 MW)
EIA[1]	557
Hudson-Jorgenson	551
AAR-1[2]	532
AAR-2[3]	557
NERC[4]	506[5]
	537[5]
Electrical World	557

[1] Energy Data Reports: Power Production, Consumption, and Capacity. Annual 1977, from FPC Form #4.

[2] AAR Series-C Utility Documentation, received from Irv Chamberlain and Jerry Eister, 11/78.

[3] Energy Information Administration. Annual Report to Congress: Volume II, 1977, Projections of Energy Supply and Demand and Their Impacts. U.S. Department of Energy, April and May, 1978.

[4] Eighth Annual Review of Overall Reliability and Adequacy of the North American Bulk Power Systems, National Electric Reliability Council (NERC), August, 1978.

[5] NERC reports 'generating capability' as of summer of a given year. The two capacity estimates given reflect summer, 1977, and summer, 1978, so the 1977 year end figure should fall between these two estimates.

TABLE 5-5

EFFICIENCY FACTORS OVER TIME
FOR
ELECTRIC GENERATING CAPACITY BY FUEL TYPE[1]

	76-85	86-90	91-2000
Oil[2]	.320	.345	.370
Gas	.314	.314	.314
Coal[3]	.338	.350	.362
Nuclear	.300	.300	.300
Hydro	.310	.310	.327
Solar: WECS	.335	.335	.335
Solar Thermal	.335	.335	.335
Photovoltaics	.335	.335	.335
OTEC	.328	.328	.328
Biomass	.291	.291	.291
Geothermal	.310	.310	.327

[1]Excludes transmission and distribution efficiency losses.

[2]Phaseout of steam, introduction of combined cycle and gas turbine.

[3]Improvements in generation efficiency.

TABLE 5-6

CAPACITY FACTORS FOR ELECTRIC GENERATION, BY FUEL TYPE[1]

	1977	1985/90/ 2000
Nuclear	64%	64%
Hydro/PS	35	31
Coal	52	54
Oil	29	33
Gas	46	41/37/32[2]
Geothermal	74	69
WECS	48	48
Solar Thermal	43	43
Photo.	28	28
OTEC	60	60
Biomass	60	60

[1]Derived from National Electrical Reliability Council (NERC) data, 8th Annual Review, August, 1978 after adjustments for the difference in capacity definition between NERC and EIA.

[2]Represents increasing use of gas for peaking purposes in 1985-2000 period.

TABLE 5-7

RETIREMENTS OF ELECTRIC GENERATING CAPACITY BY FUEL (in MW)

Electric Generating Fuel	Scenario	1977-85	1985-90	1990-2000
Oil	Medium Solar, Lower Oil Price	11073	16929[1]	42311[1]
	Medium Solar, Higher Oil Price	33217	15831	40585
	Low Solar, Lower Oil Price	11073	15831	40585
	Low Solar, Higher Oil Price	33217	15831	40585
	High Solar, Lower Oil Price	26730	15831	45154
Gas	Medium Solar, Lower Oil Price	16706	27969[1]	24773
	Medium Solar, Higher Oil Price	16706	27969[1]	24773
	Low Solar, Lower Oil Price	16706	26834[1]	24773
	Low Solar, Higher Oil Price	16706	27969[1]	24773
	High Solar, Lower Oil Price	16706	27969[1]	24773
Coal	All scenarios	7921	19946	62966
Nuclear	All scenarios	0	6874	32557
Hydro	All scenarios	67	75	100

[1]These are "accelerated retirements" (see text).

TABLE 5-8

GROSS ADDITIONS TO CAPACITY
(MW)

LOW SOLAR SCENARIO, LOWER OIL PRICE

Generating Fuel	1978-1985	1986-1990	1991-2000	Total
Oil	-0-	4496	50250	54746
Gas	-0-	-0-	11663	11663
Coal	96897	130637	220168	447702
Nuclear	67417	46697	118631	232745
Hydro	35999	3420	23793	63212
Solar:				
WECS	-0-	-0-	2801	2801
Solar Thermal	-0-	-0-	2085	2085
Photovoltaics	-0-	-0-	-0-	-0-
OTEC	-0-	-0-	-0-	-0-
Biomass	-0-	-0-	-0-	-0-
Geothermal	640	742	5909	7291
TOTAL:	200953	185992	435300	822245

TABLE 5-9

GROSS ADDITIONS TO CAPACITY
(MW)

LOW SOLAR SCENARIO, HIGHER OIL PRICE

Generating Fuel	1978-1985	1986-1990	1991-2000	Total
Oil	-0-	11954	49935	61889
Gas	-0-	-0-	6234	6234
Coal	87476	118596	190059	396131
Nuclear	61929	43718	95271	200918
Hydro	35999	3420	23793	63212
Solar:				
WECS	-0-	-0-	2801	2801
Solar Thermal	-0-	-0-	2085	2085
Photovoltaics	-0-	-0-	-0-	-0-
OTEC	-0-	-0-	-0-	-0-
Biomass	-0-	-0-	-0-	-0-
Geothermal	640	742	5909	7291
TOTAL:	186044	178430	376087	740561

TABLE 5-10

GROSS ADDITION TO CAPACITY
(MW)

MEDIUM SOLAR SCENARIO, LOWER OIL PRICE

Generating Fuel	1978-1985	1986-1990	1991-2000	Total
Oil	-0-	-0-	-0-	-0-
Gas	-0-	-0-	12798	12798
Coal	96897	130637	203352	430886
Nuclear	67417	46697	116279	230393
Hydro	35999	3420	23793	63212
Solar:				
WECS	-0-	3502	26844	30346
Solar Thermal	-0-	1303	24494	25797
Photovoltaics	-0-	-0-	400	400
OTEC	-0-	-0-	2011	2011
Biomass	-0-	-0-	487	-0-
Geothermal	640	742	5909	7291
TOTAL:	200953	186301	415880	803134

TABLE 5-11

GROSS ADDITIONS TO CAPACITY (MW)

MEDIUM SOLAR SCENARIO, HIGHER OIL PRICE

Generating Fuel	1978-1985	1986-1990	1991-2000	Total
Oil	-0-	6709	2678	9387
Gas	-0-	-0-	6194	6194
Coal	87476	117512	173206	378194
Nuclear	61929	43718	93703	199350
Hydro	35999	3420	23433	62852
Solar:				
WECS	-0-	3502	26844	30346
Solar Thermal	-0-	1303	24494	25797
Photovoltaics	-0-	-0-	400	400
OTEC	-0-	-0-	2011	2011
Biomass	-0-	-0-	487	487
Geothermal	640	742	5909	7291
TOTAL:	186044	176906	359359	722309

TABLE 5-12

GROSS ADDITIONS TO CAPACITY
(MW)

HIGH SOLAR SCENARIO, LOWER OIL PRICE

Generating Fuel	1978-1985	1986-1990	1991-2000	Total
Oil	-0-	3719	-0-	3719
Gas	-0-	-0-	6234	6234
Coal	91035	101813	124806	317654
Nuclear	65849	37603	116280	219732
Hydro	35999	20143	14127	70269
Solar:				
WECS	-0-	15640	54157	69797
Solar Thermal	-0-	17198	45340	62538
Photovoltaics	-0-	3602	23210	26812
OTEC	-0-	-0-	8045	8045
Biomass	1460	1784	1623	4867
Geothermal	691	691	5909	7291
TOTAL:	195034	202193	399731	796958

TABLE 5-13

CAPITAL INVESTMENT COST, BY TYPE OF GENERATING CAPACITY
(in $/kW, 1972$)

	1978-85	1986-90	1991-2000
Nuclear	610	700	827
Hydro/PS	528	574	629
Coal	490	570	596
Oil	NC[1]	206	334[2] 240[3]
Gas	NC[1]	NC[1]	194
Geothermal	643	708	794
WECS	1189	1030	880
Photovoltaics	NC	1288	1156
Biomass	982	1085	1264
Solar Thermal			
High Solar Scenario	NC	1300	1400
Medium Solar Scenario	NC	2000	1400
Low Solar Scenario	NC	NC	1650
OTEC			
High Solar Scenario	NC	NC	1700
Medium Solar Scenario	NC	NC	1900
Low Solar Scenario	NC	NC	NC

[1]NC = Not calculated. No investment in this type of capacity is included for that period.

[2]Low Solar Scenario.

[3]High and Medium Solar Scenarios.

[4]Assumes that one-half of capacity built with storage and one-half built without storage.

TABLE 5-14

TOTAL CAPITAL INVESTMENT IN ELECTRIC GENERATING CAPACITY
(in billions of 1972$)

LOW SOLAR SCENARIO, LOWER OIL PRICE

Generating Fuel	1978-1985	1986-1990	1991-2000	Total
Oil	-0-	.93	16.8	17.7
Gas	-0-	-0-	2.3	2.3
Coal	47.5	74.5	131.2	253.2
Nuclear	41.1	32.7	98.1	171.9
Hydro	19.0	2.0	15.0	36.0
Solar:				
WECS	-0-	-0-	2.5	2.5
Solar Thermal	-0-	-0-	3.4	3.4
Photovoltaics	-0-	-0-	-0-	-0-
OTEC	-0-	-0-	-0-	-0-
Biomass	-0-	-0-	-0-	-0-
Geothermal	.41	.53	4.7	5.6
TOTAL:	108.0	110.6	274.0	492.6

TABLE 5-15

TOTAL CAPITAL INVESTMENT IN ELECTRIC GENERATING CAPACITY
(in billions of 1972$)

LOW SOLAR SCENARIO, HIGHER OIL PRICE

Generating Fuel	1978-1985	1986-1990	1991-2000	Total
Oil	-0-	2.5	16.7	19.2
Gas	-0-	-0-	1.2	1.2
Coal	42.9	67.6	113.3	223.8
Nuclear	37.8	30.6	78.8	147.2
Hydro	19.0	2.0	15.0	36.0
Solar:				
WECS	-0-	-0-	2.5	2.5
Solar Thermal	-0-	-0-	3.4	3.4
Photovoltaics	-0-	-0-	-0-	-0-
OTEC	-0-	-0-	-0-	-0-
Biomass	-0-	-0-	-0-	-0-
Geothermal	.41	.53	4.7	5.6
TOTAL:	100.1	103.2	235.6	438.9

TABLE 5-16

CAPITAL INVESTMENT IN ELECTRIC GENERATING CAPACITY
(in billions of 1972$)

MEDIUM SOLAR SCENARIO, LOWER OIL PRICE

Generating Fuel	1978-1985	1986-1990	1991-2000	Total
Oil	-0-	-0-	-0-	-0-
Gas	-0-	-0-	2.5	2.5
Coal	47.5	74.5	121.2	243.2
Nuclear	41.1	32.7	96.2	170.0
Hydro	19.0	2.0	15.0	36.0
Solar:				
WECS	-0-	3.6	23.7	27.3
Solar Thermal	-0-	2.6	34.3	36.9
Photovoltaics	-0-	-0-	.46	.46
OTEC	-0-	-0-	3.8	3.8
Biomass	-0-	-0-	.2	.2
Geothermal	.41	.53	4.7	5.6
TOTAL:	108.0	115.9	302.1	526.0

TABLE 5-17

CAPITAL INVESTMENT IN ELECTRIC GENERATING CAPACITY
(in billions of 1972$)

MEDIUM SOLAR SCENARIO, HIGH OIL PRICE

Generating Fuel	1978-1985	1986-1990	1991-2000	Total
Oil	-0-	1.4	.64	2.0
Gas	-0-	-0-	1.2	1.2
Coal	42.9	67.0	103.2	213.1
Nuclear	37.8	30.6	77.5	145.9
Hydro	19.0	2.0	14.7	35.7
Solar:				
WECS	-0-	3.6	23.7	27.3
Solar Thermal	-0-	2.6	34.3	36.9
Photovoltaics	-0-	-0-	.46	.46
OTEC	-0-	-0-	3.8	3.8
Biomass	-0-	-0-	.2	.2
Geothermal	.41	.53	4.7	5.6
TOTAL:	100.1	107.7	264.4	472.2

TABLE 5-18

CAPITAL INVESTMENT IN ELECTRIC GENERATING CAPACITY
(in billions of 1972$)

HIGH SOLAR SCENARIO, LOWER OIL PRICE

Generating Fuel	1978-1985	1986-1990	1991-2000	Total
Oil	-0-	.77	-0-	.77
Gas	-0-	-0-	1.2	1.2
Coal	44.6	58.1	74.4	177.1
Nuclear	40.2	26.3	96.2	162.7
Hydro	19.0	11.6	8.9	39.5
Solar:				
WECS	-0-	16.1	47.6	63.7
Solar Thermal	-0-	22.4	63.5	85.9
Photovoltaics	-0-	4.6	26.8	31.4
OTEC	-0-	-0-	13.7	13.7
Biomass	.96	1.9	2.1	5.0
Geothermal	.41	.49	4.7	5.6
TOTAL:	105.2	142.3	339.1	586.6

TABLE 5-19

GROSS CAPITAL INVESTMENT REQUIREMENTS FOR SYNTHETIC FUELS
(in billions of 1972$)

Scenario	Type of Synfuel	1978-85	1986-90	1991-2000	Total
Lower Oil Price	Coal-Based [1,3]	1.96	8.71	19.16	29.83
	Biomass	---	---	3.52	3.52
	TOTAL	1.96	8.71	22.68	33.35
Higher Oil Price	Coal-Based [1,3]	1.96	8.71	27.49	38.16
	Biomass [2,3]	---	---	3.52	3.52
	TOTAL	1.96	8.71	31.01	41.68

[1] Assuming the following mix of technologies:

Methanol	20%
High-BTU Gas	30%
Low-BTU Gas	30%
Liquid (includes refining)	20%

[2] Assuming the following mix of technologies:

Methanol	13%
Syncrude	18%
SNG	66%
Ammonia	3%

[3] Includes Syncrude refining costs.

TABLE 5-20

SUMMARY OF CAPITAL INVESTMENT REQUIREMENTS FOR SELECTED SECTORS--ALL SCENARIOS (in billions of 1972$)

Scenario	Sector	1978-85	1986-90	1991-2000	Total
Low Solar, Lower Oil Price	Solar On-Site	2.76	10.20	37.41	50.37
	Electric Generation	108.00	110.60	274.00	492.60
	Synfuels	1.96	8.71	22.68	33.35
	TOTAL	112.72	129.51	334.09	576.32
Low Solar, Higher Oil Price	Solar On-Site	2.76	10.20	37.41	50.37
	Electric Generation	100.10	103.20	235.60	438.90
	Synfuels	1.96	8.71	31.01	41.68
	TOTAL	104.82	122.11	304.02	530.95
Medium Solar, Lower Oil Price	Solar On-Site	11.62	18.43	104.86	134.91
	Electric Generation	108.00	115.90	302.10	526.00
	Synfuels	1.96	8.71	22.68	33.35
	TOTAL	121.58	143.04	429.64	694.36
Medium Solar, Higher Oil Price	Solar On-Site	11.62	18.43	104.86	134.91
	Electric Generation	100.10	107.70	264.40	472.20
	Synfuels	1.96	8.71	31.01	41.68
	TOTAL	113.68	134.84	400.27	648.79
High Solar, Lower Oil Price	Solar On-Site	32.03	35.83	198.54	266.40
	Electric Generation	105.20	142.30	339.10	586.60
	Synfuels	1.96	8.71	22.68	33.35
	TOTAL	139.19	186.84	560.32	886.35

PART III

RESULTS AND ANALYSIS

CHAPTER 6

THE BASE CASE - LOW SOLAR, LOWER OIL PRICES

6.0 INTRODUCTION

The analysis begins with the Base Case projection of economic growth and energy use between the present and the year 2000. This projection provides the basis, or the starting point, for the analyses of the four other scenarios. It is based upon estimates of the future conditions in the government sector, in the U.S. labor market and economy and in the U.S. and world energy systems. The Base Case is intended to be a representative forecast of feasible and likely outcomes for the U.S. economy and energy system. The Base Case scenario is defined for the purposes of this analysis, as the Low Solar, Lower Oil Price scenario developed in Part II of this report.

Any forecast of economic growth has to be based upon many assumptions concerning demographic factors, labor force changes, and government policies. An important factor of economic growth is the increase in the size of the effective labor force. This, in turn, depends upon population growth, labor force participation rates and the length of the work week. It is assumed that population grows according to the U.S. Bureau of the Census forecast Series II, which assumes a fertility rate of 2.1. This fertility rate is approximately that required for replacement only. The trend towards greater labor force participation rates by women and minorities is assumed to continue, though at a declining rate. Acting in the opposite direction is the continued trend towards a shorter work year for full time workers. The result of these two forces is greater employment but less hours worked per person.

Another significant source of uncertainty in the future is the government sector. This Base Case assumes that government expenditures will remain a fairly stable proportion (20%) of real GNP over the next two decades. This assumption is in line with recent historical experience. In addition, it is assumed that the government's tax policy remains structurally unchanged over this period.

6.1 Economic Structure and Growth

U.S. economic growth is projected to continue at a positive but declining rate up to 2000. Real gross national product grows at 3.6% per annum up to 1985, then by 3.0% to 1990 and 2.8% thereafter. This is sufficient to secure a continuing increase in material living standards. As measured by real GNP per capita (See Table 6-1), the 1977 level of $6100 (1972$) increases at over 2% annually to reach $10,300 (1972$) by the end of the century. To put this in perspective, per capita GNP grew at approximately 2.1% annually over the 1950-1977 period.

This economic growth results from growth in labor input and from increases in gross labor productivity. Employment rises rapidly until 1985, but subsequently this labor force expansion slows. This is due to changes in the demographic structure of the population, particularly to the lower birth rates of the 1970's. Employment growth declines from about 2% annually prior to 1985 to around 1% by 2000. The labor force in 2000 corresponds to approximately 51% of the population, up from 45% in 1977. This is partially due to greater participation by women and minorities and partially due to demographic changes, particularly the greater proportion of the population in the working age groups. The rate of unemployment is exogenously set at 5.0% in 1985, falling to and remaining at 4.8% from 1990 to 2000.

Advances in gross labor productivity account for the portion of real economic growth not attributable to employment increases. Gross labor productivity grows at a rate between 1.6% and 1.7% per annum throughout the 1977 to 2000 period. This is below the historical rate of advance (2.0% per annum for 1947-1976), but still contributes significantly to overall economic growth. Gross labor productivity includes the effects of increases in labor efficiency, in capital per worker, in capital efficiency and in changes in the sectoral mix of production. Increases in capital per worker are particularly important in improving labor productivity. The ratio of capital to labor input is projected to increase by 30% between 1985 and 2000, an average annual increase of 1.78% (See Table 6-5 for the detailed patterns of inputs into production).

The increasing quantity of production permits a continuing rise in the volume of expenditure that the economy can sustain. These expenditures consist of purchases by consumers, investors, government and the rest of the world. The total volume of purchases increases from $1333 Bn (1972$) in 1977 to $2722 Bn (1972$) in 2000 (See Table 6-2). Over this period, the share of total expenditures by the consuming sector increases slightly, with the shares of the investment and government sectors remaining fairly constant. Consumption is projected to remain the dominant use of output. On a per capita basis, real consumption increases from approximately $3960 to $6720 (both in 1972$) in 2000. Government expenditures as a portion of GNP is assumed to remain constant at approximately 20%. This, in turn, contributes to the constancy of the investment share of expenditures. In sum, these projections suggest only a gradual change in the pattern of purchases.

There is a more substantial restructuring of the economy in terms of what is produced and how it is produced. Table 6-3 shows the projected pattern of real final demand and the changes in this pattern over time. The principal elements in final demand are purchases by consumers, investors and government. Final demand represents the net output of the economy. Therefore, the structure of final demand has a direct influence on the pattern of production throughout the economy. The structure of real final demand shifts away from agriculture, energy and extractive products and towards transportation, communications, trade and services. Purchases from agriculture, non-fuel mining and construction industries account for 10.0% of final demand in 1985, falling to 8.9% in 2000. Energy purchases fall from 4.7% of total purchases to 3.4% in 2000. Final demand for manufactured goods remains relatively unchanged at 28%. Transportation and services, however, show steady increases in relative importance with the transportation share in spending rising from 3.0% to 3.5% and with the services share increasing from 54.0% to 55.4%. This substantial increase in the relative importance of trade and service types of production continues, a trend that has been apparent in the recent past. Trade and services will, therefore, account for the major part of future growth in employment as well as absorbing the largest part of increased spending.

Among the remaining sectors, the changing pattern of final demand for energy is probably of the most significance. Energy purchases increase in absolute terms but, in relative terms, energy is less important in 2000 than in 1985 (3.4% of total expenditures versus 4.7%). This represents a move away from energy as purchasers respond both to higher energy prices and to regulations limiting energy use. As a result of these changes, particularly the shift away from energy and towards services, the energy intensity of consumption and other final demand declines substantially.

The changes in final demand spending are partly due to changes in relative prices. Output prices are shown in Table 6-4. Overall prices, as measured by the GNP price deflator, are assumed to increase at 6% annually through 1985 and at about 5% thereafter. Over the 1977 to 2000 period, the average output price for energy goods increases by about 7% per annum or, about 2% a year faster than the overall inflation rate. The aggregate output prices for goods from the manufacturing and transportation sectors rise but less rapidly than other prices, stimulating demand for these goods. The prices of goods from the agriculture, non-fuel mining and construction sector increase somewhat more rapidly than inflation and prices of services also rise relative to overall prices.

The patterns of price increase result partly from the relative energy and labor contents of the different types of output (since energy and labor prices rise comparatively rapidly) and partly from the different rates of productivity improvement in the different sectors.

The operation of the economy, in terms of how goods are produced, is also projected to change substantially over the next 20 years. The aggregate structure of inputs is shown in Table 6-5 in terms of capital, labor, energy and intermediate materials. The figures indicate that production will be restructured, with capital becoming relatively more important and with labor and energy becoming less so. Production steadily becomes more capital intensive, with capital service inputs accounting for 17.5% of total input in 1985, 18.4% in 1990 and 20.1% in 2000. The relative importance of labor diminishes: labor accounts for 21.3% of total input in 1985, 20.5% in 1990 and 18.7% in 2000. Energy input declines from 3.3% of total input in 1985 to 2.6% by 2000. These are major adjustments in the methods of production and in the mix of output; for example, between 1985 and 2000, the capital - labor ratio increases by 30% and the capital - energy ratio increases by 46%. The implications of the rising capital to labor ratio for increases in labor productivity have already been noted. The declining intensity of energy use in production is an indication of an increase in the economic efficiency of energy use. The causes of these changes are complex, but two major factors can be noted. The first is the changing composition of output from the economy. For example, the pattern of final demand purchases shifts away from energy and towards services, i.e. from a highly energy-intensive to a less energy-intensive type of activity. The second cause is changes in relative input prices. In particular, the prices of labor and energy continue to increase rapidly relative to other prices, especially capital. This motivates adjustments in input patterns towards capital, and economizing on energy and labor. Thus, the historical trend towards greater capital-intensity but less labor-intensity of production is continued, but the projections depart from history in that there is a substantial reduction in the energy-intensity of production.

In summary, the principal features of the projections on the course and structure of U.S. economic growth are:

- positive growth continues although at declining rates;
- productivity growth becomes relatively more important as labor force expansion slows;
- use of economic output remains essentially in the present pattern;
- there is structural change in what is produced as final demand growth is directed away from agriculture, extractive and energy activities and towards transportation, communications, trade and services;
- the structure of prices in the economy changes, with energy and agriculture and construction activities becoming more expensive relative to manufacturing and transportation activities;
- there is further structural change in how output is produced with reduction in the relative importance of labor and energy input and increases in the capital intensity of production.

6.2 The Energy System

U.S. energy consumption is projected to continue to increase but less rapidly than historically and less rapidly than economic activity as a whole. Total primary energy input in 2000 is estimated to be 115 quadrillion Btu, corresponding to an average growth rate of 1.8% annually over the 1977-2000 period. This compares to an average rate of economic growth of 3.2%. Also, to place this in a different perspective, this compares with a 3.5% average energy growth over the historical period 1950-1973.

The structure of energy use is summarized in Table 6-6. Total primary energy input increases from 76 quadrillion Btu in 1977 to 93 quads in 1985, an average growth rate of 2.6% annually; then to 101 quads in 1990, an average growth of 1.7%; then to 115 quads in 2000, an average growth of 1.3%. The slowing of the rate of energy growth reflects several features, in particular

- rising relative prices of energy
- regulations concerning energy use standards and efficiency
- the changing structure of economic activity
- the declining rate of economic growth.

A consequence of this restructuring of energy use, in particular of the first three conditions listed, is that the average energy intensity of economic activity declines. As measured by the energy/real GNP ratio, the average energy intensity of the economy falls (or the gross economic efficiency of energy use increases) by an average of 1.3% a year over the 1977-2000 period. This change occurs relatively slowly (1.1% annually) until 1985, slightly more rapidly (1.3% annually) between 1985 and 1990, and more rapidly (1.5% annually) between 1990 and 2000. This time pattern reflects both the lags involved in changing energy use patterns and the time patterns implicit in legislation and regulation concerning energy efficiency standards. As a result of these changes, the average energy content of economic output falls from 57.0 thousand Btu per (1972) dollar of output in 1977 to 42.2 in 2000, an overall decline of 26%.

The structure of fuel use within total energy consumption is also projected to change substantially. One major change is the increase in the relative importance of electricity. This is a continuation of past trends although the rate of increase of electricity use at about 4% annually is much less than the 7% growth typical in the years prior to 1973. This trend can be measured by the degree of electrification, or the proportion of total primary energy input devoted to electricity generation. This index rises from 30% in 1977 to 43% in 2000. Associated with this trend towards electricity is the greater reliance upon coal and nuclear energy input. Coal use as measured by total primary energy input, is projected to rise from 19% to 34% between 1977 and 2000, while nuclear input rises from 4% to 13% over this period. Another feature of the energy system is the declining role of oil and gas. Petroleum, 49% of total primary energy in 1977, declines to 29% in 2000, while gas declines from 26% to 16% over this period. As a result of this, imports become relatively less important within the broad energy picture. Imports of oil and gas comprised 24% of total energy supply in 1977 but this declines to 12% in 2000. A final feature of the energy supply situation is the increasing role played by solar, biomass and geothermal energy. These sources, which supply an insignificant amount of energy in the 1970's, are projected to supply 5.3 quadrillion Btu by 2000, although it must be noted that this accounts for less than 5% of total energy supply.

In summary, the central features of the energy projection can be noted:

- energy use continues to grow but at a declining rate;
- energy growth is considerably less rapid than economic growth;
- the average economic efficiency of energy use steadily improves;
- there is a continuing trend towards electricity use and, correspondingly, to greater use of coal and nuclear energy;
- oil and gas play a diminishing role in the overall energy system with oil imports correspondingly declining;
- solar, geothermal and biomass energy sources rise rapidly but are still small relative to the energy system as a whole.

TABLE 6-1

LABOR, OUTPUT AND PRODUCTIVITY
(LOW SOLAR/LOWER OIL PRICE CASE)

	1977	1985	1990	2000
Population (millions)	216.8	234.1	245.1	262.5
Employment (millions)	90.6	106.2	113.3	126.3
Unemployment Rate (%)	7.0	5.0	4.8	4.8
Real GNP (Billion 1972$)	1332.7	1773.3	2060.2	2721.7
Real GNP per Capita (Thousand 1972$)	6.147	7.575	8.406	10.368
Gross Labor Productivity Thousand 1972$ of Output per Worker	14.71	16.70	18.18	21.55
	Average Annual Growth Rates (in %)			
Population		0.96	0.92	0.69
Employment		2.00	1.30	1.09
Real GNP		3.64	3.05	2.82
Real GNP per Capita		2.65	2.10	2.12
Gross Labor Productivity		1.60	1.72	1.71

1977 figures are actual data, subsequent years are projections.

TABLE 6-2

ECONOMIC OUTPUT AND EXPENDITURE
(LOW SOLAR/LOWER OIL PRICE SCENARIO)

	1977	1985	1990	2000
Real Components (Billion 1972$)				
Consumption	857.7	1144.4	1340.2	1763.5
Investment	196.3	264.3	302.7	401.1
Government	269.2	344.4	408.0	553.0
Net Exports	9.5	20.2	9.4	4.1
GNP	1332.7	1773.3	2060.2	2721.7
Composition of Real GNP (Percent)				
Consumption	64.4	64.5	65.1	64.8
Investment	14.7	14.9	14.7	14.7
Government	20.2	19.4	19.8	20.3
Net Exports	0.7	1.1	0.5	0.2
GNP	100.0	100.0	100.0	100.0

TABLE 6-3

AGGREGATE FINAL DEMAND EXPENDITURES
(LOW SOLAR/LOWER OIL PRICE SCENARIO)

	1985	1990	2000
Purchases, (Billion 1972$)			
Agriculture, Non-Fuel Mining, Construction	173.1	208.0	257.3
Manufacturing	490.2	617.4	832.5
Transportation	52.0	67.2	101.2
Services	936.7	1180.6	1601.3
Energy	81.5	93.2	98.3
Composition of Purchases, Percent			
Agriculture, Non-Fuel Mining, Construction	10.0	9.6	8.9
Manufacturing	28.3	28.5	28.8
Transportation	3.0	3.1	3.5
Services	54.0	54.5	55.4
Energy	4.7	4.3	3.4

TABLE 6-4

LOW SOLAR/LOWER OIL PRICE SCENARIO
AGGREGATE SECTORAL OUTPUT PRICES
(Price Indices Based on 1972 = 1.0)

	1985	1990	2000
Agriculture, Non-Fuel Mining, Construction	2.785	3.709	6.457
Manufacturing	2.099	2.542	3.655
Transportation	1.904	2.240	3.099
Services	2.591	3.386	5.730
Energy	3.465	4.770	8.870
GNP Price Index	2.247	2.868	4.583

Annual Rate of Growth in Output Prices (in %)

	1977-1985	1985-1990	1990-2000
Agriculture, Non-Fuel Mining, Construction	7.8	5.9	5.7
Manufacturing	5.9	3.4	3.7
Transportation	5.6	3.3	3.3
Services	7.6	5.5	5.4
Energy	8.9	6.6	6.4
GNP Price Index	7.0	5.0	4.8

TABLE 6-5

LOW SOLAR/LOWER OIL PRICE SCENARIO
AGGREGATE ECONOMIC INPUT PATTERN
(Input - Output Coefficients for Aggregate Output)

	1985	1990	2000
Input Coefficient For:			
Capital	.1749	.1835	.2005
Labor	.2126	.2053	.1870
Energy	.0330	.0311	.0260
Materials	.5794	.5801	.5865
Average Annual Rate of Change for Input Coefficient for:			
Capital		.97	.89
Labor		-.71	-.93
Energy		-1.20	-1.77
Materials		.02	0.11

TABLE 6-6

U.S. PRIMARY ENERGY INPUT
(Quadrillion Btu)
(LOW SOLAR/LOWER OIL PRICE SCENARIO)

	1985		1990		2000	
	Input	%	Input	%	Input	%
Coal	20.47	22.0	27.13	26.9	39.56	34.4
Petroleum	39.74	42.7	38.55	38.2	33.15	28.9
Natural Gas	20.62	22.2	19.84	19.7	18.00	15.7
Nuclear	7.00	7.5	9.54	9.4	15.03	13.1
Hydro	3.20	3.4	3.30	3.3	3.80	3.3
Solar	0.10	0.1	0.50	0.5	2.00	1.7
Geothermal	0.05	0.1	0.10	0.1	0.50	0.4
Biomass	1.80	1.9	2.00	2.0	2.80	2.4
Total Primary Input	92.98	100.0	100.96	100.0	114.84	100.0
Degree of Electrification[1] (%)	33.3		36.6		43.0	
Energy/GNP Ratio[2]	52.43		49.01		42.19	
Imports of Petroleum[3]	18.67		18.25		13.84	

[1]Primary energy inputs used to produce electricity as a percent of total primary energy input.

[2]Thousand Btu/(1972$)

[3]Quadrillion Btu.

CHAPTER 7

THE EFFECTS OF GREATER SOLAR PENETRATION AT LOWER OIL PRICES*

7.1 INTRODUCTION

The Base Case projections developed in the previous chapter were based on the assumption of low market penetration by solar and other new technology energy sources and of (relatively) lower oil prices. These projections provide a reference point against which to assess the effects of increased penetration by new technology energy sources. Starting from the Base Case, all input assumptions are held the same with the exception of those pertaining to solar and new technology penetration; a new set of projections is made, based on the new assumptions. Since only the energy supply assumptions differ between the Base Case and the new projection, all the differences in the projected energy and economic future can be attributed to the direct and indirect effects of the changed energy supply conditions. In short, the energy and economic effects caused by an increased penetration by solar and other new energy supply technologies can be established by this procedure.

This approach is used to estimate the energy and economic effects of two higher levels of new supply technology penetration. Briefly, these changes are that, compared to 2 quadrillion Btu being supplied by solar and new technologies in 2000 in the base case, the 2000 supply is:

---

*The price of crude oil is assumed to equal $25/bbl in 1976$ in the year 2000.

- 7.27 quadrillion Btu in the medium penetration case
- 16.3 quadrillion Btu in the high penetration case.

(The three cases correspond to 2%, 6% and 14%, respectively, of total primary energy input being supplied by solar energy technologies). This chapter is concerned with reviewing the effects first of the move from low to medium solar penetration, second of the move from low to high solar penetration. The effects on overall economic performance and growth, on the structure of the economy, and on the structure of the energy system will be analyzed.

7.2 The Medium Solar (Lower Oil Price) Scenario

The key economic feature of solar and other new technology energy forms is that they are, at least in the initial years of their useful life, more expensive than the energy sources that they replace. In particular, they are considerably more capital intensive and slightly more labor intensive, per Btu delivered, than conventional sources. This means that increased solar penetration requires more capital input being directed to the energy sector, compared to the Base Case. This capital is diverted from uses in the non-energy part of the economy and so slows the rate of growth of overall productive capacity in the economy. A lower growth path of productive capacity means that productivity and real output increases along a lower path than in Base Case. Further, given the durable nature of this capital, any initial relative decline in capacity means that the entire future growth path is likely to be lower than in the Base Case. Thus, the expected macroeconomic outcome of increased solar penetration is that, in the medium and long run, economic growth proceeds along a lower growth path than in the Base Case. This implies that, for any given future year, real output and incomes will be somewhat lower than in the absence of the increased solar penetration. (It can be noted, though, that to the extent that total operating and maintenance costs for solar and other new technology energy sources are less than those for the conventional energy displaced, the solar program will, after the construction phase, release inputs to the rest of the economy and so tend to reduce the real income and output loss due to solar).

The projections permit these effects to be quantified. Table 7-1 presents a summary of the macroeconomic effects of the moderate penetration solar and new technologies supply program. There is no discernible macroeconomic impact up to 1990. However, solar supplies only 1% of total energy by this point, so it is not a major consideration. During the 1990's, investment in solar proceeds rapidly and by 2000, 6% of total energy is supplied by solar. The macroeconomic impact correspondingly increases. By 2000, real GNP is 0.9% less than in the Base Case. This economic reduction corresponds to a slowing but certainly not the elimination of economic growth. Average growth during the 1990's declines from 2.82% in the Base Case to 2.73% in the moderate penetration case, a decline of 0.09 percentage points in the average annual growth rate. Thus, the economy is not crippled or seriously affected by the expanded solar program; incomes, output and material living standards continue to increase almost as rapidly as in the absence of the solar program. However, the solar program does impose a significant cost on the economy: the level of real GNP, and so of real output and income, is less than in the Base Case. Thus, people are, on average, less well off in terms of real income as a result of the solar program. This macroeconomic cost in 2000 is $24 billion (1972$). The total of this cost, over the entire 1977-2000 period, is approximately $86 bn (1972$) while the present value of this cost, to 1980 using a 5% discount rate, is approximately $37 bn

(1972$). This present value of cost is equivalent to a lump sum cost of about $667 for every family in the U.S. in 1980.

The relative reduction in output resulting from the energy program is matched by a corresponding change in effective inputs into the economy. These changes are shown in the lower portion of Table 7-1. Capital stock is reduced as a result of the energy changes. The reduction amounts to 0.7% in 2000. It is due to the output - investment - capital nexus. Reduced output and income resulting from the energy changes lead to reduced investment and so to slower growth of the overall capital stock. This capital effect means that there is slower growth of productive capacity. Alternatively, it means that there is slower growth in capital per worker, which is reflected in slower growth of labor productivity. The table shows that gross labor productivity in 2000 is 0.9% less than in the Base Case. The greater part of this is due to the capital effect; the smaller remaining part is due to the restructuring of the economy, particularly the move in spending, induced by the energy changes, towards lower productivity sectors such as services. Employment does not change perceptibly as a result of the changes, e.g. total employment in 2000 is predicted to remain at 126 million. Thus, the input changes are concentrated on capital and, through this, on labor productivity. Employment does not change but real incomes, e.g. real wages and salaries, which are fundamentally influenced by productivity, increase less rapidly as a result of the increased solar penetration.

Table 7-2 disaggregates real GNP into final demand expenditure by type of purchaser. The higher penetration of new energy sources results, by 2000, in real consumption being 1.1% less than in the Base Case and investment being 1.6% lower. (The third major category of expenditure, government purchases, is assumed not to change). The decline in investment, cumulated over time, accounts for the fall in capital stock noted above. Most of the investment decline is due to the reduction in total real spending and output. In addition, however, there is a slight reduction in the share of investment in total output. The lower share reflects the lessened demand for investment (resulting from slower output growth and the changing mix of sectoral outputs) in conjunction with reduced saving due to a diminished rate of return.

The structure of prices, spending and production also change as part of the economic adjustments resulting from the increased penetration of solar energy. Table 7-3 shows these structural changes, as between the Medium Solar Scenario and the Base Case (Low Solar) for 2000. The first segment of the Table shows the impacts on final demands. Final demand spending (principally consumption, investment and government purchases), represents the net output of the economy and so is a central determinant of the production structure of the economy. Each type of final demand purchases is reduced as a result of the energy changes. Reductions averaging 0.9% are to be expected just from the lower level of output and incomes in the economy. Over and above this, there are compositional changes as purchasers adjust their spending patterns to new prices and to their new income levels. Purchases of transportation and of services decline less than total spending, while purchases of manufactured goods declines in proportion to total spending, and agricultural and construction spending declines more. The largest relative change concerns energy purchases - real final demand for energy declines by over 5%. The largest part of this energy reduction is due to solar supply displacing some conventional supply. There are no energy purchases in solar energy (there are only purchases of capital, labor and other inputs) whereas the displaced conventional energy was entirely market purchases. The decline in energy purchases therefore overstates the decline in energy actually consumed; energy actually consumed falls only by about 1%.

The second part of Table 7-3 displays the overall sectoral output prices and their relation to prices in the Base Case. Of the five sectors, output prices rise for agriculture and for services, fall for manufacturing and for energy, and are unchanged for transportation. However, none of the price changes are substantial, which is due to the assumption that solar energy is price competitive to the purchaser (even though solar may have to be subsidized to achieve this). The price changes that do occur are the result of the variation in capital and labor prices associated with the restructuring of the economy. The price decline for energy is due to compositional changes--solar displaces relatively more electricity, which is an expensive fuel, so the weighted average energy price declines as a result of the use of more solar.

The structure of production can be summarized by input-output coefficients giving the relative importance of different categories of inputs. This information is given in the third segment of Table 7-3, which shows the pattern of capital, labor, energy, and intermediate materials within total inputs. The labor input coefficient does not change significantly. The relative importance of capital does, however, rise slightly, reflecting the increasing capital intensity of energy production. The energy coefficient declines slightly but, as this covers only purchased energy and excludes solar, it overstates the fall in energy intensity of production; the effective energy content is unchanged. In sum, the main production change is the increasing capital intensity of production.

The increase in solar energy production leads to changes in the energy system more substantial than those in other sectors of the economy. Table 7-4 displays primary energy input for the year 2000 under the moderate and low solar penetration scenarios. While total primary energy input only declines marginally (by .3%), the pattern of input changes more markedly. Specifically, consumption of all fossil fuels fall substantially, ranging from

3% for natural gas to over 10% for petroleum products. This decline is due to three reasons: first, some solar energy substitutes directly for oil and gas; second, solar input to generating electricity (2.5 quads in 2000) substitutes for other fuels used to generate electricity, such as coal; and third, the lower level of economic activity reduces demand by all producers and consumers for energy in general. The lower demand for petroleum and natural gas can be primarily attributed to displacement by solar and reduced economic activity, while the reduction in coal input is due more to fuel substitutions within the electricity sector as well as lower economic activity.

The degree of electrification is a measure of how much of primary energy resources are being consumed to produce electricity. In the moderate case, 42.6% of all energy inputs are consumed by electric utilities compared to 43.0% in the Base Case. This is due primarily to displacement by solar energy. The reduction is small, however, indicating that electricity will continue to grow in both absolute and relative importance. Greater solar energy availability slightly slows the trend over time towards greater electrification in the economy.

Finally, greater solar energy has a major impact on the dependence of the U.S. on foreign supplies of energy. Specifically, the reduction in petroleum consumption described above leads to a substantial drop in imports of oil. By 2000, imports are 10.3 quadrillion Btu, more than 25% less than in the Base Case. In 1972 dollars, this savings is approximately equal to an improvement in the U.S. trade balance of $12 billion.

7.3 The High Solar (Lower Oil Price) Scenario

The approach and analysis for the high level of marked penetration by solar and other new energy supply methodologies are similar to that employed for the medium penetration case. The only differences in input assumptions from the low solar base case are those involving energy supplies; consequently, all of the projected energy and economic differences can be attributed to these changed supply conditions. The economic nature of the differences in the input assumptions is that the new energy supply technologies involve higher capital and labor inputs than the conventional energy that they displace although, later in the life cycle of the plant, operating costs may be lower. The new technologies program involves, therefore, a diversion of capital from the non-energy part of the economy, slowing the growth of effective productive capacity and of labor productivity, and slowing the rate of growth of real incomes and output. The economic impacts of the high penetration case can be expected to be similar in nature but larger in magnitude than those in the moderate case. The rest of this section reviews, in quantitative terms, the nature of the economic and energy impacts of the high penetration by solar and other new energy supply technologies.

The impacts on the level and growth of economic activity are summarized in Table 7-5. The high solar case has a macroeconomic impact beginning in the early 1980's. By 1985, real GNP is $4 billion (1972$) or 0.2%, less than its Base Case level. The difference increases after 1985. By 1990, real GNP is 0.8% lower and in 2000 the reduction is 2.9% or $78 billion (1972$). The average rate of economic growth is therefore slowed by the large scale introduction of solar energy technologies. Between 1985 and 2000, the average growth rate declines from 2.9% per annum in the low solar Base Case to 2.7% in the high penetration case. The difference is concentrated in the 1990's when over 0.2 percentage points is lost off the economic growth rate. These figures mean that economic growth continues at an appreciable rate, even though it is slowed somewhat, despite the energy changes. Even a large scale new technology program will not, therefore, seriously disrupt the economy and will not prevent a continued increase in material standards of living.

This is not to say that the large scale energy program has no economic costs. It does say that the costs are not sufficiently severe to prevent continued economic growth at a substantial rate. However, the energy program does cause economic costs that are, in absolute magnitude, very substantial. These costs take the form of real income or output foregone (i.e., although incomes continue to increase under the high penetration case, they do not increase as rapidly as in the Base Case). The difference in the real income stream is the loss or the macroeconomic cost caused by the large scale solar program. The sum of the real GNP loss over the period until 2000 is about $413 billion (1972$), a very substantial amount. The present value to 1980, of this stream of GNP reductions, using a 5% discount rate, is approximately $202 billion (1972$). This loss, in present value terms, corresponds to about 15% of the entire U.S. GNP for 1978. In a different perspective, it corresponds to a lump sum cost of about $3650 for every family in the U.S. in 1980. These are clearly substantial macroeconomic costs resulting from the high penetration of new technology energy sources.

The decline in real output is due to corresponding reduction in the volume of effective input into production. The second part of Table 7-5 gives the changes in capital stock, employment and labor productivity resulting from the higher penetration of new energy technologies. By 2000, capital stock is $166 billion (1972$), or 2.7%, less than in the Base Case. This capital reduction reflects the cumulative impact of lower investment. Employment is little changed as a result of the energy adjustments; employment in 2000 is 126 million, only about 0.1% lower than in the low solar Base Case. Gross labor productivity, however, is much more significantly affected. By 2000, the level of this productivity, or total output per worker, is 2.8% less than in the Base Case. The major part of this reduction is due to the drop in capital stock. In addition, the sectoral restructuring of the economy contributes to this change, particularly the diversion of capital from the non-energy into the energy sectors and the shifting of output patterns towards sectors, such as services, with relatively low productivity growth. The result of these adjustments is that productivity growth is slowed by the energy adjustments, causing a comparable slowing of real income growth and of output growth, although employment is not significantly affected.

Table 7-6 disaggregates GNP into final demand expenditures by categories of purchaser. Consumption and investment are each less than in the Low Solar Base Case for the entire forecast period. By 2000, consumption is 3.6% lower than in the Base Case, and investment is down by 5.8%. (Government expenditures are assumed not to change.) As capital stock is the outcome of investment a fall in investment leads to a smaller amount of new capital stock. This explains the drop in capital stock noted above. It also means that the loss in GNP is not likely to be recouped, since investment and therefore capital, are on a growth path that is permanently lower than in the Base Case. The composition of GNP remains similar to that of the Base Case. The assumption of constant government expenditures results in an expansion of this sector relative to the consuming and investing sectors, although this change is not large.

The impact of greater solar penetration on final demand expenditures by type of purchase is displayed in Table 7-7. All categories of expenditures decline from their Base Case levels, reflecting the overall reduction, in 2000, of 2.9% in the level of economic activity. As in the moderate solar case, expenditures on output from the agriculture, non-fuel mining and construction, and from the manufacturing sectors decline proportionately more than total expenditures, while purchases of transportation and services decline relatively less. Thus, the share of services and of transportation in spending and production increase slightly. Purchases of market fuels declines drastically, by 17% from Base Case levels. However, most of this is due to the diversion of supply to solar capacity which is not included in current fuel purchases. If energy purchases are adjusted for the greater use of solar, total energy expenditure would fall by only 4.1%. This fall is mainly due to the lower level of economic activity but also reflects a compositional shift of purchases, particularly with purchases being diverted away from electricity.

The overall sectoral output prices are also affected by the changes in economic activity. The pattern of change is similar to that observed in the Medium Solar (Lower Oil Price) Scenario; with output prices for the agriculture, non-fuel mining and construction, and the services sectors increasing, and prices for manufacturing and energy declining relative to the Base Case. As before, none of the changes are substantial. These changes result from changes in input prices, mainly capital and labor, as these resources are shifted between sectors.

The structure of inputs into production, as summarized by the capital, labor, energy, and materials input-output coefficients for aggregate production, is given in the third section of Table 7-7. As with the Medium Solar (Lower Oil Price) Scenario, there is virtually no change in the input share or coefficient for labor. The intensity of capital use increases as a result of greater production of solar energy, accentuating the trend towards greater capital intensity of production. The energy coefficient declines slightly but this is mainly due to the purchases of less market energy with more non-market solar energy being used; the overall energy intensity of production is little changed by the adjustments. The principal change, in fact, is the movement to more capital intensive production.

The increase in solar utilization and availability leads to significant alterations in the energy system. Table 7-8 displays primary energy input for 2000 under high and low solar assumptions. The reduction in total primary input is 1.7 quadrillion Btu, on 1.4%, under the high solar conditions. This decline is primarily the result of the decline in the overall level of economic activity. The pattern of energy input changes substantially, with consumption of conventional fuels, particularly coal, oil and gas, falling significantly. The reasons for these declines are: direct substitution of solar for oil, gas and electricity in end-uses, the substitution of solar input for coal and nuclear in the generation of electricity, and lower demand for all energy services due to the reduction in economic growth. The degree of electrification is slightly lower than in the Base Case: in 2000, 41.8% of total primary energy input is used for electricity generation compared to 43% in the Base Case, but both of these figures are substantially higher than the 33% electrification of 1977. Thus, while the move to high use of solar involves some slowing of electrification, the trend to increasing electricity use and to electricity increasing in relative importance within the energy system continues.

The energy supply situation is greatly changed by the introduction of the solar and new technology energy sources. The relative importance of fossil fuels is greatly reduced: in 2000, fossil fuels account for 66% of total energy input, compared to to 79% in the Base Case. There is a major substitution, therefore, from fossil fuels to new technology sources. One key area where this leads to changes is in petroleum imports. Slower growth of the economy together with the large scale movement away from petroleum lead to oil demand falling by 7 quadrillion Btu. Virtually all of this decline is translated into reduced imports so oil imports in 2000 are halved, from 14 to 7 quads, as a result of the new supply measures. In this situation, imports comprise only 26% of total petroleum supply, down from 42% in the Base Case. This represents a substantial reduction in the degree of U.S. reliance on imported energy. Also, the position of the U.S. dollar is improved due to the reduced oil import bill - the saving in import payments in 2000 alone is approximately $25 billion (1972$).

In summary, an increase in solar penetration to the High Solar Scenario has measurable and significant impacts on the whole economy. These impacts are similar to those in the Medium Solar Scenario, although they are considerably greater in magnitude. In both cases, economic growth is slowed, due to the shift of capital and labor services caused by the solar and new energy technology program. Although employment is little affected, labor productivity is adversely affected, resulting in slower growth of both incomes and output. In the high penetration case, economic growth (the average annual rate between 1985 and 2000) drops to 2.7%, compared to 2.9% in the low solar Base Case and real GNP in 2000 is 2.9% lower. Both consumption and investment are affected by this slower growth. The investment decline is significant as it reduces the growth of the capital stock, which, in turn, dampens the rate of economic growth. The consumption decline is significant as it represents a slower growth of material standards of living. The composition of spending changes slightly, particularly with services becoming relatively more important and with conventional energy sectors declining in importance. The composition of production and inputs also changes with labor remaining relatively constant but with the capital intensity of production increasing. The historical trend towards greater capital intensity is thus accelerated. Finally, while total energy use does not decline greatly, the composition of that use is greatly affected, with solar and new technology sources displacing substantial amounts of fossil fuels. Accordingly, use of fossil fuels, particularly oil and gas, and the imports of these fuels are substantially lower in the High Solar Scenario than in the Low Solar Base Case.

TABLE 7-1

ECONOMIC SUMMARY FOR THE MEDIUM SOLAR/
LOWER OIL PRICE SCENARIO

	1985	1990	2000
Macroeconomic Output			
Real GNP (Bn 1972$)	1773.3	2060.2	2697.3
Change from Base Case			
Percent	0	0	-0.9
Billion 1972$	0	0	-24.4
Real GNP Growth Rates[(1)]			
New	3.64	3.05	2.73
Base Case	3.64	3.05	2.82
Difference	0	0	0.09
Macroeconomic Inputs			
Macroeconomic Inputs			
Capital Stock			
Billion 1972$	4400.3	4996.1	6069.2
Percent Change from Base Case	0	0	-0.7
Employment			
Billion 1972$	106.2	113.3	126.2
Percent change from Base Case	0	0	0
Gross Labor Productivity			
Thousand 1972$/person	16.70	18.18	21.36
Percent change from Base Case	0	0	-0.9

[(1)] Average percent per annum.

TABLE 7-2

COMPOSITION OF SPENDING IN THE MEDIUM SOLAR/
LOWER OIL PRICE SCENARIO

	1985	1990	2000
Real GNP Components (Bn 1972$)			
Consumption	1144.4	1340.1	1743.3
Investment	264.3	302.6	394.6
Government	344.4	408.0	553.0
Net Exports	20.2	9.4	6.4
GNP	1773.0	2060.2	2697.3
Composition of Real GNP (%)			
Consumption	64.5	65.1	64.6
Investment	14.9	14.7	14.6
Government	19.4	19.8	20.5
Net Exports	1.1	0.5	0.2
GNP	100.0	100.0	100.0
Change from Base Case (%)			
Consumption	0	0	-1.1
Investment	0	0	-1.6
GNP	0	0	-0.9

TABLE 7-3

ECONOMIC STRUCTURE IN THE MEDIUM SOLAR SCENARIO/
LOWER OIL PRICE IN 2000

	New	Base	Change, %
(a) Final Demand Expenditures (Bn 1972$)			
Agriculture, Non-Fuel Mining and Construction	254.7	257.3	-1.0
Manufacturing	824.6	832.5	-0.9
Transportation	100.5	101.2	-0.7
Services	1588.1	1601.3	-0.8
Energy	92.9	98.3	-5.5
(b) Output Prices (Price Indices, 1972=1.0)			
Agriculture, Non-Fuel Mining and Construction	6.466	6.457	0.1
Manufacturing	3.652	3.655	-0.1
Transportation	3.098	3.099	0
Services	5.736	5.730	0.1
Energy	8.845	8.870	-0.3
(c) Aggregate Input Coefficients			
Capital	.2016	.2005	0.5
Labor	.1871	.1870	0.1
Energy	.0259	.0260	-0.4
Intermediate Materials	.5854	.5865	-0.2

TABLE 7-4

PRIMARY ENERGY INPUT,
2000 FOR THE MEDIUM SOLAR SCENARIO/
LOWER OIL PRICE
(Quadrillion Btu)

	New	Base	Change, %
Coal	38.02	39.56	-3.9
Petroleum	29.64	33.15	-10.6
Natural Gas	17.46	18.00	-3.0
Nuclear	15.00	15.03	-0.2
Hydro	3.80	3.80	0
Solar	7.27	2.00	263.5
Geothermal	0.50	0.50	0
Biomass	2.83	2.80	1.1
Total	114.52	114.84	-0.3
Degree of Electrification[1]	42.6	43.0	-0.9
Energy/GNP Ratio[2]	42.5	42.2	0.6
Imports of Petroleum[3]	10.33	13.84	-25.4

[1] Proportion of total energy used to generate electricity.

[2] Ratio of primary energy input to real GNP, thousand Btu/$(1972).

[3] Quadrillion Btu.

TABLE 7-5

ECONOMIC SUMMARY FOR THE HIGH SOLAR/
LOWER OIL PRICE SCENARIO

	1985	1990	2000
Macroeconomic Output			
Real GNP (Bn 1972$)	1769.4	2044.3	2643.6
Change from Base Case			
Percent	-0.2	-0.8	-2.9
Billion 1972$	-3.9	-15.9	-78.1
Real GNP Growth Rates (1)			
New	3.61	2.93	2.60
Base Case	3.64	3.05	2.82
Difference	-0.03	-0.12	-0.22
Macroeconomic Inputs			
Capital Stock			
Billion 1972$	4399.3	4983.4	5948.4
Percent change from Base Case	0	-0.3	-2.7
Employment			
Million	106.2	113.2	126.2
Percent change from Base Case	0	-0.1	-0.1
Gross Labor Productivity			
Thousand 1972$ /person	16.66	18.06	20.95
Percent change from Base Case	-0.2	-0.7	-2.8

(1) Average percent per annum.

TABLE 7-6

COMPOSITION OF SPENDING IN THE HIGH SOLAR/
LOWER OIL PRICE SCENARIO

	1985	1990	2000
Real GNP Components (Bn 1972$)			
Consumption	1141.1	1326.9	1700.2
Investment	263.8	299.9	377.8
Government	344.4	408.0	553.0
Net Exports	20.1	9.4	12.6
GNP	1769.4	2044.3	2643.6
Composition of Real GNP (%)			
Consumption	64.5	64.9	64.3
Investment	14.9	14.7	14.3
Government	19.5	20.0	20.9
Net Exports	1.1	0.5	0.5
GNP	100.0	100.0	100.0
Change from Base Case (%)			
Consumption	-0.3	-1.0	-3.6
Investment	-0.2	-0.9	-5.8
GNP	-0.2	-0.8	-2.9

TABLE 7-7

ECONOMIC STRUCTURE IN 2000 IN THE HIGH SOLAR/
LOWER OIL PRICE SCENARIO

	New	Base	Change, %
(a) Final Demand Expenditures (Bn 1972$)			
Agriculture, Non-Fuel Mining and Construction	248.4	257.3	-3.5
Manufacturing	798.1	832.5	-4.1
Transportation	99.1	101.2	-2.1
Services	1561.8	1601.3	-2.5
Energy	81.9	98.3	-16.7
(b) Output Prices (Price Indices, 1972 = 1.0)			
Agriculture, Non-Fuel Mining and Construction	6.497	6.457	0.6
Manufacturing	3.649	3.655	-0.2
Transportation	3.106	3.099	0.2
Services	5.747	5.730	0.3
Energy	8.826	8.870	-0.5
(c) Aggregate Input Coefficients			
Capital	.2028	.2005	1.3
Labor	.1874	.1870	0.2
Energy	.0256	.0260	-1.4
Materials	.5842	.5865	-0.4

TABLE 7-8

PRIMARY ENERGY INPUT IN 2000 FOR THE HIGH SOLAR/
LOWER OIL PRICE SCENARIO
(Quadrillion Btu)

	New	Base	Change, %
Coal	32.86	39.56	-16.9
Petroleum	25.99	33.15	-21.6
Natural Gas	16.23	18.00	-9.8
Nuclear	14.20	15.03	-5.5
Hydro	4.00	3.80	5.3
Solar	16.30	2.00	715.0
Geothermal	0.50	0.50	0
Biomass	3.10	2.80	10.7
Total	113.18	114.84	-1.4
Degree of Electrification (1)	41.8	43.0	-2.8
Energy/GNP Ratio (2)	42.8	42.2	1.5
Imports of Petroleum (3)	6.68	13.84	-51.7

(1) Proportion of total primary energy input used in electricity generation.

(2) Ratio of primary energy input to real GNP, thousand Btu/(1972$).

(3) Quadrillion Btu.

CHAPTER 8

SOLAR AND NEW ENERGY TECHNOLOGIES WITH HIGHER OIL PRICES*

8.1 INTRODUCTION

The price of oil is one of the central parameters of the energy system. On the demand side, the oil price influences the prices of delivered fuel, and so influences the level of demand for energy. On the supply side, the price of oil influences the economics of new supply sources--the higher the price of oil, the greater the range and quantity of supply sources, including new technologies, that become economically viable. In particular, the role and impact of solar and new technology supply programs will be linked to the oil price.

To investigate the relationship between the oil price and the impacts of new supply programs, some of the previous analyses were repeated using a reference projection based upon a higher world oil price. Specifically, the analysis proceeds through two steps. First, a new reference case was prepared, differing from the lower oil price Base Case in having a more rapid increase in the world oil price and lower total energy use. Second, the solar and new energy supply technology assumptions from the low and medium market penetrations used in the lower oil price analysis were adopted, with all other assumptions held constant, and a new set of projections compared. The differences in energy and economic parameter values between the new Medium Solar Scenario and

---

*The price of crude oil is assumed to equal $35/bbl in 1976$ in the year 2000.

the new Reference (Low Solar) Scenario can thus be attributed entirely to the increased penetration of solar in a world of higher oil prices. Finally, the impact of increased solar penetration under higher oil prices can be compared to its impact under lower oil prices to assess the extent to which the solar impacts are sensitive to the level of oil prices.

8.2 The Higher Oil Price Reference Scenario

The reference case for this analysis is the low solar, high oil price case. A summary of the macroeconomic features of this case is given in Table 8-1. This table also compares these projections with the low solar, low oil price Base Case. With the higher oil prices, real GNP is projected to reach $2670 (1972$) in 2000. This corresponds to an average annual growth rate of 3.07% over the 1977-2000 period. Economic growth is most rapid over the period until 1985 and then slows; growth through 1985 averages 3.55% annually while growth during the 1990's averages only 2.75%. In all of these features this Scenario is similar to the Base Case except that growth rates are lower. In short, the more rapid increase in oil prices leads to slower growth of real incomes and output in the economy. Real GNP under the higher oil price conditions is 0.7% less than in the Base Case in 1985, 1.2% less by 1990, and 1.9% less in 2000. This corresponds to average economic growth over the whole forecast period being reduced by 0.08 percentage points (from 3.15 to 3.07% annually). The principal growth impacts occur in the late 1980's, when the growth rate drops by 0.11% annually, but the effect is long lasting and even in the 1990's the growth rate is lower than in the Base Case. In sum, therefore, the more rapid rise in oil prices has a permanent adverse macroeconomic impact: growth of real incomes and output is slowed and the level of income and output in every future year is lower than in the Base Case.

The second part of Table 8-1 shows the impact of the higher oil prices on macroeconomic inputs, specifically capital, labor and labor productivity. Two sets of mechanisms are involved in the adjustment to higher oil prices. The first set involves restructuring of the energy and economic systems and results in lower productivity and so lower incomes and output. Higher oil prices induce a substitution of other fuels for oil, within the energy system, and a substitution of other inputs for energy, within the economic system. Any such substitutions involve moving away from the selected efficient mix of inputs into production and so involve some loss in productivity. Also, any substitution of labor for energy results in production becoming more labor intensive, which implies that there is less output per unit of labor input, i.e. labor productivity is adversely affected. The slowing of productivity growth results in less output and GNP. From this GNP reduction, investment will also be affected. The second set of adjustments involves investment and capital. Lower GNP directly leads to less investment. In addition, the investment share of GNP declines slightly, compounding the impact on capital. The slower growth of capital and productive capacity accentuates the slowing of productivity growth. Thus, the overall impact, is that, under the higher oil price conditions, capital and productivity grow less rapidly than in the Low Solar (Lower Oil Price) Base Case. Employment growth remains largely unchanged. The result is that real wages and salaries as well as total income and output, increase less rapidly.

The composition of spending, by type of purchaser, is shown in Table 8-2. The reduction, compared to the Base Case, of up to 1.9% in real GNP is carried by consumption and investment. The dollar reduction in consumption exceeds that in investment but is somewhat less in proportionate terms. Total allocation of spending shifts away from investment, and to a lesser extent from consumption, although the overall spending pattern remains similar to that in the Base Case.

Other indicators of economic structure are given in Table 8-3. Final demand spending is redirected towards services and away from energy, transportation and goods. The average reduction in final spending in 2000 is 1.9%. Compared to this, the 1% decline in services spending represents an increase in the relative importance of services. In contrast, transportation, manufacturing and agricultural purchases decline slightly in relative importance while energy declines much more substantially. An important reason for the changing composition of final demand is the adjustment in relative output prices. Average energy prices rise substantially, by 8.7%, while services prices are virtually unchanged and prices of manufactured goods and transport increase slightly. These price changes provide a strong inducement for the diversion of some of the increase in purchases away from energy and towards services. The pattern of inputs into production also changes in response to the new price structure. These changes are shown in the input coefficients for capital, labor, energy and intermediate materials in the third segment of the table. Higher energy prices lead producers to reduce on energy use and it is here, with energy input 6.2% down in relative importance, that the main impact is felt. However, reduced energy must be offset by increased use of other inputs. Labor is the main replacement. Labor-energy substitution leads the input coefficient for energy to rise by 1.8%. Finally, there is some complementarity between capital and energy which leads to a small reduction in the average capital intensity of production. Thus, the oil price rise leads to a shift away from energy, and to a small extent from capital, and towards labor in the pattern of inputs to production.

The energy system changes resulting from the higher oil price are summarized in Table 8-4. The details of these energy figures were estimated based on NPAC1 energy use scenarios. Total primary energy input in 2000 is estimated to be 8.7% less than under lower oil price conditions. Petroleum use is reduced from 33.2 to 29.6 quadrillion Btu, a decline of 10.6%. Coal and nuclear use are also predicted to decline, resulting from the lower degree of electrification. (It is not clear, however, why electricity demand should decline to this extent). Lower petroleum demand implies that there is less demand for imports, as imports are the marginal source of supply, and the level of petroleum imports declines significantly - from 13.8 to 9.9 quadrillion Btu or 29%. Also, the reduction in energy use and the redirection of final demand and input purchases away from energy reduces the energy-intensity of economic activity; the energy-GNP ratio is 6.9% less in the high oil price conditions than in the Base Case.

8.3 The Medium Solar/Higher Oil Price Scenario

Starting from the higher oil price reference case (Low Solar, Higher Oil Price Scenario), the level of penetration of solar technology energy sources was increased from low to medium. This energy specification in terms of absolute penetration levels for solar technologies is the same as the low to medium penetration shift in the low oil price cases except that the initial energy and economic configuration is now different. The impacts of the increased level of penetration by solar technologies is now examined. The points of comparison are macroeconomic performance, on both output and input sides, economic structure and energy structure.

The macroeconomic impact of the increased solar penetration is presented in Table 8-5. This table gives the macroeconomic indicators for the Medium Solar/Higher Oil Price Scenario and compares them to those in the corresponding reference case, the Low Solar/Higher Oil Price Scenario. The impact of increased solar penetration is adverse, although the effects do not become apparent until the 1990's. By 2000, real GNP is 1.0% less than in the reference case. This corresponds to a decline of 0.1 percentage points in the average annual growth rate during the 1990's, with the rate declining from 2.75 to 2.65%. These impacts certainly do not imply the end to economic growth or an absolute reduction in material standards of living. However, they do represent an economic cost in that real income and output are lower than they would be in the absence of the increased penetration by solar technologies. The cost in 2000, as measured by the real GNP reduction, is $26 billion (1972$). The total cost in GNP foregone is approximately $91 billion (1972$). This represents a present value, to 1980 at a 5% discount rate, of $41 billion (1972$) which corresponds to a lump sum cost of $740 for every family in the U.S. in 1980. While this cost is not overwhelming, it is nonetheless significant, particularly when viewed in relation to the magnitude of expenditures made within the energy system.

This output reduction has an exact correspondence in terms of reduced quantity and productivity of inputs. Employment is projected to remain unchanged. However, gross labor productivity growth is slowed by the energy changes and by 2000 is 1% less than in the reference case. The principal cause of this productivity change is the slower growth of capital, which by 2000 is 0.8% less than in the reference case, although this is compounded by the effects of changes in the sectoral and input patterns of production. In turn, the capital reduction, and its immediate cause in an investment reduction, are due to lower productivity and yields following the diversion of investment into the energy sector.

The impact of the energy changes on the overall pattern of expenditure is shown in Table 8-6 for consumption, investment, government and net export purchases. The adjustment is centered on consumption and investment with government purchases being assumed to remain constant. The volume of consumption purchases, in 2000, is reduced by 1.2% while real investment is 1.9% lower. (This investment effect is reflected in the capital stock and productivity changes outlined above). Other aspects of spending and production structure are presented in Table 8-7. Final demand spending is reduced in volume, in line with the 1.0% real GNP decline, as well as changed in composition. The effects, however, are relatively minor. Energy purchases show the greatest decline, 7%, but this refers to fuels purchased in the market. If account were taken of solar energy, the reduction would be much smaller. There is some realignment of non-energy expenditures with services and transportation becoming relatively more important and agriculture and manufacturing becoming slightly less important. The price changes, given in the second segment of the table, show very little price change. The main effect is on energy prices, but this reflects a compositional shift, with solar displacing relatively expensive electricity from part of final expenditure. The patterns of inputs into production, given in the third segment of the table, show a systematic although only moderate change. Energy inputs in the form of purchased fuels decline by 0.8% in relative importance, although some of this is offset by increased use of non-market solar energy. Labor input is very little affected--there is a marginal rise in the labor-intensity of production. The main change concerns capital, with the capital intensity of production rising by 0.6%. This is associated with the increased capital intensity of the energy sector as well as with the sectoral shifts in output patterns.

The increase in the supply of energy from solar and other new sources has a significant impact on the structure of the U.S. energy system. Table 8-8 displays primary energy input for the year 2000 for this scenario and the Low Solar/Higher Oil Price Reference Scenario. While total energy input changes only marginally, the pattern of input undergoes more substantial changes. Consumption of all fossil fuels decreases, with the greatest impact being on petroleum. These declines result from solar substituting directly for oil and gas; electricity generated by solar energy substituting for other fuels used to generate electricity, in particular, coal; and reduced energy demand because of the lower level of economic activity. The reduction in petroleum use is due primarily to direct substitution and reduced economic activity since petroleum is not a substantial source of electricity in these scenarios. The degree of electrification--the ratio of primary inputs used to generate electricity to total primary inputs--falls slightly. This is due to substitutions of solar energy for electricity in final energy uses. This decline is small, however. Electricity continues its relatively rapid growth, even with greater solar market penetration.

Greater energy from solar and other new sources has a large impact on the level of U.S. imports of petroleum. The reduction in use of petroleum noted above produces a substantial drop in imports, as these are the marginal source of supply. By 2000, imports are 6.7 quadrillion Btu, or approximately 3.4 million barrels a day compared to 9.9 quads in the reference case. The increased use of solar energy has a considerable impact, therefore, on U.S. energy imports and the extent of the nation's reliance upon foreign energy supplies.

TABLE 8-1

ECONOMIC SUMMARY OF THE LOW SOLAR/
HIGHER OIL PRICE SCENARIO

	1985	1990	2000
Macroeconomic Output			
Real GNP (Billion 1972$)	1761.5	2036.1	2669.9
Change from Base Case			
Percent	-0.7	-1.2	-1.9
Billion 1972$	-11.8	-24.1	-51.8
Real GNP Growth Rates(1)			
New	3.55	2.94	2.75
Base Case	3.64	3.05	2.82
Difference	-.09	-0.11	-.07
Macroeconomic Inputs			
Capital Stock			
Billion 1972$	4393.2	4933.6	5931.9
Percent change from Base Case	-0.2	-1.3	-3.0
Employment			
Millions	106.3	113.3	126.3
Percent change from Base Case	0.1	0	0
Gross Labor Productivity			
Thousand 1972$/person	16.57	17.97	21.14
Percent change from Base Case	-0.8	-1.2	-1.9

(1) Average percent per annum for the 1977-85, 1985-90, 1990-2000 periods, respectively.

TABLE 8-2

COMPOSITION OF SPENDING IN THE LOW SOLAR/
HIGHER OIL PRICE SCENARIO

	1985	1990	2000
Real GNP Components (Bn 1972$)			
Consumption	1135.1	1320.1	1726.0
Investment	261.4	293.6	379.9
Government	344.4	408.0	553.0
Net Exports	20.6	14.4	11.0
GNP	1761.5	2036.1	2669.9
Composition of Real GNP (%)			
Consumption	64.4	64.8	64.6
Investment	14.8	14.4	14.2
Government	19.6	20.0	20.7
Net Exports	1.2	0.7	0.4
GNP	100.0	100.0	100.0
Change from Base Case (%)			
Consumption	-0.8	-1.5	-2.1
Investment	-1.1	-3.0	-5.3
GNP	-0.7	-1.2	-1.9

TABLE 8-3

ECONOMIC STRUCTURE IN 2000 IN THE LOW SOLAR/ HIGHER OIL PRICE SCENARIO

	New	Base	Change, %
(a) Final Demand Expenditures (Bn 1972$)			
Agriculture, Non-Fuel Mining and Construction	249.6	257.3	-3.0
Manufacturing	808.9	832.5	-2.8
Transportation	99.0	101.2	-2.2
Services	1584.7	1601.3	-1.0
Energy	92.0	98.3	-6.4
(b) Output Prices (Price Indices, 1972 = 1.0)			
Agriculture, Non-Fuel Mining and Construction	6.489	6.457	0.5
Manufacturing	3.700	3.655	1.0
Transportation	3.137	3.099	1.2
Services	5.742	5.730	0.2
Energy	9.645	8.870	8.7
(c) Aggregate Input Coefficients			
Capital	.1988	.2005	-0.8
Labor	.1904	.1870	1.8
Energy	.0244	.0260	-6.2
Materials	.5863	.5865	0

TABLE 8-4

U.S. PRIMARY ENERGY INPUT IN 2000 IN THE LOW SOLAR/
HIGHER OIL PRICE SCENARIO
(Quadrillion Btu)

	New	Base	Change, %
Coal	35.95	39.56	-9.1
Petroleum	29.62	33.15	-10.6
Natural Gas	17.06	18.00	-5.2
Nuclear	13.00	15.03	-13.5
Hydro	3.80	3.80	0
Solar	2.00	2.00	0
Geothermal	0.60	0.50	20.0
Biomass	2.80	2.80	0
Total Primary Input	104.83	114.84	-8.7
Degree of Electrification(1) (%)	42.5	43.0	
Energy/GNP Rates(2)	39.26	42.19	-6.9
Imports of Petroleum(3)	9.89	13.84	-28.5

(1) Primary energy inputs used to produce electricity as a percent of total primary energy input.

(2) Thousand Btu/$(1972)

(3) Quadrillion Btu.

TABLE 8-5

ECONOMIC SUMMARY FOR THE MEDIUM SOLAR/
HIGHER OIL PRICES SCENARIO

	1985	1990	2000
Macroeconomic Output			
Real GNP (Billion 1972$)	1761.5	2036.1	2643.9
Change from Low Solar/ Higher Oil Price Scenario			
Percent	0	0	-1.0
Billion 1972$	0	0	-26.0
Real GNP Growth Rates[1]			
New	3.55	2.94	2.65
Low Solar/Higher Oil Price Scenario	3.55	2.94	2.75
Differences	0	0	-0.10
Macroeconomic Inputs			
Capital Stock			
Billion 1972$	4393.2	4933.6	5887.4
Percent change from Low Solar/Higher Oil Price Scenario	0	0	-0.8
Employment			
Millions	106.3	113.2	126.3
Percent change from Low Solar/Higher Oil Price Scenario	0	0	0
Gross Labor Productivity			
Thousand 1972$/person	16.57	17.99	20.93
Percent change from Low Solar/Higher Oil Price Scenario	0	0	-1.0

(1) Average percent per annum.

TABLE 8-6

COMPOSITION OF SPENDING IN THE MEDIUM SOLAR/
HIGHER OIL PRICE SCENARIO

	1985	1990	2000
Real GNP Components (Bn 1972$)			
Consumption	1135.1	1320.1	1704.5
Investment	261.4	293.6	372.7
Government	344.4	408.0	553.0
Net Exports	20.6	14.4	13.6
GNP	1761.5	2036.1	2643.9
Composition of Real GNP (%)			
Consumption	64.4	64.8	64.5
Investment	14.8	14.4	14.1
Government	19.6	20.0	20.9
Net Exports	1.2	0.7	0.5
GNP	100.0	100.0	100.0
Change from Low Solar/ Higher Oil Price Scenario (%)			
Consumption	0	0	-1.2
Investment	0	0	-1.9
GNP	0	0	-1.0

TABLE 8-7

ECONOMIC STRUCTURE IN 2000 IN THE MEDIUM SOLAR/ HIGHER OIL PRICE SCENARIO

	New	Low Solar	Change, %
(a) Final Demand Expenditure (Bn 1972$)			
Agriculture, Non-Fuel Mining and Construction	246.8	249.6	-1.1
Manufacturing	800.4	808.9	-1.1
Transportation	98.3	99.0	-0.7
Services	1571.0	1584.7	-0.9
Energy	85.6	92.0	-7.0
(b) Output Prices (Price Indices, 1972 = 1.0)			
Agriculture, Non-Fuel Mining and Construction	6.497	6.489	0.1
Manufacturing	3.702	3.700	0.0
Transportation	3.135	3.137	0.0
Services	5.750	5.742	0.1
Energy	9.617	9.645	-0.3
(c) Aggregate Input Coefficients			
Capital	.1999	.1988	0.6
Labor	.1905	.1904	0.1
Energy	.0242	.0244	-0.8
Materials	.5854	.5863	-0.3

TABLE 8-8

PRIMARY ENERGY INPUT FOR 2000 FOR MEDIUM SOLAR/ HIGHER OIL PRICE SCENARIO (Quadrillion Btu)

	New	Low Solar, Higher Oil Price Scenario	Change, %
Coal	34.42	35.95	-4.3
Petroleum	26.39	29.62	-10.9
Natural Gas	16.47	17.06	-3.5
Nuclear	12.84	13.00	-1.2
Hydro	3.80	3.80	0
Solar	7.27	2.00	263.5
Geothermal	0.60	0.60	0
Biomass	2.83	2.80	1.1
Total	104.62	104.83	-0.2
Degree of Electrification[(1)]	42.1	42.5	-0.9
Energy GNP Ratio[(2)]	39.57	39.26	0.8
Imports of Petroleum[(3)]	6.66	9.89	-32.7

[(1)] Proportion of total primary energy input used in electricity generation.

[(2)] Ratio of primary energy input to real GNP, thousand Btu/$(1972).

[(3)] Quadrillion Btu.

CHAPTER 9

CAPITAL EFFECTS OF SOLAR AND NEW TECHNOLOGY ENERGY SUPPLIES

The capital requirements of solar energy are substantial. This section is directed towards reviewing the magnitude of these capital requirements and examining them in the perspective of investment and capital in the economy as a whole. All capital stock figures are expressed in terms of depreciated capital stock in this chapter (see Appendix A for a discussion of how value of depreciated capital stock for solar and other new technologies was calculated).

The starting point in this analysis is the level of capital stock (each type of capital in each year) required to provide the energy supplies specified in the scenarios analyzed in this report. The capital stocks are given for three types of capital in Tables 9-1, 9-2, and 9-3. These give the level of installed capital stock, at five year intervals, for direct solar, for new technology electricity generation and for synthetic fuels. These capital stocks are in constant 1972 dollars and give aggregated capital in place <u>after allowing for depreciation</u>. Thus, by 2000, direct solar capital stock ranges from $27 bn, for the low penetration case, to $142 bn in the high penetration case. Similarly, capital stock in new technology electricity generation (solar, biomass and geothermal) ranges from $7 to

$119 billion. The capital absorbed in synthetic fuels is a function of the oil price. For the lower oil price, synthetic fuels account for $16 bn of capital stock in 2000; for the higher oil price the stock is $21 bn.

The sum of these depreciated capital requirements is given in Table 9-4. This gives total depreciated capital stock in direct solar, new technology electricity generation, and synthetics. For 2000, the total stock in 2000 is $50 bn (1972$) in the Low Solar (Lower Oil Price) Scenario; it is $276 bn (1972$) in the High Solar (Lower Oil Price) Scenario. These are substantial volumes of capital. The question arises as to their size relative to the total capital stock in the economy and, consequently, to their impact on the capital system.

Table 9-5 shows capital stock in the solar and new technology supply categories relative to total private capital stock in the economy. The projected capital stock for the base case (low solar, lower oil price) is given to indicate the magnitude of capital in the economy as a whole. Then, the new energy source capital stocks are expressed as percentages of the total projected capital stock in the corresponding simulation. Thus, the $50 bn (1972$) of new energy source capital in 2000 in the Low Solar, Lower Oil Price Scenario corresponds to 0.83% of total depreciated capital stock in the economy under these conditions. Similarly, in the high solar, lower oil price case, the year 2000 new energy source capital stock of $276 bn (1972$) accounts for 4.63% of total private capital stock in the economy.

These capital figures in fact overstate the differential capital requirements of moving from a low to a medium solar or from a low to a high solar future. There are two reasons for this overstatement:

- o the relevant solar and new technology energy supply capital cost is the differential due to increased penetration, not the absolute level. Therefore, the solar and new technology capital costs for the medium and high solar scenarios should be reduced by the capital costs required in the Base Case.

- o the capital absorbed in new supply sources should be reduced by the decline in capital required in conventional sources in order to find the net impact.

Allowance for these factors is made in Table 9-6. These adjustments reduce the overall capital impact of new energy technologies. In 2000, moving from low to medium new technology penetration involves a net capital requirements of about $50 bn (1972$), or 0.8% of total capital stock. Moving from low to high penetration involves net capital of $122 bn (1972$), or 2.0% of the total capital stock. These impacts are substantially less than the gross impacts considered above.

In net terms, therefore, the difference between the low and high penetration cases involves a capital cost of approximately $120 billion (1972$), or around 2% of the total private capital projected to be in place in 2000. Although $120 bn is a substantial figure in absolute magnitude, it is much less substantial in relative magnitude. The new sources program would appear, therefore, to have a noticeable but not catastrophic effect on the capital available in the economy. The diversion of 2% of total capital is unlikely to be enough to stop economic growth, although it is certainly enough to slow the rate of that growth. However, it must be recognized that this analysis is in terms of capital stock and a more meaningful perspective on this impact can be gained by examining the investment requirements of new energy sources. The investment, or rate of change of capital, perspective allows for the fact that there is currently almost no solar supply capital in place and that rapid investment is needed to have 2% of total capital in 2000 devoted to solar and other new technology energy supply. The next chapter, therefore, focusses on the investment impacts of new energy supply programs.

TABLE 9-1

DIRECT SOLAR CAPITAL STOCK LEVELS, 1977-2000
(CAPITAL STOCKS IN BILLIONS OF 1972$)

Year	Solar Market Penetration		
	Low	Medium	High
1977	0	0	0
1978	0.9	3.8	10.4
1985	1.9	8.0	22.1
1990	9.2	19.5	41.8
1995	20.4	53.4	104.2
2000	27.2	73.9	141.7

TABLE 9-2

NEW TECHNOLOGY CAPITAL STOCK IN ELECTRICITY GENERATION, 1977-2000
(CAPITAL STOCK FOR SOLAR, BIOMASS AND GEOTHERMAL
ELECTRICITY GENERATION; BILLIONS OF 1972$)

Year	Level of Market Penetration		
	Low	Medium	High
1977	0	0	0
1980	0.1	0.1	0.1
1985	0.3	0.3	1.0
1990	0.6	5.6	37.2
1995	4.5	30.4	87.1
2000	7.0	46.1	118.6

TABLE 9-3

CAPITAL STOCK IN SYNTHETIC FUELS, 1977-2000
(BILLIONS OF 1972$)

Year	Oil Price Level	
	Lower	Higher
1977	0	0
1980	0	0
1985	1.6	1.6
1990	7.5	7.5
1995	12.6	15.8
2000	15.8	20.7

TABLE 9-4

GROSS CAPITAL REQUIREMENTS OF SOLAR AND NEW TECHNOLOGY ENERGY SUPPLY SOURCES, 1977-2000[1]
(DEPRECIATED CAPITAL STOCK IN BILLIONS OF 1972$)

Year	Level of Solar Market Penetration		
	Low	Medium	High
1977	0	0	0
1980	1.0	3.9	10.5
1985	3.8	9.9	24.7
1990	17.3	32.6	86.5
1995	37.5	96.4	203.9
2000	50.0	135.8	276.1

[1] These figures are for the lower oil price case.

TABLE 9-5

SOLAR AND NEW TECHNOLOGY CAPITAL RELATIVE TO TOTAL CAPITAL (DEPRECIATED CAPITAL STOCKS IN BILLIONS OF 1972$)[1]

Year	Total depreciated capital stock, Base Case	Total Solar Capital Stock[2]					
		Low Solar		Medium Solar		High Solar	
		Stock[3]	%[4]	Stock	%	Stock	%
1977	3537	0	0	0	0	0	0
1980	3780	1	0.03	4	0.11	11	0.29
1985	4400	4	0.09	10	0.23	25	0.57
1990	4997	17	0.34	33	0.66	87	1.75
1995	5551	37	0.67	96	1.73	210	3.83
2000	6114	50	0.83	136	2.23	276	4.63

(1) These figures are for the lower oil price scenarios.

(2) Capital stock in solar residential, commercial and industrial energy sources; plus stock in solar, biomass and geothermal electric energy sources; plus capital in synthetic fuel supply.

(3) End of year total depreciated capital stock in place.

(4) Solar capital as a percentage of total private capital stock in the corresponding projection e.g. high solar capital as a percent of total private capital in the lower oil price, high solar projection.

TABLE 9-6

NET CAPITAL REQUIREMENTS OF SOLAR AND NEW TECHNOLOGY SUPPLY SOURCES IN 2000[1]

	Level of Solar Market Penetration	
	Medium	High
Gross New Source Capital, Bn 1972$	136	276
Less New Source Capital for Base Case, Bn 1972$	50	50
Differential New Source Capital, Bn 1972$[2]	86	226
Reduction in Conventional Capital, Bn 1972$, in: (3)		
Electricity	22	75
Coal, Petroleum, Gas	14	29
TOTAL:	36	104
Net Capital Requirements, Bn 1972$	50	122
Net Increase in Energy Capital Stock Relative to Base Case, as a % of All Capital	0.8	2.0

(1) These figures are for the lower oil price case.

(2) New source capital is, for the medium and high penetration cases, the differential relative to the low solar base case.

(3) Reduction in capital in conventional energy supply due to displacement, relative to the low penetration case, by new energy sources.

CHAPTER 10

INVESTMENT EFFECTS OF SOLAR AND NEW TECHNOLOGY ENERGY SUPPLIES

10.1 Gross Investment Effects

The magnitude of the capital requirements of solar and other new energy sources relative to the total capital stock in the economy gives a long run perspective on the capital effects of the new supply program. However, the transition to the long run situation is also important, and to assess this it is necessary to focus on the investment requirements (where investment is the rate of addition to capital stock) both in absolute magnitude and also relative to the investment flows in the economy as a whole.

The investment in solar energy under the three levels of solar penetration is given in Table 10-1.* This shows, for three time periods covering the entire period until 2000, the levels of investment in direct solar and in solar generation of electricity. For the low and medium market penetration scenarios, investment in direct solar substantially exceeds that in solar electric; for high penetration, the two types of investment are similar in magnitude. The investment over the 1977-2000 period averages from $2 bn (1972$) a year in the low penetration case up to $19 bn (1972$) annually for high penetration. The peak investment rates occur during the 1990's with the annual

*Data in this chapter refer to conditions under lower oil price assumptions unless stated otherwise.

average for this decade being $4 and $35 bn (1972$) for the low and high penetration cases, respectively.

The investment required for solar and other new technology energy sources is shown in Table 10-2. This investment covers biomass and geothermal electric and synthetic fuels, as well as direct solar and solar electric. These investments correspond to an annual average of from $4 bn in the low penetration case, to $10 bn in the moderate case, to $21 bn for high penetration (all in 1972$). Again, activity prior to 1985 is small, investment accelerates during the late 1980's and peaks during the 1990's. These peak investment rates range from $7 to $20 bn (1972$) annually for the low and high penetration rates, respectively.

These investment requirements are substantial in absolute terms. For any industry or even for the Federal government, annual investment levels of $20 bn (1972$) are certainly sizeable. However, the present analysis is concerned with the overall economic impacts of these investment programs. The relevant focus for this study is the size of this investment relative to investment in the economy as a whole.

Total investment occurring in the economy as a whole is given in Table 10-3 for the three different levels of solar penetration at the lower oil price. The total investment projections differ since the solar programs themselves, with their implied capital demands, affect economic productivity and the rate of sustainable economic growth. The new energy source investment requirements can now be viewed relative to the total investment flows in the economy. The relative magnitudes of these investment requirements are given in Table 10-4 for each of the three cases of solar market penetration. In the low penetration base case, new energy sources represent a very minor claim on the total investment stream: on average they absorb 1.3% of total investment with a peak, during the 1990's, of 1.8% of the total. In the medium penetration case, new energy sources extract a larger fraction of the investment flow--on average 3.3% with a peak, during the 1990's, of 5.0%. In the high penetration case, the investment requirements are still larger with 7% of investment, on average, being absorbed in new energy sources and with the fraction rising to 10% in the 1990's.

These are very sizeable investment requirements, even in relative terms. In particular, the diversion of 10% of total investment during the 1990's into new technology energy supply represents a very large economic impact. These investment requirements are in addition to those of conventional energy sources. (However, as considered below in Section 10.2, there is some reduction in conventional energy investment because of the expanded solar supply.)

A comparison with recent investment requirements for the electric power industry is instructive. The relative magnitude of electric power investment for the period 1965-77 is contained in Table 10-5. This shows that the conventional electric sector has, in recent years, absorbed 7 or 8% of total economic investment (including the totals for both energy and non-energy sector investments). Thus, the peak new technology investment requirements for the high solar scenario are larger relative to total economic investment than current investments for the entire electric energy sector.

It is also important to note that these new technology investments may occur in conjunction with increasing investment requirements for conventional energy supply sectors. Investment in the electric sector, which has recently increased rapidly as a fraction of total economic investment, may continue to increase in the future to the extent that higher real construction costs or more stringent environmental and safety regulations result in greater capital costs of generation capacity. In addition, depletion of conventional petroleum and gas sources may require heavy investment in these industries in order to tap the increasingly expensive supplies that will form the basis for future oil and gas production. In short, the solar and other new technology energy investment represents only a part of the total investment requirements for the energy sectors. When all these requirements are summed, 20 or even 25% of total investment may be absorbed in the energy system. This is a huge amount of investment for a sector that supplies only about 5% of the real output of the economy. The effect will be a diversion of investment away from the nonenergy sectors, slowing the rate of capacity growth in these sectors and the overall rate of growth of output in the economy.

10.2 Net Investment Effects

The investment impact of solar and other new technologies is slightly reduced if account is taken of the reduction in conventional energy investment made possible by the expanded solar supply.* Table 10-6 shows this calculation. Under conditions of lower oil prices, the low solar Base Case requires a total investment of $95 bn (1972$) for solar and new technology supply, or 1.3% of total economic investment over the 1978-2000 period. The medium penetration case involves a total net investment figure for solar and other new technology supply of $195 bn (1972$), about twice the investment requirements of the base case (2.7% of total economic investment vs. 1.3% for the base case). In the high penetration case, allowance for displacement of conventional energy investment reduces the investment requirements of solar and other new technologies for 1978-2000 from $505 bn to $367 bn (both in 1972$). This represents a reduction from 7.0% to 5.1% of total economy-wide investment when the net as opposed to the gross investment requirements of solar are considered.

*Recall that other new technology (i.e., geothermal and biomass electric and synthetic fuels) investment remains constant across all scenarios by assumption and, thus, no additional conventional energy sources are displaced by these technologies in the high or medium vs. low solar scenarios.

Thus, in comparison to the Base Case, the medium solar market penetration scenario requires that an additional 1.4% of total economic investment from 1977 to 2000 be diverted to the energy sector. For the high solar scenario compared to the Base Case, an additional 3.8% of total economic investment over the 1977 to 2000 period must be diverted to the energy sector to construct the solar technology capacity. These additional investments do not increase the total supply of energy available to the economy, but only maintain it, while further restricting the total investible funds available to the remaining production sectors.

The net peak investment requirements for solar energy are similarly large, particularly for the high solar scenario. During the 1990's, approximately 10% of all economic investment is claimed by new energy technologies in the high penetration case. When adjusted for the conventional energy investment displaced (high vs. low solar scenario), solar and other new technologies still require about 8% of all investment during the 1990's under the high solar market penetration conditions. To place this in perspective it can be noted from Table 10-5 that the large increase in electric utility investment that occurred in the early 1970's as a result of extra environment and safety related costs increased investment requirements by about 3% of total, economy-wide investment. The solar investment in the high penetration case represents more than double this impact. In addition, as noted above, this peak impact will occur at a time when the conventional energy sectors, in general, may be claiming an increasing percentage of total economic investment.

10.3 Conclusions

In view of these considerations, several conclusions emerge about the investment requirements of new energy technologies:

- o the investment requirements, particularly in the 1990's, are large in absolute magnitude;

- the net investment requirements of new technology energy supplies in the low penetration case average 1% of total investment, 3% of total investment in the medium penetration case and, in the high penetration case, 5% of the total, with peak requirements, during the 1990's, ranging up to 8% of the total;

- it is possible that new demands of up to 8% of total investment can be accommodated within the capital markets, but, particularly in conjunction with heavy investment likely elsewhere in the energy system, will represent a substantial additional demand, bidding up interest rates and diverting capital funds away from many nonenergy industries;

- these additional investment claims, by diverting investment from the nonenergy sectors of the economy, will slow the growth of capacity and of output in the economy in general (i.e., will impose a cost in terms of slower growth of output and incomes throughout the economy).

TABLE 10-1

INVESTMENT IN SOLAR ENERGY SUPPLY
(INVESTMENT IN BILLIONS OF 1972$)

	Solar Market Penetration								
	Low			Medium			High		
	D	E	Total	D	E	Total	D	E	Total
1977-84	2.8	0	2.8	11.6	0	11.6	32.0	0	32.0
1985-89	10.2	0	10.2	18.4	6.2	24.6	35.8	43.1	78.9
1990-2000	37.4	5.9	43.3	104.9	62.3	167.2	198.5	151.6	350.1
Total	50.4	5.9	56.4	134.9	68.5	203.4	266.4	194.7	461.1
Annual Average	2.1	0.3	2.4	5.6	2.9	8.5	11.1	8.1	19.2

D = Direct solar supply to the residential, commercial and industrial sectors.

E = Investment in solar generation of electricity (WECS, solar thermal, photovoltaics, OTEC)

Total = Investment in direct solar plus solar electric.

TABLE 10-2

INVESTMENT IN SOLAR AND NEW TECHNOLOGY ENERGY SOURCES, 1977-2000[1]
(INVESTMENT IN BILLIONS OF 1972$)

Oil Price	Lower	Lower	Lower	Higher	Higher
Solar Penetration	Low	Medium	High	Low	Medium
1977-84	5.2	14.0	35.4	5.2	14.0
1985-89	19.4	33.8	89.9	19.4	33.8
1990-2000	70.7	194.8	379.6	79.0	203.1
Total	95.3	242.6	504.9	103.6	250.9
Annual Average	4.0	10.1	21.0	4.3	10.5

[1] Includes direct and electric solar plus biomass electric, geothermal electric and synthetic fuels.

TABLE 10-3

TOTAL ENERGY AND NONENERGY
INVESTMENT, 1977-2000
(INVESTMENT IN BILLIONS OF 1972$)[1]

	Solar Market Penetration		
	Low	Medium	High
1977-84	1862	1862	1860
1985-89	1491	1491	1483
1990-2000	3952	3920	3822
Total	7305	7273	7165

(1) These projections are for the lower oil price cases.

TABLE 10-4

INVESTMENT IN SOLAR AND NEW TECHNOLOGY
ENERGY SOURCES RELATIVE TO TOTAL INVESTMENT, 1977-2000
(PERCENT OF TOTAL INVESTMENT)[1]

Level of Solar Market of Penetration	Low			Medium			High		
Type of Investment[2]	Solar	Other	Total	Solar	Other	Total	Solar	Other	Total
1977-84	0.2	0.1	0.3	0.6	0.2	0.8	1.7	0.2	1.9
1985-89	0.7	0.6	1.3	1.7	0.6	2.3	5.3	0.8	6.1
1990-2000	1.1	0.7	1.8	4.3	0.7	5.0	9.2	0.7	9.9
Total	0.8	0.5	1.3	2.8	0.5	3.3	6.4	0.6	7.0

(1) Energy investment for the specified level of penetration as a percentage of total investment in the economy for that solar penetration and for the lower oil price.

(2) Solar investment is that indirect solar and in solar electricity generation; other investment is in the remaining new technology sources: biomass and geothermal electricity generation, and synthetic fuels.

TABLE 10-5

ELECTRIC UTILITY INVESTMENT RELATIVE TO TOTAL INVESTMENT, 1965-1977

	Investment by Electric Utilities		Gross Investment	Electric as % of Gross Investment
	$ Bn	Bn 1972$	Bn 1972$	
1965	4.0	5.4	150.1	3.6
1966	4.9	6.4	161.3	4.0
1967	6.1	7.7	152.7	5.0
1968	6.1	8.6	159.5	5.4
1969	8.3	9.5	168.0	5.7
1970	10.1	11.1	154.7	7.2
1971	11.9	12.4	166.8	7.4
1972	13.4	13.4	188.3	7.1
1973	14.9	14.1	207.4	6.8
1974	16.4	14.1	180.0	7.8
1975	15.1	12.0	138.0	8.7
1976	17.0	12.7	173.0	7.3
1977	19.8	14.0	195.5	7.2

Sources: Edison Electric Institute Statistical Year Book for 1977. U.S. National Income and Product Accounts.

TABLE 10-6

NET INVESTMENT REQUIREMENTS OF SOLAR AND NEW TECHNOLOGY ENERGY SOURCES, 1977-2000[1]

	Level of Solar Market Penetration		
	Low	Medium	High
New Source Investment, Bn 1972$	95	243	505
Reduction[2] in Conventional Supply Investment, Bn 1972$ in			
Electricity	0	29	100
Coal, Petroleum, Gas	0	19	38
TOTAL:	0	48	138
Net Investment Requirements Total, Bn 1972$	95	195	367
Annual Average, Bn 1972$[3]	4.1	8.5	16.0
Relative to Total Investment %[3]	1.3	2.7	5.1

(1) Investment figures for the lower oil price case.

(2) Compared to the Low Solar, Base Case.

(3) Average over the period 1978-2000.

CHAPTER 11

MACROECONOMIC IMPACTS OF INCREASED SOLAR PENETRATION

The introduction of solar and other new technology energy supply programs can have a significant effect on overall U.S. economic performance. The previous chapters analyzed the economic impact of two higher levels of solar penetration, relative to a low solar Base Case, for lower (relatively) oil price conditions; and of one higher level of penetration, relative to a low solar reference case, for higher oil price conditions. This analysis showed that increased penetration of solar energy imposes a cost on the U.S. economy, in terms of slower growth of total income and output, and also leads to some restructuring of the economy. This chapter collects the information on macroeconomic impacts and analyzes its nature and its sensitivity both to the extent of the solar program and to oil price. For this analysis, a single indicator of impact is useful. Thus, real GNP is used for this purpose. While real GNP does not cover all dimensions of impact, it does cover real income (and its counterpart, real output or production) and so is an index of the performance of the economy and of total material standards of living. Given real GNP change as the impact measure, therefore, this chapter examines:

- The predicted macroeconomic impact of increased solar penetration;
- The size of this impact and its significance;

- The sensitivity of this impact to the magnitude of the solar energy program;
- The sensitivity of this impact to the level of oil prices.

The real GNP impacts of increased solar penetration for the lower oil price are summarized in Table 11-1. The first conclusion that is apparent from these figures is that increased penetration has an adverse effect on the economy -- as solar penetration increases real GNP decreases. The second set of conclusions concerns the relative magnitude of the impacts: an increased solar penetration will not prevent or even substantially slow the rate of economic growth. By 2000, real GNP is 0.9% lower in the medium solar case than in the Base Case; for the high solar penetration case the reduction is 2.9%. These reductions are not absolute declines over time -- i.e., it is not the case that the absolute level of GNP is less in one year than in the previous year due to the solar program. It is the case that the growth rate is slowed below what it otherwise would have been (i.e., in the Base Case). Over the 1990-2000 period for example, economic growth in the Base Case occurs at an average of 2.82% annually, in the medium solar penetration scenario this growth is slowed to 2.73% and for the high solar scenario it is further slowed to 2.60% (all scenarios at the lower oil price). Even at 2.60% annually, the economy continues to grow and material living standards continue to increase at a steady rate. In fact, for all three scenarios, under conditions of lower oil prices, GNP per capita increases by more than 60% (in real terms) from 1977 to 2000.

Thus, economic growth continues but at a somewhat reduced rate as a result of the introduction of these new energy supply technologies. The third set of conclusions concern the absolute magnitude of these macroeconomic costs. Even though the relative GNP reductions are small, they are still very significant in absolute magnitude. In 2000, compared to the Base Case, the reduction is $24 billion (1972$) in the shift to medium solar penetration and $78 bn (1972$) for high penetration. These are substantial costs, particularly when cumulated over time. Alternatively, a 3% relative GNP decline, such as is associated with the high penetration case in 2000, would be equivalent to a serious economic recession if it occurred within a short time span. (In fact, this relative cost is incurred in each of many years, not just in 2000.) Thus, when viewed in terms of conventional standards for recession and aggregate economic performance, the macroeconomic effects of solar energy are highly significant. While the economy can sustain such costs and still grow, the cost in lost growth or lost income and output is still large.

The comparable macroeconomic summary for the impact of new energy technologies in higher oil price conditions is given in Table 11-2. A similar set of conclusions emerges from these figures. First, the impact is adverse, as the real GNP differences resulting from increased solar penetration are either zero or negative. Second, the impacts are small in relative size--by 2000, real GNP under medium solar penetration is only 1.0% less than it would have been in the low solar case, and average economic growth during the 1990's is slowed only from 2.75% in the Base Case to 2.65%. These impacts are sustainable in that economic growth is not prevented and the economy is not seriously disrupted. Third, the absolute magnitude of the impacts is still significant--in 2000, the real GNP reduction is $26 billion (1972$) and the cumulative effect over time is still larger. Again, therefore, the impacts are non-trivial, even though they are sustainable.

At both oil price levels the absolute magnitude of these real GNP reductions warrants further discussion. The total reduction over time is a more complete indicator of this effect than the reduction just in 2000. In Table 11-3, therefore, several measures of this overall cost are developed. The first measure is the sum, over the entire 1977 to 2000 time period, of the reduction in real GNP. This total comes to $85 billion (1972$) for the medium case (vs. the Base Case) and $413 bn (1972$) for the high penetration case (vs. the Base Case). It is probably more meaningful, however, to take the time pattern of these impacts into account and this can be done by discounting, calculating the total present value of the reductions. This is done in the second row of the table which gives the present value to 1980, using a 5% real discount rate, of the stream of real GNP reductions.* The lower oil price, medium solar case involves a total present value cost of $37 bn (1972$) while the high penetration case involves $202 bn (1972$) in present cost.

These figures can be placed in perspective in several ways. One is to relate them to the size of the economy in 1980--real GNP in 1980 is projected to be approximately $1500 bn (1972$) so these costs correspond to 2% and 13%, respectively, of the entire income or production generated in the U.S. in 1980. Another way is to express the cost in an equivalent tax levied on every household or family in the U.S. in 1980. The result is a tax of $667 for the medium solar case and $3648 (1972$) for the high penetration case. This lump sum tax corresponds, in turn, to increases in average income tax payments, of about 25% and 140% respectively. Alternatively, the average household expenditure on energy for all non-transportation purposes in 1977 was $602. Therefore, the economic cost for new supply sources is, even in the medium penetration case, approximately equal to the entire annual cost of energy for the average household. When viewed in any of these ways it is clear that the general economic cost associated with increased use of solar energy is, especially for the high penetration case, very substantial.

---

*The appropriate discount rate for this present value calculation is that relating to the trade-off between present and future consumption. A real rate of 5%, corresponding to a nominal rate of about 10-12%,is used to represent this tradeoff.

The macroeconomic cost of solar energy may be sensititve to the scale of the solar program. Thus, the overall economic cost per Btu of energy provided may well be greater for a large scale than for a small scale solar supply program. This issue is addressed in the figures presented in Table 11-4. These figures relate the real GNP loss in each year to the Btu's of solar energy supplied in the year 2000. Here, the real GNP loss per million Btu of solar energy supplied is $4.60 (1972$) for the medium penetration case and $5.40 (1972$) for the high penetration case. This shows a non-proportional relationship, with more extensive solar programs involving relatively greater economic cost. A broader measure can be gained by viewing the present value of the time stream of GNP losses in relation to the solar energy supplied. This information is given in the last line of Table 11-3 which shows a present value of cost in 1972$ per million Btu of solar energy in 2000 of $7.00 and $13.90 for the medium and high penetration cases, respectively. This shows a still greater proportional cost for increasing scales of solar supply programs. These figures imply, therefore, that the macroeconomic cost of solar supply programs rises more than in proportion to the quantity of energy supplied.

Similarly, the macroeconomic cost of solar supply programs may be dependent on the level of oil prices. Table 11-5 provides the information needed to assess this sensitivity. Here it emerges that the relative GNP impact caused by a shift from low to medium solar penetration is very close to 1.0% regardless of whether lower or higher oil prices prevail. This suggests that the overall effects of solar energy are not sensitive to the world price of oil. (There are some issues in the energy specifications of these simulations which might have clouded this issue. In particular, the NPAC1 energy numbers in the higher oil price case showed a large reduction in coal and nuclear generation of electricity compared to the lower oil price case. This would have reduced the conventional capital required in the higher oil price scenarios. For these reasons, the oil price sensitivity result should be viewed as being characterized by considerable uncertainty.)

These various aspects of the macroeconomic effects of increased solar penetration can now be summarized in a set of conclusions:

- Increasing solar and new energy supply technology penetration will involve economic costs for the U.S. in the sense of slower growth of total incomes and output;
- The relative magnitude of these costs is such that economic growth continues, although at rates somewhat below those projected in the absence of increased penetration of solar energy. In all cases, however, regardless of the level of solar market penetration, GNP per capita in real terms increases significantly over current levels by the year 2000;
- The absolute magnitude of these costs, for example, as expressed in terms of an equivalent lump sum tax, are significant;
- This implies that a solar program is sustainable in the sense that it will slow but not prevent economic growth. However, it still involves substantial costs to all segments of the country and the economy;
- The macroeconomic cost per Btu of energy delivered rises with the scale of a new technology supply program.

The policy conclusions following from these results should recognize the trade-off involved with solar energy. Given the current and future costs for solar and other new energy supply technologies used in this study, the policy conclusions might be stated:

- A solar program does involve non-trivial economic costs in the sense of real income and production foregone;
- A solar program may involve other benefits, in terms of (possible) improved environ-

mental conditions surrounding energy supply and in terms of decreased dependence upon imported oil;

- The overall desirability of a solar program involves the comparison of these two facets, the costs and the benefits, to estimate whether the program is justified in broader social and economic interests;

- The fact that the economic cost of solar, per Btu produced, rises rapidly with increases in the scale of a solar program implies that additional research directed to lowering the capital costs of solar energy would be worthwhile prior to any widespread adoption of those solar and other new technology energy sources which are more expensive that the conventional technologies they replace.

TABLE 11-1

REAL GNP IMPACTS OF SOLAR AND NEW ENERGY TECHNOLOGIES IN LOWER OIL PRICE CONDITIONS

	1985	1990	2000
Real GNP, Billion 1972$			
Base Case (Low solar)	1773.3	2060.2	2721.7
Medium Solar	1773.3	2060.2	2697.3
High Solar	1769.4	2044.3	2643.6
Difference from Base Case, Billion 1972$			
Medium Solar	0	0	-24.4
High Solar	-3.9	-15.9	-78.1
Difference from Base Case, %			
Medium Solar	0	0	-0.9
High Solar	-0.2	-0.8	-2.9
Real GNP Growth Rates (1)			
Base Case	3.64	3.05	2.82
Medium Solar	3.64	3.05	2.73
High Solar	3.61	2.93	2.60

(1) Average percent per annum.

TABLE 11-2

REAL GNP IMPACTS OF SOLAR AND NEW ENERGY TECHNOLOGIES IN HIGHER OIL PRICE CONDITIONS

	1985	1990	2000
Real GNP, Billion 1972$			
Reference Case (Low Solar)	1761.5	2036.1	2669.9
Medium Solar	1761.5	2036.1	2643.9
Difference from Reference Case			
Billion 1972$	0	0	-26.0
Percent	0	0	-1.0
Real GNP Growth Rates [(1)]			
Reference Case	3.55	2.94	2.75
Medium Solar	3.55	2.94	2.65

[(1)] Average percent per annum

TABLE 11-3

MACROECONOMIC IMPACTS OF INCREASED SOLAR PENETRATION, 1977-2000 (1)

	Medium Solar Penetration	High Solar Penetration
Total Real GNP Loss, 1977-2000 Billion 1972$ (2)	85.5	413.1
Present Value of the Real GNP Loss (to 1980, in bn 1972$, using a 5% discount rate)	37.0	202.4
Lump Sum Cost Equivalent per Family in 1980, $ (3)	667	3648
Present Value of Cost per 10^6 Btu in 2000 of Solar Energy (4)	7.0	13.9

(1) These impacts are for the lower oil price conditions.

(2) Reduction relative to the Low Solar Base Case.

(3) Total present value to 1980, converted to current, i.e. 1980, dollars, per family where a family is taken as an average household of 2.3 people.

(4) Total present value to 1980 divided by Btu primary energy supply from solar and biomass in 2000, (1972$)/million Btu.

TABLE 11-4

SENSITIVITY OF REAL GNP IMPACTS OF SOLAR ENERGY TO THE LEVEL OF SOLAR ENERGY (DIFFERENT IMPACTS FOR THE LOWER OIL PRICE CASE)

	1985	1990	2000
Real GNP Reduction, Billion 1972$, Relative to Base Case			
Medium Solar	0	0	-24.4
High Solar	-3.9	-15.9	-78.1
New Technology Energy Supply, Quadrillion Btu, Relative to Base Case (1)			
Medium Solar	0.3	0.8	5.3
High Solar	0.9	3.3	14.6
Real GNP Reduction Per Quadrillion Btu of New Supply (2)			
Medium Solar	0	0	-4.6
High Solar	-4.3	-4.8	-5.4

(1) Total primary energy input for solar and biomass sources relative to that in the low solar, lower oil price Base Case.

(2) Billion 1972$ per Quadrillion Btu.

TABLE 11-5

SENSITIVITY OF REAL GNP IMPACTS OF SOLAR ENERGY TO THE OIL PRICE

	1985	1990	2000
Real GNP Reduction, Billion 1972$, for Medium Solar with			
Lower Oil Price	0	0	-24.4
Higher Oil Price	0	0	-26.0
Real GNP Reduction, Percent, for Medium Solar with			
Lower Oil Price	0	0	-0.9
Higher Oil Price	0	0	-1.0

APPENDIX A

EXOGENOUS SECTOR CAPITAL STOCK INPUTS TO THE HUDSON-JORGENSON MODEL

In Chapter 5, total capital investment requirements were developed for selected energy supply technologies. For most electric technologies--including fossil fuel, large-scale hydroelectric, and nuclear technologies--capital investment requirements can be input to the Hudson-Jorgenson energy/economic model directly through the model's electric sector submodel. However, for the other technologies considered in Chapter 5, exogenous estimates of depreciated capital stock in selected forecast years had to be developed for input to the model. This chapter explains the procedure for developing these inputs and the resulting estimate of depreciated capital stock for each year.

A.1 Procedures

Estimates for depreciated capital stock for future years had to be developed exogenously for the following technology groups:

- residential, commercial, and industrial on-site solar technologies (including small-scale hydro);
- utility-owned geothermal electric, biomass electric and solar electric technologies;
- synthetic fuels.

The following procedure was used to transform total capital investment for each of the technologies for each of the five scenarios (i.e., see Tables 5-1 through 5-3, 5-14 through 5-18, and 5-19) into estimates of depreciated capital stock for selected future years (i.e., 1978, 1980, 1985, 1990, 1995, and 2000):

- First, it was assumed that investment per year within each of the three sub-periods (1978-85, 1986-90, and 1991-2000) during the overall forecast period (1978-2000) was equivalent in dollar terms for each technology. Thus, for example, total capital investment, in dollars, for residential on-site solar technologies was the same in 1978 as in 1979, 1980, etc., through 1985. The annual investment was derived by dividing total investment in that period by 8 (the number of years 1978-85, inclusive). Likewise, annual investment in the 1986-90 period for each technology was derived by dividing total investment in that period by 5.

- Second, to simulate in simplified form the effect of continuous investment throughout the year, one-half of the investment for each year was assumed to be made on January 1 of that year and one-half on December 31. This allocation was necessitated by the transformation of gross investment to depreciated capital stock (see below).

- Third, tax depreciation schedules were used to define asset depreciation lifetimes for each technology. These lifetimes are set forth in Table A-1.

- Fourth, the double-declining balance method of depreciation was used to transform total annual capital investment for each technology for each year. The double declining balance method is compatible with the asset depreciation algorithmns utilized in the Hudson-Jorgenson model.

The resulting depreciated capital stock estimates are presented in Table A-2 through A-6 for each of the five scenarios. These estimates were used as inputs to the model. Note that these estimates presented represent depreciated capital stock at the end of each year noted.

TABLE A-1

ASSET DEPRECIATION LIFETIMES USED IN THIS ANALYSIS

TECHNOLOGY	ASSET DEPRECIATION LIFETIME IN YEARS	SOURCE FOR SOURCE INFORMATION	COMMENTS
Geothermal Electric	20	IRS*	Equivalent to average for Asset Depreciation Lifetimes for nuclear and combustion electric power plants (the shortest depreciation lifetimes among all electric power plant types)
Coal-Based Synthetic Fuels	18	IRS	Equivalent to Average Asset Depreciation Lifetime for Substitute Natural Gas-Coal Gasification plants.
Biomass Syncrude	18	NPAC 1**	NPAC 1 Market Analysis used 19 years, this was decreased by 1 year for computational compatibility with coal-based synthetic fuels.
Biomass Synthetic Fuels (except Biomass Syncrude)	23	NPAC 1	
Solar On-Site Residential/ Commercial	20	Average Equipment Lifetime	For depreciation purposes, Solar On-Site Residential/ Commercial asset lifetimes was assumed to be equal to the assumed lifetime for this equipment.
Solar On-Site Industrial (including small-scale hydroelectric)	23	IRS	Equivalent to lower limit of asset depreciation lifetime for industrial steam and electric generation systems
Solar Electric (Utility-Owned)	23	NPAC 1	
Biomass Electric	20	NPAC 1	

*IRS = IRS Publication 534, Tax Information on Depreciation, 1978

**NPAC 1 = Unpublished Market Analysis Documentation developed for NPAC 1.

TABLE A-2

TOTAL VALUE OF DEPRECIATED CAPITAL STOCK, BY SECTOR
LOW SOLAR, LOWER OIL PRICE SCENARIO
(in billions of 1972$)

Year	Solar Residential, Commercial, Industrial Investment	Solar, Biomass and Geothermal Electric Investment	Synthetic Fuels Investment
1977	0.0	0.0	0.0
1978	.323	.047	0.0
1980	.875	.129	0.0
1985	1.871	.280	1.567
1990	9.193	.578	7.461
1995	20.404	4.542	12.625
2000	27.163	6.968	15.765

TABLE A-3

TOTAL VALUE OF DEPRECIATED CAPITAL STOCK, BY SECTOR
MEDIUM SOLAR, LOWER OIL PRICE SCENARIO
(in billions of 1972$)

Year	Solar Residential, Commercial, Industrial Investment	Solar, Biomass and Geothermal Electric Investment	Synthetic Fuels Investment
1977	0.0	0.0	0.0
1978	1.382	.047	0.0
1980	3.764	.129	0.0
1985	8.020	.280	1.567
1990	19.516	5.563	7.461
1995	53.438	30.425	12.625
2000	73.859	46.138	15.765

TABLE A-4

TOTAL VALUE OF DEPRECIATED CAPITAL STOCK, BY SECTOR
HIGH SOLAR, LOWER OIL PRICE SCENARIO
(in billions of 1972$)

Year	Solar Residential, Commercial, Industrial Investment	Solar, Biomass and Geothermal Electric Investment	Synthetic Fuels Investment
1977	0.0	0.0	0.0
1978	3.801	.047	0.0
1980	10.373	.129	0.0
1985	22.104	1.028	1.567
1990	41.821	37.151	7.461
1995	104.225	87.054	12.625
2000	141.670	118.617	15.765

TABLE A-5

TOTAL VALUE OF DEPRECIATED CAPITAL STOCK, BY SECTOR
LOW SOLAR, HIGHER OIL PRICE SCENARIO
(in billions of 1972$)

Year	Solar Residential, Commercial, Industrial Investment	Solar, Biomass and Geothermal Electric Investment	Synthetic Fuels Investment
1977	0.0	0.0	0.0
1978	.323	.047	0.0
1980	.875	.129	0.0
1985	1.871	.280	1.567
1990	9.193	.578	7.461
1995	20.404	4.542	15.781
2000	27.163	6.968	20.671

TABLE A-6

TOTAL VALUE OF DEPRECIATED CAPITAL STOCK, BY SECTOR
MEDIUM SOLAR, HIGHER OIL PRICE SCENARIO
(in billions of 1972$)

Year	Solar Residential, Commercial, Industrial Investment	Solar, Biomass and Geothermal Electric Investment	Synthetic Fuels Investment
1977	0.0	0.0	0.0
1978	1.382	.047	0.0
1980	3.764	.129	0.0
1985	8.020	.280	1.567
1990	19.516	5.563	7.461
1995	53.438	30.425	15.781
2000	73.859	46.138	20.671

☆U.S. GOVERNMENT PRINTING OFFICE: 1980 -640-258/ 2044