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for the U.S. Department of Energy
Solar Thermal Technology Division

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Solar Thermal Technology Development: Estimated Market Size and Energy Cost Savings

Volume II - Assumptions, Methodology, and Results

W. R. Gates



February 1983

Prepared for
U.S. Department of Energy
and Sandia National Laboratories, Livermore
Through an Agreement with
National Aeronautics and Space Administration
by
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

JPL Publication 83-14

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ABSTRACT

Estimated future energy cost savings associated with the development of cost-competitive solar thermal technologies (STT) are discussed. Analysis is restricted to STT in electric applications for 16 high-insolation/high-energy-price states. Three fuel price scenarios and three 1990 STT system costs are considered, reflecting uncertainty over future fuel prices and STT cost projections.

Solar thermal technology research and development (R&D) is found to be unacceptably risky for private industry in the absence of Federal support. Energy cost savings are projected to range from \$0 to 10 billion (1990 values in 1981 dollars), depending on the system cost and fuel price scenario. Normal R&D investment risks are accentuated because the Organization of Petroleum Exporting Countries (OPEC) cartel can artificially manipulate oil prices and undercut growth of alternative energy sources. Federal participation in STT R&D to help capture the potential benefits of developing cost-competitive STT was found to be in the national interest.

Analysis is also provided regarding two Federal incentives currently in use: the Federal Business Energy Tax Credit and direct R&D funding. These mechanisms can be expected to provide the required incentives to establish a viable self-sustaining private STT industry. Discussions of STT impacts on the environment and on oil imports are also included.

FOREWORD

The Jet Propulsion Laboratory's Benefits Assessment Task has responsibility for evaluating the benefits and impacts associated with the successful development of cost-competitive solar thermal energy technologies. During 1981, the Benefits Assessment Task focused on developing a methodology to assess the potential economic and social benefits associated with solar thermal electric systems. During 1982, efforts centered on refining the benefit assessment methodology. The computer model was modified to allow reoptimization of the conventional generating capacity with increases in the level of solar penetration; the data base was updated to include revised regional synthetic utilities; and the analytical assumptions were updated to reflect changes in tax laws and other factors.

The results of the FY 1981 analysis were reported in JPL Publication 82-70, Solar Thermal Technologies Benefits Assessment: Objectives, Methodologies, and Results for 1981. The results contained in the 1981 report were updated in FY 1982 and are superseded by the results presented here.

This report is divided into two volumes. Volume I is an Executive Summary, and Volume II contains the detailed assumptions, methodology, results, and discussion of the study.

ACKNOWLEDGMENT

The work described in this report was performed during FY 1982 by the Benefits Assessment Task of the Solar Thermal Planning and Information Project at the Jet Propulsion Laboratory (JPL), California Institute of Technology. It was sponsored by the Solar Thermal Technical Program Integrator at Sandia National Laboratories-Livermore (SNLL), for the U.S. Department of Energy's Solar Thermal Technology Division through an agreement with the National Aeronautics and Space Administration. (Task RE-152, Amendment 354; Sandia Order 92-9714.)

This analysis involved the collaborative efforts of many individuals at JPL and SNLL. Katsuaki Terasawa established the basis for the methodology and provided insights for interpreting the results. Hamid Habib-agahi assisted in formulating the approach, conducting the analytical work, and interpreting the results. Michael Davisson developed the computer program used in the utility simulations and provided the data required to conduct the simulations. Michael Guth assisted with the utility simulations and examined the impact of solar thermal electric systems on U.S. oil imports. Robert Gershman conducted the regional environmental analysis. E.S. (Ab) Davis, Richard O'Toole, and Julia Sheldon of JPL and Patrick Eicker and Joan Woodard of SNLL provided feedback during the effort which improved the quality and clarity of the results. Susan Elrod typed the many drafts of this report and drew the figures supplementing the text. Peggy Panda edited and prepared the text for publication. Any remaining errors, omissions, misrepresentations, or misinterpretations are the responsibility of the author.

CONTENTS

1. INTRODUCTION 1-1

 1.1 STT IN ELECTRIC UTILITY APPLICATIONS 1-3

 1.2 SCOPE OF WORK 1-5

2. OVERVIEW 2-1

 2.1 OBJECTIVES 2-1

 2.2 METHODOLOGY 2-1

3. IMPACT IDENTIFICATION 3-1

 3.1 DIRECT IMPACTS 3-1

 3.2 INDIRECT IMPACTS 3-2

 3.3 PRIMARY IMPACTS 3-4

 3.4 BENEFICIARIES 3-4

4. THE DEMAND FOR STT 4-1

 4.1 ASSUMPTIONS 4-2

 4.1.1 Insolation Levels 4-2

 4.1.2 Fuel Price Projections Under Uncertainty 4-2

 4.1.3 Utility Characteristics 4-7

 4.1.4 Financial Parameters 4-11

 4.1.5 Inter-Technology Competition 4-11

 4.1.6 1990 Installations 4-11

 4.2 METHODOLOGY 4-15

 4.3 1990 STT DEMAND 4-17

5. THE COST OF STT: EVALUATION METHODOLOGY 5-1

 5.1 STT COST GOALS 5-1

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6.	RESULTS: 1990 STT ECONOMIC MARKET POTENTIAL AND ENERGY COST SAVINGS	6-1
6.1	1990 STT ECONOMIC MARKET POTENTIAL	6-1
6.2	ENERGY COST SAVINGS	6-1
6.3	STT, THE TRANSITION TO COAL, AND THE EPRI SYNTHETIC UTILITIES	6-6
7.	EARLY MARKETS FOR SOLAR THERMAL ELECTRIC SYSTEMS	7-1
7.1	FAVORABLE GRID-CONNECTED ELECTRIC UTILITIES	7-1
7.2	REMOTE SITE APPLICATIONS	7-4
7.3	THIRD PARTY OWNERSHIP	7-4
7.4	STORAGE-COUPLED SOLAR THERMAL ELECTRIC SYSTEMS	7-12
8.	FEDERAL PARTICIPATION IN THE DEVELOPMENT OF STT	8-1
8.1	IMPLICATIONS FOR PRIVATE-SECTOR INVESTMENT	8-1
8.1.1	Fuel Price Uncertainty	8-1
8.1.2	OPEC Control	8-1
8.1.3	Public Versus Private Objectives	8-3
8.2	CURRENT FEDERAL INCENTIVES	8-3
9.	CONCLUSIONS	9-1
	REFERENCES	R-1
APPENDIXES		
A.	INDIRECT IMPACTS	A-1
B.	DERIVATION OF EQUATIONS	B-1
C.	EIA FUEL PRICE PROJECTIONS: IMPACT OF WORLD OIL PRICES ON THE DOMESTIC PRICE OF NATURAL GAS	C-1

Figures

1-1.	Demand for Fuels and Power by Sector	1-2
2-1.	Elements of the Benefits Assessment Study	2-2
4-1.	Average Fuel Price Escalation Rates	4-6
4-2.	Projected Electric Utility Demand for Fuel by Source	4-8
4-3.	1990 Incremental Value of Solar Thermal Electric Systems	4-18
4-4.	The Value of STT: Fuel Versus Capacity Credits	4-19
6-1.	1990 Market Potential for Cost-Competitive Solar Thermal Electric Systems	6-2
6-2.	1990 STT Net Energy Cost Savings: Medium Fuel Prices	6-4
6-3.	1990 Solar Thermal Electric Capacity and Life-Cycle Coal Displacement	6-7
7-1.	STT Value and the Percentage of Coal Displacement	7-2
7-2.	Net Energy Cost Savings and the Percentage of Coal Displacement	7-3
7-3.	Third Party Financing Before TEFRA	7-7
7-4.	Third Party Financing After TEFRA	7-9
7-5.	STT Value and Third Party Financing in California	7-11
7-6.	1990 Incremental Value of STT with Storage	7-14
8-1.	Baseline Imported Crude Oil Price Forecasts	8-2
8-2.	1997 STT Value and the Percentage of Coal Displacement	8-5

Tables

2-1.	Summary of Assumptions Used in Analysis	2-4
4-1.	Regional Variations: Insolation Levels and States Considered	4-3
4-2.	Fuel Price Assumptions	4-5
4-3.	EIA/NEP-III Scaling Factors	4-7
4-4.	Utility Capacity Expansion Plan: No-Solar Base Case	4-10

4-5.	2019 "Optimal" Generating Capacity: Region A (Western) . . .	4-12
4-6.	2019 "Optimal" Generating Capacity: Regions B and C (South Central)	4-13
4-7.	Regional Generating Plant Characteristics	4-14
4-8.	Financial Parameters for an Investor-Owned Utility	4-15
6-1.	Total Net Energy Cost Savings of Solar Thermal Electric Systems	6-5
6-2.	EPRI Regional Utility Systems: Peak Electricity Demand . . .	6-9
7-1.	Financial Parameters: Third Party Investors and Investor-Owned Utilities	7-6
7-2.	State Income Tax Incentives for Solar Energy	7-10

SECTION 1

INTRODUCTION

Federal participation in solar thermal technology research and development (R&D) is in the national interest. Prior to the 1970s, Federal energy R&D expenditures were limited, with the exception of R&D for nuclear-fired electrical generating capacity. However, the 1973 Arab oil embargo and the 1978/79 Iranian oil supply curtailments focused attention on the precarious nature of a domestic energy market relying heavily on imported petroleum resources. Widespread public and political support has developed a national energy policy designed to solve the "energy crisis" in a manner consistent with the overall objectives for the U.S. economy. The resulting energy policy stresses reducing petroleum dependence in the near-term through conservation, augmented in the mid- to long-term by the development of a broad range of alternative energy technologies. In the presence of technical, economic, and environmental uncertainties concerning future energy supply technologies, a diversified R&D portfolio increases the probability of successfully developing domestic energy resources capable of satisfying a broad range of future energy demands without imposing excessive environmental hazards. Due to the scope of the effort required to develop new energy technologies, the market imperfections characterizing the domestic energy supply and demand sectors, and the Organization of Petroleum Exporting Countries (OPEC) cartel's control over world energy prices, private industry is unlikely to invest the required resources in the development of alternative energy systems (Ref. 1). As a result, the Federal government has embarked on a vigorous R&D effort to develop conservation technologies and unconventional energy sources, including solar energy.

Solar thermal technologies (STT) represent an important component of the Federal solar energy R&D program. Solar thermal power systems differ technologically in many important ways from other conventional and alternative energy systems. Therefore, STT diversifies the Federal energy R&D portfolio. Furthermore, Federal energy R&D programs in the post-1973 period have concentrated primarily on developing alternative technologies for the generation of electricity. Primary emphasis in the development of coal and nuclear technologies, for example, centers on the use of these resources in electric applications. Similarly, many solar energy technologies, including photovoltaics and wind systems, produce electricity as their primary output. The electric utility sector, however, is projected to account for only 35 to 40% of the total energy consumption in the United States through the end of this century (Figure 1-1). Significant progress toward diversifying the nation's energy resources requires technologies that directly serve the household and commercial sector, the industrial sector, and the transportation sector, in addition to the electric utility sector.

Solar thermal energy systems represent such a technology. Solar thermal energy provides a renewable domestic source of power that can be used to generate electricity, heat, or can serve in a total energy capacity to provide both electric and thermal power. Therefore, STT can be employed in a variety of sectors including electric utilities, industries requiring thermal power, and agricultural applications. In the future, STT may also be used to produce

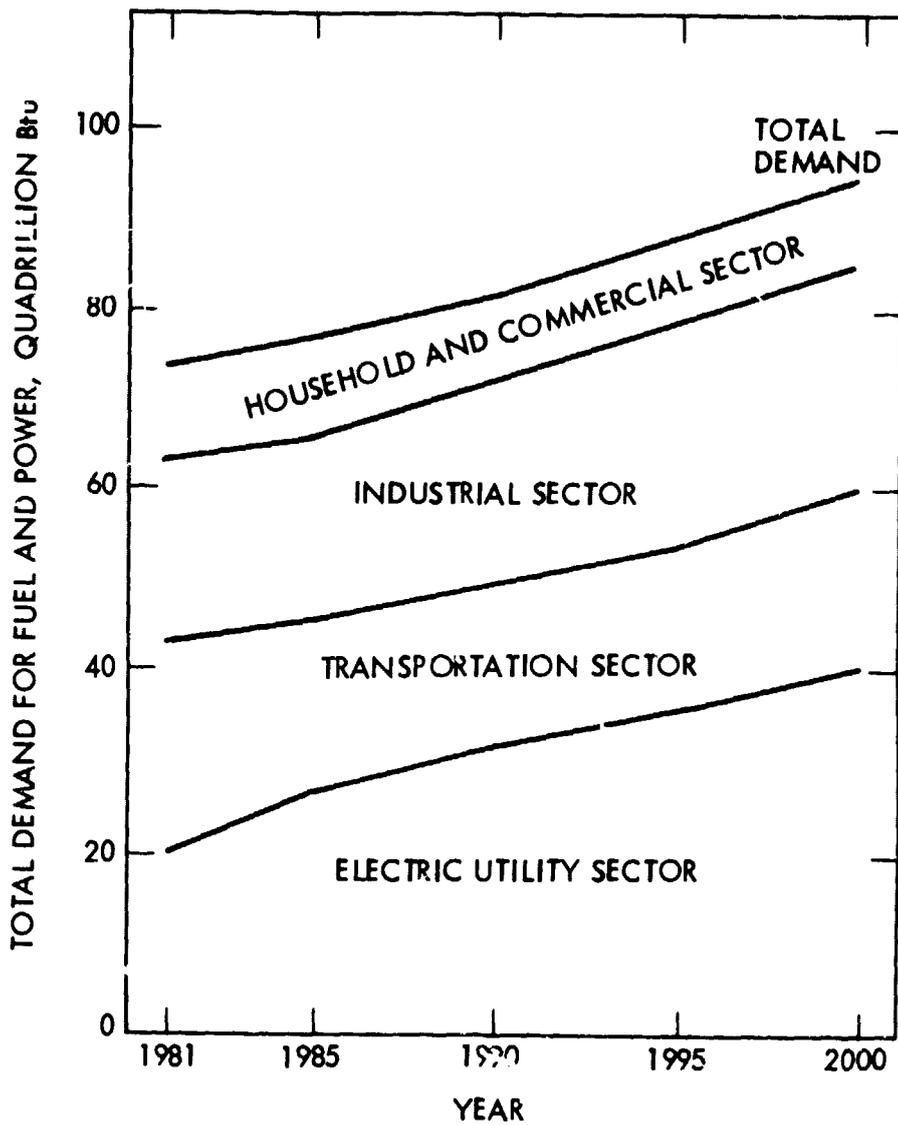


Figure 1-1. Demand for Fuels and Power by Sector
 (Ref. 8, Tables A-68 to A-75, pp 212-219)

transportable fuels and chemical feedstocks. Furthermore, solar thermal energy can be supplied by systems ranging in size from tens of kilowatts (kW) to hundreds of megawatts (MW). This flexibility of system size requirements and range of applications enables STT to satisfy many categories of energy demand.

Solar thermal conversion processes also exhibit varying degrees of technological and commercial readiness. Some systems, notably water and space heating, have virtually completed the R&D required prior to market-entry, and represent near-term technologies. Other systems, such as solar thermal electric technologies, still require additional R&D before they can be introduced into mid- or long-term markets. Therefore, solar thermal technologies can provide cost-competitive systems for both near-term and far-term deployment.

The Solar Thermal Technology Program's practical impetus is to learn how complete STT systems work and how they function at the interface with industrial plants and electric grids and then to disseminate these data. Accomplishing these objectives will assist in forming the technological base of an STT industry founded in the national interest. Historically, the STT Program has supported three types of activities: (1) R&D to reduce costs and to ensure that long-term market growth continues, (2) systems applications experiments to enhance awareness of STT, thereby stimulating private demand that will result in further system cost reductions through volume production, and (3) Federal financial incentives to speed the near-term deployment of STT systems (Refs. 2 and 3). Recently, however, with the institution of current Federal solar tax credits, as well as petroleum and natural gas price deregulation, the emphasis of the program has shifted from systems applications experiments to longer-range R&D projects, which, when compared to their expected level of benefits, exhibit excessive risks to private investors but acceptable risks to society as a whole (Refs. 4 and 5).

While the Federal STT Program is concerned with a variety of applications, attention in this analysis has been restricted to solar thermal technologies in electric utility applications. This task will identify the future economic and social impacts attributable to the development of solar thermal electric systems. A partial list of these impacts will be evaluated to determine their net present value. The expected benefits must be understood to identify high payoff R&D projects, to determine the optimal allocation of the limited R&D budget across technology options, and to ensure that the proposed level of Federal participation in the development of STT is both economically justified and consistent with the Administration's stated policy for solar energy R&D.

1.1 STT IN ELECTRIC UTILITY APPLICATIONS

As outlined previously, an excessive reliance on imported petroleum is frequently perceived as a major cause of the 1973 "energy crisis." In the electric utility industry, for example, generating capacities prior to 1973 included a high proportion of petroleum-fired technologies for use in base, intermediate, and peaking applications (Refs. 6 and 7). As a result of the 1973 Arab oil embargo, a variety of Federal policies have been implemented in an effort to reduce the use of petroleum as a fuel source. Conservation has been encouraged to lower electricity consumption in general, and alternative

domestic energy technologies are being developed to replace petroleum-based systems. Due to the dwindling reserves of natural gas in the United States (Ref. 7, pp 40, 41), efforts were initiated to reduce domestic consumption of this resource as well. Coal and nuclear technologies have been particularly successful in displacing petroleum and natural gas technologies for base-load applications, and this trend is expected to continue through the end of this century (Refs. 6 through 10). Due to these measures, coal and nuclear systems are expected to account for an increasing portion of electric power generation, while the share attributable to petroleum and natural gas is expected to decrease. This shift in generation mix results from the economically driven replacement of petroleum and gas-fired power plants by coal and nuclear power plants in non-peak-load applications. In the year 2000, projections indicate that this transition will be virtually complete (Refs. 6 through 10). The remaining petroleum and natural gas consumption represents peak-load applications. Further petroleum and natural gas displacement by nuclear and coal systems is unlikely due to the prohibitive cost of using coal and nuclear energy for peaking applications.

In order to provide a viable alternative, solar thermal electric systems must be cost-competitive in an environment dominated by coal or nuclear technologies for base- and intermediate-load applications, and by oil or natural gas in peaking applications. Solar thermal technologies without storage offer the opportunity for additional economic displacement of petroleum and natural gas. The relatively low start-up and shutdown costs of solar energy technologies combined with the good correlation between peak electricity demand and peak insolation in some areas of the southern and southwestern United States, enable solar thermal energy systems without storage to provide a potential means for the economic displacement of the petroleum and natural gas used to satisfy peak-load electrical demands. Thus, without storage, STT complements nuclear- and coal-fired technologies by displacing petroleum in usages for which nuclear and coal substitution are not feasible or are economically prohibitive.

Solar thermal technologies also provide a potential cost competitive alternative for base- and intermediate-load electric power applications. The addition of storage capacity can extend the flow of energy from a solar energy system beyond daylight hours. Energy is collected and stored during periods of high insolation and discharged, on demand, during the night. Depending on the storage capacity, storage-coupled solar energy systems are technically able to provide a constant flow of energy twenty-four hours a day.¹ This enables solar energy to serve base- and intermediate-load electric power applications as well as peak load applications where there is a poor correspondence between peak energy demand and peak insolation. Thermal storage is currently the most cost-efficient storage medium. The ability of solar thermal technologies to effectively utilize thermal storage makes these technologies particularly attractive for base- and intermediate-load applications.

¹Of course, the optimal storage capacity and dispatching strategy will depend on both storage related costs and the time dependent value of the energy displaced by the solar energy system.

Thus, solar thermal electric technologies represent an important element in the national effort to develop a broad range of domestic energy alternatives. Technologically, the unique characteristics of STT help diversify the Federal energy R&D portfolio. As alternative energy systems, solar thermal technologies complement other electrical technologies, such as nuclear and coal, by encouraging additional cost-effective displacement of peak-load oil and natural gas -- fuel displacement that would not be economically feasible in the absence of a solar option. Storage-coupled solar thermal systems can also provide a potential cost-competitive alternative to coal and nuclear systems in base- and intermediate-load electric power applications.

In the electric utility sector, this analysis will consider only peak-load applications of solar thermal technologies (no storage), though some discussion will be provided regarding the impact of storage on the value of solar thermal electric systems. Despite the relatively small usage of oil and natural gas in electric utilities by 1990 and beyond, the results presented later in this analysis indicate that the potential energy cost savings from this application of STT are significant under reasonable scenarios outlining future energy costs and R&D program success. Additional economic and environmental benefits will also characterize the deployment of solar energy systems in electric utility applications. The value of these benefits is expected to exceed the remaining costs for developing S.T systems for the early 1990s.²

1.2 SCOPE OF WORK

This report documents work that was conducted at the Jet Propulsion Laboratory (JPL) during 1982. JPL is responsible for assessing the benefits and impacts associated with the successful development of cost-competitive solar thermal energy technologies. During 1981, JPL focused on developing a methodology to assess the potential economic and social benefits associated with solar thermal electric systems. Using a single representative utility, with regional insolation and fuel price data, the methodology was employed to examine the average regional characteristics of the market for solar thermal technologies in the southwest and south central United States. In particular, the analysis assessed both the average regional energy cost savings associated with electric utility applications of solar thermal technologies and the impact on environmental quality and national security of an expanding domestic STT industry that displaces imported petroleum. Results of the 1981 benefit assessment task were reported in an earlier document (Ref. 11), and have been used both in the Backup Sunset Review Document (Ref. 2) and in the Solar Thermal Technology Program Multi-Year Program Plan (forthcoming). The analytical assumptions and methodology used in the 1981 report are updated herein to reflect changes in the tax laws and other factors, thus making the 1981 report obsolete.

²In deciding whether to continue an R&D project, the expected payoffs should be compared with the remaining R&D costs. Past R&D expenditures are costs that cannot be recaptured if the project is terminated. Therefore, past R&D costs should not be included in future funding decisions.

During 1982, the benefit assessment methodology was refined and the capabilities extended to consider additional impacts. The refined methodology used in this report allows the mix of conventional generating capacity to change as solar thermal penetration increases. Previously, the utility's conventional capacity mix was held constant for all levels of STT penetration. Reoptimization of the capacity mix as STT capacity increases allows the utility to minimize total energy costs, and reflects more accurately the potential value of STT and its impact on fuel consumption. In addition, the hypothetical utility used in the 1981 analysis was replaced by two updated regional utilities representing the southwest and south central United States. Based on this refined analysis and data, the energy cost savings attributed to STT (no storage) were reevaluated. The corresponding fuel displacement data were used to consider impacts on the environment and on petroleum imports. While the primary focus centered on STT systems without storage, preliminary consideration was given to the impact of storage on the value of STT.

This report documents the refinements made in the benefit assessment methodology and presents the results of the refined methodology for an illustrative calculation using hypothetical utilities reflecting average regional characteristics. It also discusses early solar thermal markets and the transition from a high-priced, small-scale STT industry to a lower-price STT industry employing mass-production technologies.

SECTION 2

OVERVIEW

2.1 OBJECTIVES

The U.S. Department of Energy's Solar Thermal Technology Program is developing four concentrating solar thermal technologies (central receiver, parabolic dish, parabolic trough, and hemispherical bowl) and one non-concentrating technology (solar pond). The thermal output of these systems can be used for generating electricity, providing industrial process heat (IPH) and cogeneration, or producing fuels and chemicals. Numerous combinations of technologies and applications resulting in a broad range of potential impacts and benefits are possible if solar thermal technologies can be developed successfully into cost-competitive products. Quantifying the relationship between the development risks and potential benefits is essential for determining the future Federal role in solar thermal R&D and in formulating an R&D strategy that maximizes the benefits accruing from the Solar Thermal Technology Program.

Previous studies that estimated the potential economic and social benefits of solar thermal technologies have not attempted to quantify the correlation between the success of the R&D program and the expected market size. The methodology employed in this study accounts for both the risks inherent in the R&D program and the uncertainties of the future energy market in calculating the size of the markets for solar thermal technology.

2.2 METHODOLOGY

The report first identifies the direct and indirect benefits and impacts³ accruing from the development and installation of cost-competitive STT systems in electric utility applications. Because assessment of the entire list of impacts is beyond the scope of this task, a partial list has been selected for detailed consideration. The analysis was designed to quantify two primary variables associated with achieving the STT Program's 1990 cost goals: (1) potential economic market size for STT and (2) energy cost savings. Using the results of these calculations, the implications of STT for public versus private benefits and the Federal R&D role were analyzed and discussed. STT's impact on environmental quality and oil imports is included in Appendix A.

Although not specifically analyzed in this study, the results of the model could have also been used to examine the impact of STT on issues such as employment opportunities, tax revenue effects, export market potential, and technology base expansion. Figure 2-1 summarizes the components of the benefits assessment study.

³In this analysis, the term impact is used to refer to all types of effects. Some impacts exert positive influences on society, some negative, and some have ambiguous effects. Impacts that are expected to exert a positive influence on society, such as savings in energy-related costs, are frequently referred to as benefits in this report.

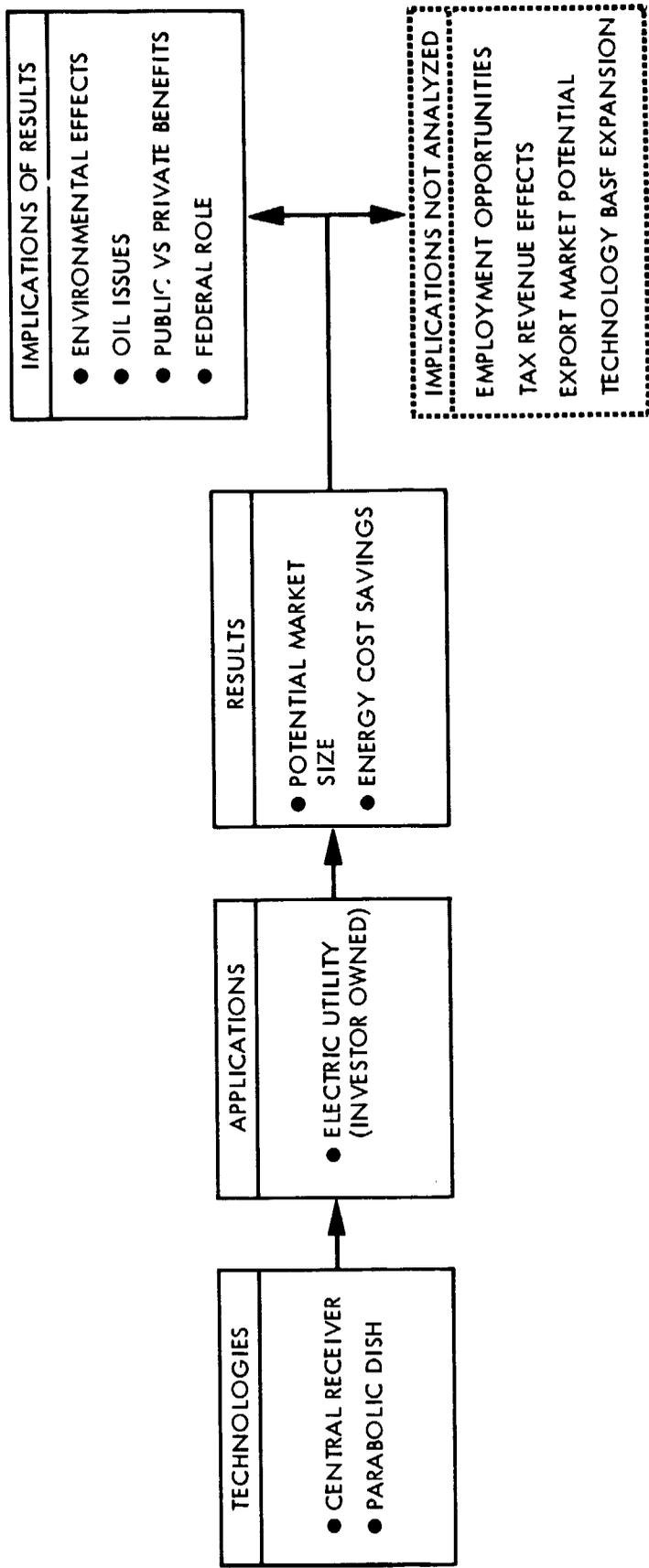


Figure 2-1. Elements of the Benefits Assessment Study

The capacity of economically justified STT installations and corresponding energy cost savings are determined by two factors: (1) the cost of producing STT (STT supply side) and (2) the value of STT to electric utilities (STT demand side).

On the demand side, the value of STT depends on a variety of considerations: some, including insolation levels and fuel prices, will vary across geographic regions; others, such as the demand for electricity, electric utility generating capacity and financial parameters, and STT storage capacity will vary across both utilities and solar thermal systems. Many of these considerations will also vary over time. To simplify the required analysis, attention was restricted to solar thermal electric applications for central receivers and parabolic dishes without storage. The analysis was further limited to 16 states in the southern and southwestern U.S. Two hypothetical electric utilities were examined: one represents the southwestern states while the other represents south central and southeastern states. The financial parameters selected for this analysis characterize an investor-owned utility, though some discussion is presented regarding municipal utility ownership and third party ownership (limited partnerships). Three insolation levels were selected to reflect regional variations in solar radiation. The fuel price assumptions for the southwestern states differ from those used for the south central and southeastern states, reflecting regional variations in fuel prices. High, medium, and low fuel price scenarios were used for each region to reflect uncertainty over future fuel prices. Only one time horizon was considered: 1990 STT installations. The STT system examined in this report has no storage capacity; however, some discussion is provided regarding the impact of storage on the value of STT to an electric utility. These assumptions are summarized in Table 2-1 and will be discussed in detail later in this report.

On the supply side, STT production costs will be influenced by the success of the R&D effort, production volume, STT storage capacity, and such regional considerations as labor and material costs. Because estimating STT production costs is beyond the scope of this report, benefits were assessed assuming three alternative STT system costs without storage. The range of costs reflects variations in STT production volume and R&D success. It was selected to include the STT cost goal established by the Solar Thermal Cost Goals Committee for solar thermal installations in 1990 with no storage capacity.

A methodology was devised to estimate the expected demand for solar thermal technology (i.e., the economic market potential) and calculate the corresponding net savings in energy costs. The methodology uses a utility simulation model to compute the type and quantity of fuel, conventional generating capacity, and operation and maintenance (O&M) expenses displaced by STT systems of different capacities. Together, these measures determine the total value of solar thermal systems to electric utility owners. Purchase decisions, however, are based on changes in the total value of STT to utilities as STT capacity increases. Changes in the total value, referred to as incremental values, indicate the economic benefits attributable to expanding STT capacity. As long as the incremental value of STT exceeds its cost, utilities will purchase additional solar thermal capacity.

Table 2-1. Summary of Assumptions Used in Analysis

Assumption	Comments
(1) Parabolic dish and central receiver STT systems	--
(2) No storage	Forces STT to compete with coal.
(3) Investor-owned utility	Uses less attractive financing than that available to municipal utilities and rural electric cooperatives or third-party owners.
(4) Aggressive transition to coal	Utilities assumed to be installing coal plants in preference to oil or nuclear plants, except where environmentally constrained. Thus, STT must compete with the lower-priced coal facilities in the future.
(5) Southwest and south central/southeastern regions only	Average characteristics of utilities in these two regions were used.
(6) 1990 installation	Calculation is simplified by assuming that all STT plants installed in the early 1990s are installed in a single year, 1990. Overstates actual 1990 installations, but ignores post-1990 increases in demand.
(7) Electric Power Research Institute (EPRI) utility data	Gives lower conventional generating cost estimates than other sources; captures expected improvements in conventional technology; predominantly early morning and early evening peak demands.
(8) SOLMET insolation data	Three levels: high (Albuquerque, NM), medium (Fresno, CA), and low (Fort Worth, TX).
(9) 1981 dollars	--
(10) National Energy Plan (NEP-III) fuel prices	Source: Energy Information Administration's 1980 Annual Report to Congress.
(11) Electricity demand escalation rate	3% per year.
(12) No inter-technology competition for alternative energy sources	May overstate the potential market share captured by STT.
(13) Supply side cost - 1990s' cost goal +25% (i.e., 2200, 1750, and 1300 \$/kWe)	Provides three STT production cost scenarios based on varying degrees of R&D success by 1990.

The incremental value of STT is calculated by determining the change in total value between successive STT capacity levels and normalizing by the change in system capacity. The utility simulation model is used to estimate incremental STT values for electric utility owners (STT demand side), given the assumptions summarized in Table 2-1. Using three estimates for STT production costs (representing the STT supply side), the economic market size and corresponding net energy cost savings were estimated for solar thermal electric systems installed in 1990.

Another important issue confronting the Solar Thermal Technology Program concerns the transition of the STT industry from its current high-price, small-scale status to a large-scale industry employing mass-production techniques. Early markets, in which STT has a particularly high value, are expected to provide the incentive required to stimulate investments in mass-production technology. Once the industrial infrastructure has been established, STT production costs are expected to decrease, leading to a self-sustaining STT industry. Early installations of solar thermal electric systems are expected in utilities that use a significant amount of oil-fired generating capacity and that have a close correspondence between peak insolation and peak electricity demand. If the Federal energy tax credit is extended, third party investors are likely to finance many of these early systems. These high valued STT applications are expected to account for the solar thermal installations occurring during the 1980s and early 1990s. As production capacity increases and system costs decrease, STT will begin penetrating lower valued applications.

Because early STT installations will occur in applications having characteristics and financing arrangements that are particularly favorable to STT, they must be considered on a case-specific basis. An aggregate analysis of the type described in this report (which considers average regional characteristics) cannot address these early STT applications. Because of the importance of these markets, early STT installations and their relation to a self-sustaining STT industry will be discussed explicitly in this report.

SECTION 3

IMPACT IDENTIFICATION

To accurately evaluate the impacts of the Federal STT Program, potential impacts, both quantitative and qualitative, should be identified for alternative solar thermal technologies in alternative applications. The impacts expected from the STT Program can be divided into two broad categories: (1) direct impacts, which are reflected in market transactions and (2) indirect impacts, which are not. The primary direct benefit is the total savings in energy-related costs as utilities and agricultural and industrial users replace conventional generating capacity with economically competitive solar thermal energy systems. Secondary direct impacts include changes in employment levels and the effect of lower energy costs on other sectors of the domestic economy. Indirect impacts include improvements in environmental quality; changes in the level of oil imports, which affect both national security and the balance of payments; tax impacts; the STT export potential; increased competition in the energy market; and diversification of domestic energy resources. Benefit assessment requires consideration of both direct and indirect impacts.

3.1 DIRECT IMPACTS

The savings in energy costs (the primary direct benefit of the STT Program) will include displacement of conventional fuel and generating capacity and potential savings in operation, maintenance, transmission, and distribution costs. The mix of the conventional fuel and generating capacity displaced by STT depends critically both on the match between peak electricity demand and peak insolation and on the STT storage capability. Without storage, STT fuel displacement will be determined by the fuel mix used when solar energy is available. In areas where peak electricity demand occurs mid-day, petroleum and natural gas will be the fuel types most affected by STT. If peak electricity demand occurs in the evening or early morning, an STT system without storage will primarily displace intermediate-load capacity. Coal is expected to be the fuel type used for intermediate-load capacity in the post-1990 period. As will be discussed later, the consumption of oil can actually increase in this case. With storage, solar thermal energy can be used to satisfy peak-load demands, even in areas where peak demand occurs at night. Petroleum and natural gas will be the most affected fuel types in this case.

In addition to energy costs, the installation of solar thermal electric systems will directly impact other market transactions as well. In the labor market, for example, a growing solar thermal industry will create new jobs. However, this will be offset by corresponding reductions in employment levels for industries that STT displaces. The net impact depends on both the relative capital/labor intensities and the unemployment rates of the industries involved. Furthermore, because STT production techniques and labor skill requirements are similar to existing industries and because STT production will not be restricted to areas with the highest demand for STT, any dislocational effects and/or retraining costs associated with a growing STT industry should be minimal.

Lower energy costs will also affect the stability of the entire economy. Experience over the past decade has shown that continually rising real energy costs exert strong inflationary pressures on the domestic price level. Therefore, a cost-competitive solar thermal industry, delivering energy at a relatively constant cost over the life of the solar thermal system, will contribute to reducing inflationary pressures on the U.S. domestic economy.

3.2 INDIRECT IMPACTS

Impacts in the second category are those not directly reflected through market transactions. One of the primary benefits in this category is improvement in environmental quality. As a replacement for conventional fossil-fuel systems, STT improves environmental quality in the short term by reducing air pollutants (SO_x and NO_x); in the long term, STT will reduce CO_2 emissions and minimize coal mining, oil and gas drilling, and the transport of these fuels. STT also provides a capital savings by lowering the expenditures on pollution control technologies required to achieve a given standard of air quality. When compared to the total projected use of petroleum and coal, the potential energy displacement attributable to STT during the 1990s and early 2000s may be relatively small. Regionally, however, the environmental impact can be considerable. If STT installations are concentrated in highly industrialized population centers, environmental quality for localized metropolitan areas can be significantly improved. (See Appendix A, Section A.1, and Ref. 12.) Furthermore, most metropolitan areas exceed the critical emission standards for burning fossil fuels; thus, their industrial growth potential is restricted by law. Industries and utilities are often major polluters in these metropolitan centers. Because emissions offsets can be traded between firms and industries, emissions reductions achieved by adopting STT can be allocated to other firms, permitting old firms to expand or new firms to locate within the affected area. On both the national and local levels, this can mean a higher rate of economic growth.

In addition to improving air quality, oil displaced by the installation of cost-competitive STT can reduce U.S. dependence on foreign sources of petroleum. Reductions in oil imports will positively impact both the national security and balance of payments position of the U.S. (See Appendix A, Section A.2, and Ref. 13.) Natural gas displaced by STT will be available to further reduce the consumption of imported oil. The magnitude of these impacts again depends on the economic market potential of solar thermal systems and the mix of fuels displaced, which in turn depends upon the demand for energy, the STT system storage capacity, and the relative costs of solar thermal systems and other energy technologies.

Because capital and fuel price expenditures are treated differently for tax purposes, STT installations will also have a direct impact on state and Federal tax revenues.⁴ Fuel costs are considered as utility expenses and

⁴Taxes do not affect the energy cost savings realized by society from the installation of an STT system. They represent a transfer of income from the private sector to the public sector. As such, changes in tax revenues cannot be classified as either positive or negative benefits.

are deducted from a utility's taxable revenue in the year incurred before the tax bill is calculated. Capital expenditures are also deducted from utility revenue, but the deduction is spread over time through depreciation allowances, investment tax credits, and deductions for interest payments. Installation of STT capacity by an electric utility will reduce the utility's tax liability during the early years of the solar thermal system's life-cycle. During this period, the tax deductions associated with the Federal investment tax credit and accelerated depreciation will dominate the increases in taxable income associated with decreases in the utility's deductible fuel expenses. Later in the STT life-cycle, as depreciation allowances diminish, both the utility's taxable income and Federal tax revenues will increase. The net present value of the direct tax impact over the entire STT system's life-cycle will depend on both the value of the fuel displaced by STT relative to the capital cost of the system and the discount rate used to evaluate Federal programs.⁵ In addition to this direct tax impact, there will also be an indirect tax impact as the STT manufacturing industry expands and replaces other industries that are currently supplying the electric utility industry.⁶

Furthermore, STT has a significant export potential. As energy prices and foreign demands increase, other countries will broaden their search for indigenous energy resources. As a result, the export potential for STT can be expected to grow (Refs. 14, 15). When solar thermal energy completes the R&D process, a substantial export market for STT can be expected to exist. This will increase production volume in the domestic STT manufacturing industry, thus reducing STT system costs, and will contribute to the U.S. balance of payments position.

STT also diversifies the range of potential energy supply technologies. Solar thermal energy systems can be sized from tens of kilowatts to hundreds of megawatts and used in electrical, agricultural and industrial applications. In the long-term, STT potentially can be used to produce transportable fuels and chemical feedstocks. By meeting the specific requirements for a range of energy markets, STT will provide flexibility that will increase the level of competition characterizing the U.S. energy market and provide the United States added flexibility in responding to OPEC price increases and supply disruptions.

⁵A high Federal discount rate indicates concern over short-run impacts on Federal expenditures and revenues. A discount rate in the range of 25 to 50%, for example, focuses primary attention on a 4- or 5-year period. A lower discount rate would signify a longer-range outlook for capital-intensive investments. The higher the Federal discount rate, the larger the relative importance of the investment tax credit and accelerated depreciation allowances. For high discount rates, the direct tax impact of STT is likely to be negative, indicating a decrease in the net present value of tax revenues. As the discount rate decreases, the net present value of the direct tax impact will increase.

⁶This discussion assumes that the quantity of electricity produced by the utility in question and the rate schedule both remain unchanged. If the regulators change the rate schedule after STT installation, some of the changes in tax liability will likely be passed on to the rate payers. As discussed in a previous footnote, however, this will not affect the benefits attributed to an STT installation.

Finally, because some solar thermal technologies are highly modular, solar thermal generating facilities can be operated and expanded simultaneously (Refs. 16, 17). This factor diminishes the level of capital investment required for STT systems facilities (relative to non-modular energy technologies) because operating revenues can partially offset cash flow requirements during construction. Modularity also allows generating capacity to be installed in units that closely track fluctuating future demand levels.

3.3 PRIMARY IMPACTS

In this analysis, one direct benefit and four indirect benefits are considered explicitly. The direct benefit is the potential energy cost savings. The indirect benefits include improvements in environmental quality, direct tax impacts, and the national security and balance of payments implications of an expanding STT industry that influences U.S. oil imports. Since the entire list of direct and indirect benefits possible for each STT technology/application combination is too extensive for detailed analysis in this report, this limited list of primary benefits was used to assess the Federal STT Program.

3.4 BENEFICIARIES

The benefits described in this section will accrue to a wide range of beneficiaries. These beneficiaries can be divided into two categories: direct and indirect beneficiaries. Direct beneficiaries are all suppliers and customers directly involved in the manufacture and use of STT. On the supply side, this category includes firms that manufacture, design, integrate, and install systems or components for both domestic and export markets; on the demand side, direct beneficiaries include all STT customers. Preliminary studies indicate that early STT customers (1990s' installations) will include those municipal electric utilities, rural electric cooperatives, and island utilities that currently rely on petroleum to satisfy a high proportion of their fuel requirements; investor-owned electric utilities in high insolation and/or high fuel price regions; industries using industrial process heat in high insolation and/or high fuel price regions; agricultural producers currently using diesel power for irrigation purposes; and companies currently using diesel fuel both for enhanced oil recovery and stripper well applications.

Indirect beneficiaries also are served by the STT program. As discussed above, successful development of STT will reduce the domestic demand for oil and provide a hedge against future petroleum price increases. This will benefit all petroleum users and consumers of petroleum-based or petroleum manufactured products. The owners and customers of those firms and electric utilities that rely primarily on petroleum (i.e., fertilizer manufacturers, farmers, small municipal electric utilities, etc.) will be the main beneficiaries. Furthermore, since the domestic rate of inflation is extremely sensitive to changes in energy prices, STT can help stabilize the domestic price level. The entire U.S. domestic economy will benefit indirectly from the reduced dependence on imported petroleum and natural gas, and the increased flexibility of response to long-term oil embargoes.

The actual division of benefits among the many direct and indirect beneficiaries will affect income distribution, but the objective of this study is simply to estimate the value of the total benefits available. As a result, the distribution of benefits will not be considered beyond this brief discussion of potential beneficiaries.

SECTION 4

THE DEMAND FOR STT

After potential impacts are identified, their value must be estimated. In general, the magnitude of the impacts associated with ST development depends on the installed STT capacity. The capacity of STT installed in a particular application is determined by comparing the value of (demand for) STT systems to potential customers in that application area with the cost of producing those systems. Demand in this analysis is based on the incremental value of STT, that is, the greatest amount any consumer would willingly pay for one additional unit of that product, expressed as a function of installed peak STT generating capacity. As long as the incremental value of STT exceeds system costs, additional STT capacity will be installed. When projections of STT system costs are combined with estimates of the incremental value, the economic market potential for cost-competitive applications of STT can be estimated. This market potential is instrumental in estimating the benefits attributable to the Federal STT Program.⁷

The incremental value of STT depends on a variety of factors, including (1) the demand for electricity, (2) the current and future expected cost of energy from STT relative to the costs of other energy resources, and (3) the state of the U.S. economy in general and energy markets in particular both at the time of installation and over the life of the STT system. STT benefits to electric utilities are likely to vary across geographic areas in the U.S., reflecting regional differences in these factors. Relative energy costs will also be time-dependent due to differing price escalation rates.

In this analysis, attention has been restricted to 1990 STT electric applications in the high insolation/high energy price areas of the U.S. To approximate the demand for STT in electric utility applications, utilities were subdivided into three groups according to insolation levels. Representative utilities and fuel prices were selected for each region. The total value of STT to the representative utility was then determined for alternative STT system generating capacities. The change in the total value of STT as capacity increases approximates the incremental value of the added capacity to the representative utility.⁸ This approach approximates the demand curve for STT for each representative utility. Individual demand curves were then scaled according to the size of the corresponding region. Finally, the region-specific demand curves were aggregated to approximate the total 1990 demand for STT in electric utility applications. A range of STT demand curves was estimated by analyzing alternative future fuel price scenarios. These demand curves, reflecting average regional characteristics, have been used to assess a few of the expected impacts associated with the Federal STT Program.

⁷Note that when the demand for STT is derived from the incremental value of STT, it corresponds to the demand curve found in standard economics.

⁸The demand curve is the functional relationship between the value of an additional unit of STT and the installed peak STT generating capacity.

4.1 ASSUMPTIONS

On the demand side, insolation levels, fuel price projections, utility system characteristics, and the financial parameters represent the primary assumptions used to estimate the value of STT systems.

4.1.1 Insolation Levels

This analysis concentrates on 16 states in the southern and southwestern portion of the U.S. Individual states were grouped into three insolation regions, corresponding to above average (Region A), average (Region B), and below average (Region C) insolation levels relative to the norm for the states considered. SOLMET data were used to represent the insolation levels in these three regions. Albuquerque insolation was used to represent the above-average insolation region, Fresno for the average insolation region, and Fort Worth for the below average case (Table 4-1). For each state, STT is expected to penetrate electric utility applications earlier in the higher insolation areas of the state. STT systems can be connected to existing power lines if high insolation areas do not correspond with electricity demand centers. Therefore, states were assigned to insolation groups based on the highest insolation level for which a significant land area exists. Representative insolation data for each region were selected based on (1) the availability and quality of the data and (2) the correspondence between the insolation level of the representative sites and the relevant areas of the states included within the grouping in question.

4.1.2 Fuel Price Projections Under Uncertainty

As with insolation levels, fuel prices vary across geographic regions. There is also uncertainty regarding future trends in fuel prices. This uncertainty must be considered when assessing the benefits of the Federal STT Program. Point estimates of future fuel costs are of little practical use because they obscure the underlying uncertainty characterizing these estimates. A range of possible fuel costs was considered to reflect this uncertainty.

Many possible events affect both absolute and relative energy costs (e.g., an oil embargo, the collapse of OPEC, a nuclear disaster, a technical breakthrough in a competitive energy technology, a war in the Mid-East, etc.) Each individual event, or combination of events, would cause a different scenario for the future state of the energy sector. Because the demand for STT depends critically on the characteristics of the energy sector in which it must compete, a range of demand curves was generated using alternative fuel price scenarios. The scenarios were selected to encompass the likely range of outcomes.

Table 4-1. Regional Variations: Insolation Levels and States Considered (Grouped by Insolation Level)

Region	SOLMET Insolation Data ^(a)	States ^(b)
A High Insolation $I \geq 7.0^{(c)}$	Albuquerque	California Arizona New Mexico Nevada
B Medium Insolation $6.0 \leq I < 7.0^{(c)}$	Fresno	Utah Colorado Texas
C Low Insolation $I < 6.0^{(c)}$	Fort Worth	Kansas Oklahoma Missouri Arkansas Louisiana Hawaii Mississippi Alabama Florida

(a) Selection based on availability and quality of data as well as consistency with relevant insolation levels for the states in each region.

(b) Groupings based on highest insolation level for which a significant land area exists.

(c) Insolation values measure average direct normal insolation and are expressed in kWh/m²/day.

More specifically, three energy price scenarios were selected for this analysis: (1) a favorable case for STT penetration, based on high petroleum prices and fuel price escalation rates; (2) an unfavorable case, based on low petroleum prices and escalation rates; and (3) a middle-of-the-road case, based on moderate petroleum prices and escalation rates (Table 4-2). These fuel prices correspond to the three NEP-III (National Energy Plan) 1990 fuel price projections (Ref. 18) and are based on Energy Information Administration (EIA) regional fuel prices for the Southwest and West. EIA presents four fuel price scenarios: high (H), medium (M), and low (L) world oil prices, assuming compliance with the Powerplant and Industrial Fuel Use Act, and a medium world oil price scenario, assuming no enforcement of the Fuel Use Act (Ref. 19). It is not expected that the Fuel Use Act will be strictly enforced, so JPL generated high and low scenarios for the "no-compliance" case under the assumption of proportionality (i.e., high, medium, and low prices in the no-compliance case are assumed to bear the same relationship to one another as the high, medium, and low prices in the compliance case). The no-compliance EIA prices were then rescaled to achieve parity with NEP-III world oil prices.⁹ These scaling factors are given in Table 4-3. (See Ref. 20 for further discussion.) Finally, three fuel price escalation rates were assumed for the post-1990 period: real annual fuel price escalation rates of 5, 3, and 0%, corresponding to the high, medium, and low fuel price scenarios, respectively. As indicated in Figure 4-1, these fuel price escalation rates reflect a dramatic decrease in the actual rates experienced during the 1970s, while they represent a slight increase over the rates witnessed during the 1960s.

These fuel price scenarios do not correspond to specific scenarios of future events; they merely represent the range of plausible values. Estimating the likelihood that the energy sector will more closely track one scenario or another is a subjective assessment, which varies dramatically over time. For example, the medium to high fuel price scenario was generally accepted as most likely following the 1978-79 Iranian oil embargo; conversely, the low oil price scenario currently seems most probable considering the oil glut beginning early in 1982. Because of their subjective nature, no probabilities were attached to any of these fuel price scenarios. It should also be stressed that the fuel price scenarios adopted in this analysis were selected to reflect a range of plausible long-term trends, not short-term fluctuations. Thus, this analysis will simply present benefit projections for all three scenarios, without assessing their relative likelihood. Furthermore, the wide range of benefit estimates under alternative fuel price scenarios has important implications for Federal participation in STT R&D. These implications will be discussed in Section 7 of this report.

⁹Note that the price of natural gas in Regions B and C is inversely related to the price of oil. As oil prices increase, EIA's projected price of natural gas decreases. According to EIA, this seemingly counter-intuitive relationship is explained by two factors: the limited opportunities to substitute natural gas for oil and the impact of higher oil prices on domestic gross national product (GNP). For a further discussion, see Appendix C of this report.

Table 4-2. Fuel Price Assumptions (1990 Fuel Prices in 1981 \$/Btu x 10⁶)

Fuel Price Scenario	Region/ Insolation	Fuel Type				
		Distillate	Residual	Nuclear	Natural Gas	Coal
Low	B: Fresno & C: Fort Worth	7.87	7.02	0.92	6.63	1.61
	A: Albuquerque	7.43	6.73	0.92	6.98	2.34
	B: Fresno & C: Fort Worth	9.75	8.74	0.91	6.32	1.61
Medium	A: Albuquerque	9.23	8.37	0.91	6.94	2.40
	B: Fresno & C: Fort Worth	12.61	11.30	1.00	6.08	1.81
High	A: Albuquerque	12.01	10.86	1.00	7.63	2.78

NOTES:

- a. Fuel prices based on 1980 EIA Annual Report to Congress. Prices adjusted for NEP-III energy projections for world oil prices.
- b. Medium fuel price scenario corresponds to NEP-III medium scenario of \$52/barrel (1990 price in 1981 \$).
- c. Low and high scenarios correspond to NEP-III range of \$41/barrel to \$68/barrel, respectively (1990 price in 1981 \$).
- d. 1981 to 1990 oil price annual escalation rates: 2, 4, and 8% for low, medium, and high scenarios, respectively.
- e. Post-1990 annual rates of escalation: 0, 3, and 5% for low, medium, and high scenarios, respectively.

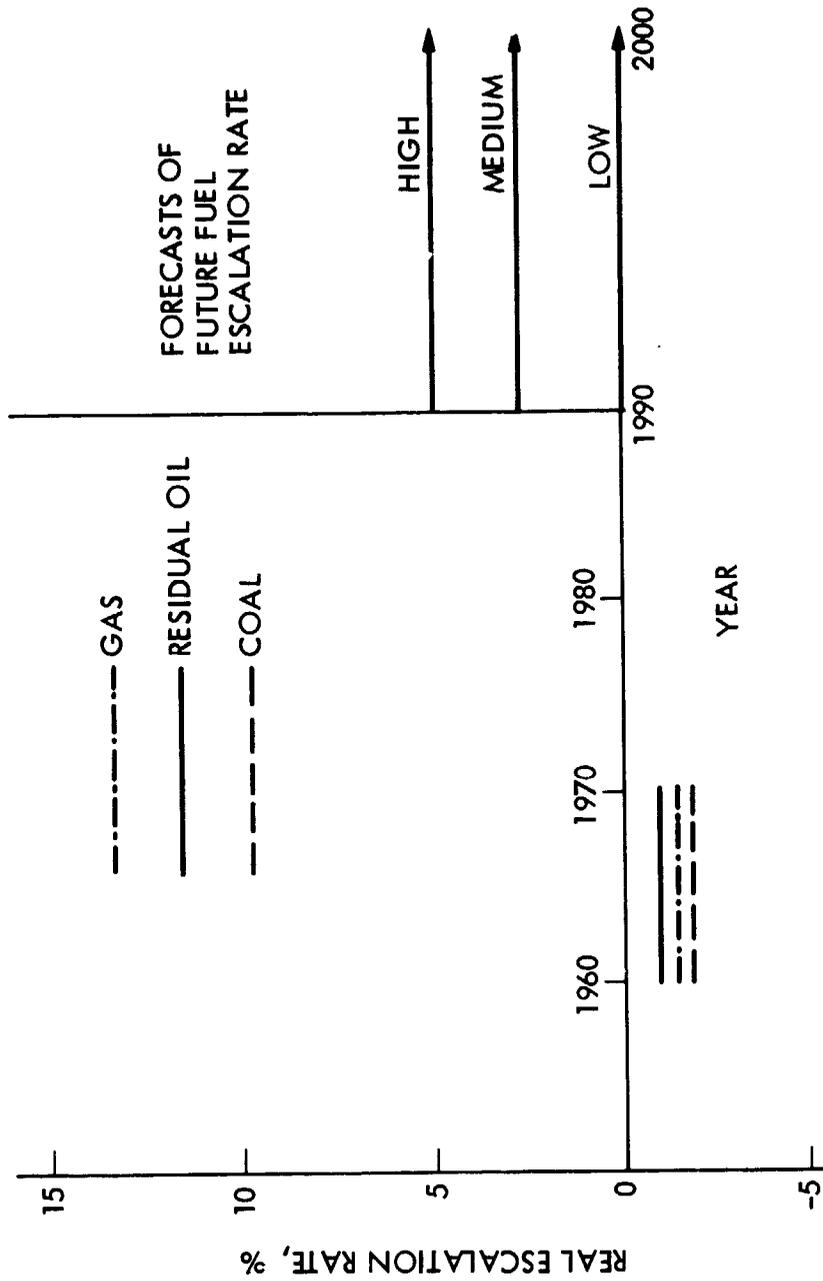


Figure 4-1. Average Fuel Price Escalation Rates (Source: Data Resources, Inc., Lexington, Massachusetts)

Table 4-3. EIA/NEP-III Scaling Factors

Price Scenario	EIA Oil Prices 1979 \$/barrel	EIA Oil Prices 1981 \$/barrel	NEP-III Oil Prices 1981 \$/barrel	Multiplier Applied to 1979 EIA Prices
Low	32	38.4	41	1.281
Medium	41	49.2	52	1.268
High	49	58.8	68	1.388

4.1.3 Utility Characteristics

Electric utility simulation will generate meaningful estimates of the actual value of STT only if the utility systems used in the simulation accurately represent the characteristics of the corresponding region. Therefore, the utilities selected must reflect the mix of generating capacities and fuel use patterns of the regions in question. Both the current mix of capacity and fuel types used as well as projections of how these mixtures will change over time must be considered in selecting representative utilities.¹⁰

Projections regarding changes in the mixture of generating capacity and fuel use patterns over time were obtained from Electric World (Ref. 21), Data Resources, Inc. (Ref. 8), DOE (Refs. 9, 10, 19), EPRI (Ref. 6, 22), the California Energy Commission (Ref. 23), and Southern California Edison (Ref. 24). These studies all revealed a similar trend. Currently, a substantial percentage of the oil and gas burned by electric utilities is used to satisfy base- and intermediate-load demands. Nuclear and coal-fired systems are expected to replace oil and gas in these uses; oil and gas will continue to serve peak energy requirements in the foreseeable future due to the prohibitive cost of using nuclear and coal technologies for peak demand. The referenced studies predict a gradual transition, driven by economic considerations, from oil and gas to nuclear and coal. According to Data Resources, Inc., oil and gas will still supply some base and intermediate demands in 1990, but the transition should be virtually complete for the regions included in this study by 2000 (Figure 4-2). The utility descriptions used in this analysis will reflect this transition to coal-fired power plants.¹¹

¹⁰This analysis considers only a single utility for each region examined. As a result, the utility simulation reflects the average regional utility characteristics. Utility specific variations within a region will be discussed later in this report.

¹¹In recent months, oil price projections have changed dramatically. Real oil prices are expected to fall during the 1980s and then begin increasing. If this trend continues, the transition to coal-fired power plants may be delayed.

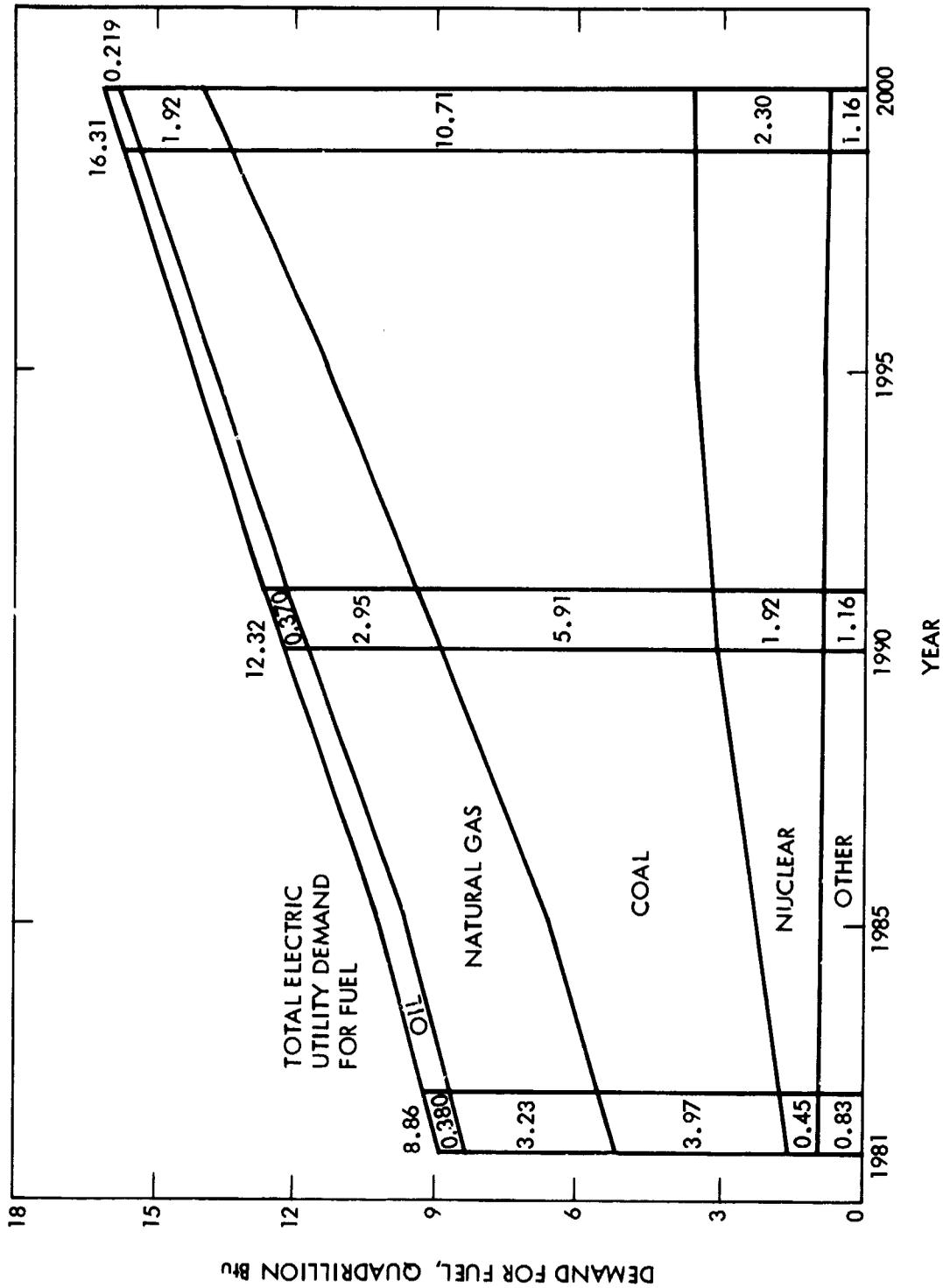


Figure 4-2. Projected Electric Utility Demand for Fuel by Source (Includes the following Data Resources, Inc., regions: East South Central, West South Central, Mountain #1, Mountain #2, and Pacific #2. Individual fuel demands may not sum to annual totals due to rounding errors. Source: Ref. 8, Tables A-62, A-63, A-64, A-65, A-67.)

The Electric Power Research Institute (EPRI) has modeled various synthetic utilities, providing hourly load data, generation capacity mixtures, and information regarding the technical operation and maintenance characteristics for these hypothetical utilities (Ref. 6). The data for each synthetic utility represent average values for a particular region in the United States, thus providing a consistent set of data covering all aspects of utility power generation and energy demand. The states grouped in regions B and C are represented by the EPRI south central synthetic utility. The states grouped in region A are represented by the EPRI western synthetic utility. The western utility, however, has been modified. Approximately 33% of the generating capacity of that utility is hydroelectric capacity. Since this hydro capacity occurs primarily in the Pacific Northwest, an area not considered in this benefit assessment, the hydro capacity has been changed to coal capacity for the purposes of this analysis. While no utilities in the western or south central regions actually exhibit the characteristics of the EPRI synthetic utilities, the EPRI utilities are designed to reflect the average characteristics of the relevant regions.

The 1990 generation mixes for the regional synthetic utilities used in this analysis are shown in Table 4-4. During the period between 1990 and 2019, peak electricity demand was assumed to grow at an annual rate of 3% and have a constant load shape. With the exception of nuclear power plants, a screening curve methodology was used to determine the "optimal" generation mix in 2019, given the projected demand for electricity and the expected relative fuel, O&M, and capital costs in the year 2019, the last year of the study.¹² The growth of nuclear capacity was constrained to a maximum of 6% per year. Generating capacity was adjusted in equal increments every five years to ensure a smooth transition from the baseline 1990 generation mix to the "optimal" 2019 system. The 2019 generating mix for the no-solar case is shown in Table 4-4. Due to the influence of fuel prices on the optimal generating mix, there are different capacity mixtures in 2019 for each region and each fuel price scenario.

As solar thermal electric capacity increases, the "optimal" generating capacity mix will change as well. Because solar thermal systems have low operating costs, solar energy will be dispatched whenever available and can be expected to displace the most expensive fuel types in use at that time.¹³ If peak insolation and peak electricity demand coincide, solar energy can be used to displace peak-load fuels (typically diesel oil). If peak electricity demand occurs when solar energy is not available, solar energy will be used to displace the less valuable intermediate- and base-load fuels (principally coal). In either case, increasing solar thermal plant capacity will alter both the size and pattern of the electricity load remaining to be satisfied by the conventional generating capacity, which will then affect the cost-minimizing mix of conventional generating capacity. If solar energy displaces peak-load

¹²Screening curves consider both annualized capital costs as well as variable fuel and O&M costs to determine the capacity mix that minimizes the total cost of satisfying a given demand for electricity.

¹³This statement is true of solar thermal systems without storage. With storage, solar energy production and dispatching do not have to occur simultaneously. Solar energy can be stored and used at a later time if that increases the value of the fuel displaced.

Table 4-4. Utility Capacity Expansion Plan: No-Solar Base Case (MWe)^(a)

Unit Type	Fuel Price Scenario							
	Western (Region A)				South Central (Regions B and C)			
	All Fuel Prices ^(b)	High ^(c)	Medium ^(c)	Low ^(c)	All Fuel Prices ^(b)	High ^(c)	Medium ^(c)	Low ^(c)
Nuclear	1800	10200	10200	10200	1200	7200	7200	7200
Coal	6100	19500	18800	17300	5000	22000	21400	20000
Oil and Natural Gas	3800	600	900	1300	5600	1200	1600	1700
Combustion Turbine	700	200	500	1300	600	100	200	1550

(a) The required change in capacities between 1990 and 2019 were assumed to occur proportionately over the 30-year time period.

(b) 1990 generating capacity based on the EPRI synthetic utilities for western and south central regions (Ref. 6). Capacity mix is constant across fuel price scenarios.

(c) 2019 generating capacity mix estimated using a screening curve methodology. Capacity mixes vary across fuel price scenarios reflecting variations in fuel prices.

fuels, peak-load capacity will decrease relative to intermediate- and base-load capacity in the "optimal" capacity mix. If solar replaces intermediate- or base-load fuels, peak-load capacity may actually increase.

In this analysis, the generating capacity mix is reoptimized as solar penetration increases, which allows the utility to respond to changes in solar thermal capacity and provides a more accurate measure of the true value of solar thermal energy. All changes in the baseline capacity were assumed to occur in 1990, the year of solar installation.¹⁴ Tables 4-5 and 4-6 show

¹⁴This may understate the actual time required for utilities to respond to the installation of solar thermal generating capacity. If changes in conventional capacity occur at a later time, the value of the savings in capital costs should be discounted to account for the time value of money. However, in this analysis, savings in capital expenditures represent only 10% of the total value of STT on the average. Therefore, assumptions regarding the response time for conventional generating capacity will not have significant impact on the value of STT as estimated here.

the "optimal" 2019 generating capacity and the change from the no-solar base-line case for the western and south central regions, respectively. The 2019 generating capacity varies over fuel price scenarios and levels of solar penetration. As will be discussed in more detail in Section 7 of this report, the load patterns in the EPRI synthetic utilities for the western and south central regions exhibit a poor correlation between peak demand and peak insolation. As a result, Tables 4-5 and 4-6 indicate that as solar penetration increases, peak-load capacity increases while intermediate- and base-load capacity decreases.

Heat rates, forced outage rates, scheduled maintenance, operation and maintenance costs, and capital costs were also derived from EPRI data (Refs. 6, 22). These data are shown in Table 4-7.

4.1.4 Financial Parameters

This analysis considers only the financial parameters of an investor-owned utility. As municipal utilities, rural electric cooperatives, and Federal utilities can obtain more favorable capital financing, this analysis will reflect conservative estimates for those utility types. The financial parameters used in this analysis correspond to the parameters adopted by the Solar Thermal Cost Goals Committee (Ref. 25). These parameters are listed in Table 4-8.

4.1.5 Inter-Technology Competition

The value of STT depends on the cost of the best alternative to STT. Estimating the future demand for STT requires explicit or implicit assumptions regarding the relative costs of all alternative energy sources, both those currently in use and those expected to become available during the time horizon being considered. Many demand analyses, including this one, assume that STT displaces current technologies. This is equivalent to assuming that all other energy-related R&D projects fail to produce economically competitive technologies that satisfy energy demands similar to those served by STT. If this in fact turns out to be an inaccurate prediction, the demand curves for STT estimated here will overstate the true demand. Competition between STT and similar innovative energy technologies is an important element of demand curve analysis. Due to the difficulty involved in estimating the future outcome of alternative R&D projects, this analysis does not consider inter-technology competition. Conventional technologies with projected 1990 characteristics are assumed to represent the best available alternatives to STT during the time frame considered in this analysis. This assumption becomes less realistic for the high fuel price scenario. When oil prices are high, oil is less likely to represent the best available alternative.

4.1.6 1990 Installations

This analysis estimates the demand for STT at a particular point in time, 1990. Implicit in these demand projections are assumptions regarding STT installations both before and after the time being examined. Many

Table 4-5. 2019 "Optimal" Generating Capacity: Region A (Western)

Fuel Price Scenario	Solar Thermal Capacity, MWe	2019 Generating Capacity, MWe				Change from Base Case		
		Nuclear	Coal	Oil	Combustion Turbine	Coal	Oil	Combustion Turbine
Low	0	10200	17300	1300	1300	-	-	-
	103	10200	17300	1200	1400	0	-100	+100
	515	10200	1720	1200	1500	-100	-100	+200
	1030	10200	1700	1300	1600	-300	0	+300
	2060	10200	16700	1400	1700	-600	+100	+400
	3090	10200	16400	1500	1800	-900	+200	+500
Medium	0	10200	18800	900	500	-	-	-
	103	10200	18800	800	600	0	-100	+100
	515	10200	18800	700	700	0	-200	+200
	1030	10200	18600	800	750	-200	-100	+250
	2060	10200	18400	900	850	-400	0	+350
	3090	10200	18100	1000	1000	-700	+100	+500
High	0	10200	19500	600	200	-	-	-
	103	10200	19500	500	300	0	-100	+100
	515	10200	19400	500	400	-100	-100	+200
	1030	10200	19300	400	500	-200	-200	+300
	2060	10200	19000	500	700	-500	-100	+500
	3090	10200	18800	600	700	-700	0	+500

Table 4-6. 2019 "Optimal" Generating Capacity: Regions B and C (South Central)

Fuel Price Scenario	Solar Thermal Capacity, MWe	2019 Generating Capacity, MWe				Change from Base Case		
		Nuclear	Coal	Natural Gas	Combustion Turbine	Coal	Natural Gas	Combustion Turbine
Low	0	7200	20000	1700	1550	-	-	-
	103	7200	20000	1600	1650	0	-100	+100
	515	7200	20000	1500	1750	0	-200	+200
	1030	7200	19900	1500	1850	-100	-200	+300
	2060	7200	19500	1600	2050	-500	-100	+500
	3090	7200	19200	1700	2250	-800	0	+700
Medium	0	7200	21400	1600	200	-	-	-
	103	7200	21400	1500	300	0	-100	+100
	515	7200	21400	1400	400	0	-200	+200
	1030	7200	21300	1400	500	-100	-200	+300
	2060	7200	21100	1500	500	-300	-100	+300
	3090	7200	20900	1500	700	-500	-100	+500
High	0	7200	22000	1200	100	-	-	-
	103	7200	22000	1100	200	0	-100	+100
	515	7200	22000	1000	300	0	-200	+200
	1030	7200	21800	1200	300	-200	0	+200
	2060	7200	21600	1200	400	-400	0	+300
	3090	7200	21400	1300	500	-600	+100	+400

Table 4-7. Regional Generating Plant Characteristics (1990 values expressed in 1981 dollars; Refs. 6, 22)

Unit Size and Fuel Type, MWe	Capital Cost, \$/kWe			Heat Rate, 10 ⁶ Btu/MWeh			Fixed O&M, \$/kWe/yr			Variable O&M, \$/MWeh			Forced Outage Rate			Sched. Maint., days/yr		
	Region			Region			Region			Region			Region			Region		
	A	B+C	A	B+C	A	B+C	A	B+C	A	B+C	A	B+C	A	B+C	A	B+C	A	B+C
1200 Nuclear	1720	1575	10.7	10.7	10.7	9.50	8.60	1.80	1.70	0.18	0.12	47	47	47	47	47	47	47
800 Coal	1070	985	9.70	10.21	12.80	11.80	2.30	1.80	0.21	0.21	0.21	54	54	54	54	54	54	54
600 Coal	1115	1025	9.96	10.61	13.90	12.80	2.30	1.80	0.18	0.18	0.18	52	52	52	52	52	52	52
400 Coal	1180	1090	10.16	10.47	15.80	14.50	2.30	1.80	0.15	0.15	0.15	48	48	48	48	48	48	48
200 Coal	1315	1210	10.71	11.19	19.40	17.80	2.30	1.80	0.10	0.10	0.10	39	39	39	39	39	39	39
800 Oil(a)/Nat. Gas	465	450	9.31	9.38	1.50	1.50	1.80	1.80	0.15	0.11	0.11	61	61	61	61	61	61	61
600 Oil(a)/Nat. Gas	465	450	9.68	9.76	1.60	1.60	1.80	1.80	0.13	0.10	0.10	55	55	55	55	55	55	55
400 Oil(a)/Nat. Gas	465	450	9.68	9.76	1.80	1.80	1.80	1.80	0.11	0.08	0.08	49	49	49	49	49	49	49
200 Oil(a)/Nat. Gas	465	450	10.09	10.27	2.20	2.20	1.80	1.80	0.07	0.05	0.05	35	35	35	35	35	35	35
100 Oil(a)/Nat. Gas	465	450	11.84	11.94	2.70	2.70	1.80	1.80	0.05	0.03	0.03	21	21	21	21	21	21	21
50 Combustion Turbine(b)	245	245	14.00	14.00	0.30	0.30	3.20	3.20	0.08	0.08	0.08	12	12	12	12	12	12	12

(a)Residual Oil

(b)Distillate Oil

Table 4-8. Financial Parameters for an Investor-Owned Utility

Parameter	
Fixed Charge Rate, %	13
System Life, yr	30
Depreciation Life, yr	15
Depreciation Method	ACRS ^(a)
Effective Tax Rate, %	48
Investment Tax Credit, %	10
Energy Tax Credit, %	0
Other Taxes and Insurances as Fraction of Capital Investment, %	2
General Inflation Rate, %	0
Discount Rate (Real), %	3.6
O&M Escalation Rate (Real), %	1
Return on Equity (Real), %	5.6
Debt Fraction, %	50

(a) The 1981 Accelerated Cash Recovery System

studies, including this analysis, estimate the demand for STT in a future year assuming no installations prior to that year. Any change in this assumption results in a shift of the demand curve for the year in question. Prior installations reduce the demand for STT. Future demand characteristics and installation decisions can also influence STT purchases. The impacts of dynamic considerations are currently being examined, but were not included in this analysis. The demand curves estimated here represent the total STT market demand projected to be economically viable by 1990, not the actual purchases of STT capacity in that year.

4.2 METHODOLOGY

Using the regional insulation data, fuel price projections, synthetic utility descriptions, and financial parameters outlined above, estimates were

made of the value of the fuel, O&M, and capital costs displaced by STT systems of varying capacities. More specifically, using regional insolation data, the energy output of a generic solar thermal electric power plant was estimated for a variety of system capacities. System capacities were selected to represent 1, 5, 10, 20, and 30% of 1990 peak power demand for the representative utility system. Assuming STT systems of these capacities and the reoptimized conventional capacity mix, a probabilistic capacity-dispatching model was used to determine the fuel and O&M requirements of the conventional generating capacity over the 30-year expected life of the STT system. By comparing the conventional capacity, fuel, and O&M requirements corresponding to each alternative STT system capacity with the conventional capacity, fuel, and O&M requirements of the no-solar baseline case, the quantity and value of conventional capacity, fuel, and O&M displaced in each year of the analysis for each case considered can be determined.

Based on the financial parameters indicated in Table 4-8 and the capacity, fuel, and O&M credits described above, the after-tax value of STT to the representative utilities was determined for each system capacity considered. The STT after tax values were calculated using a methodology developed at JPL. (See Appendix B for a detailed description.) This methodology is equivalent to other frequently cited valuation procedures.¹⁵

The incremental value of an additional MWe of STT capacity is calculated by determining the change in total value between successive STT capacity levels and by normalizing according to the change in system capacity. The change in the total value, referred to as the incremental value, indicates the extra value attributable to the expanded STT capacity. Dividing the total incremental value by the amount of capacity added expresses the incremental value on a per unit basis. These incremental values represent points on the demand curve for STT. The demand curve indicates that, up to a point, utilities will prefer using solar thermal technologies to conventional power plants. The prices that utilities would be willing to pay for STT are higher at lower levels of usage corresponding to installations that displace the highest priced fuels. Values decrease as the level of usage increases because STT must displace lower priced fuels. It should be stressed that the incremental value as measured by the demand curve in this analysis indicates the price a utility would willingly pay for a turn-key STT system.¹⁶

¹⁵It has been shown, for example, that the analysis described in Appendix B is equivalent to the methodology presented in J. Doane, et al, The Cost of Energy from Utility-Owned Solar Electric Systems, ERDA/JPL-1012-76/3, Jet Propulsion Laboratory, Pasadena, California, June 1976.

¹⁶Note: As discussed previously, the mix of fuels displaced and corresponding incremental value will also depend both on the match between peak electricity demand and peak insolation and on the storage capacity of the STT system in question. Recall that this analysis assumes no storage capacity. The addition of storage capacity would increase both the cost and incremental value of the STT system.

4.3 1990 STT DEMAND

The incremental value was estimated for all three fuel price scenarios in each of the three regions considered. The resulting demand curves were scaled up according to generating capacity estimates for each of the three regions and then aggregated to determine the total STT demand curve for the 16 states included in this analysis (Figure 4-3).

Fuel cost savings are the primary determinant of the incremental value curves depicted in Figure 4-3. As discussed in Section 7 of this report, there is a relatively poor correspondence between peak insolation and peak electricity demand in the EPRI synthetic utility data. Therefore, STT installations will not displace conventional generating capacity. As indicated in Tables 4-5 and 4-6, additions of STT capacity merely reduce the proportional amount of coal-fired generating capacity in favor of oil-fired capacity. Since capital costs are lower for oil-fired power plants, STT can claim a capacity credit. The capacity credit, however, is small relative to the corresponding fuel credit (Figure 4-4).

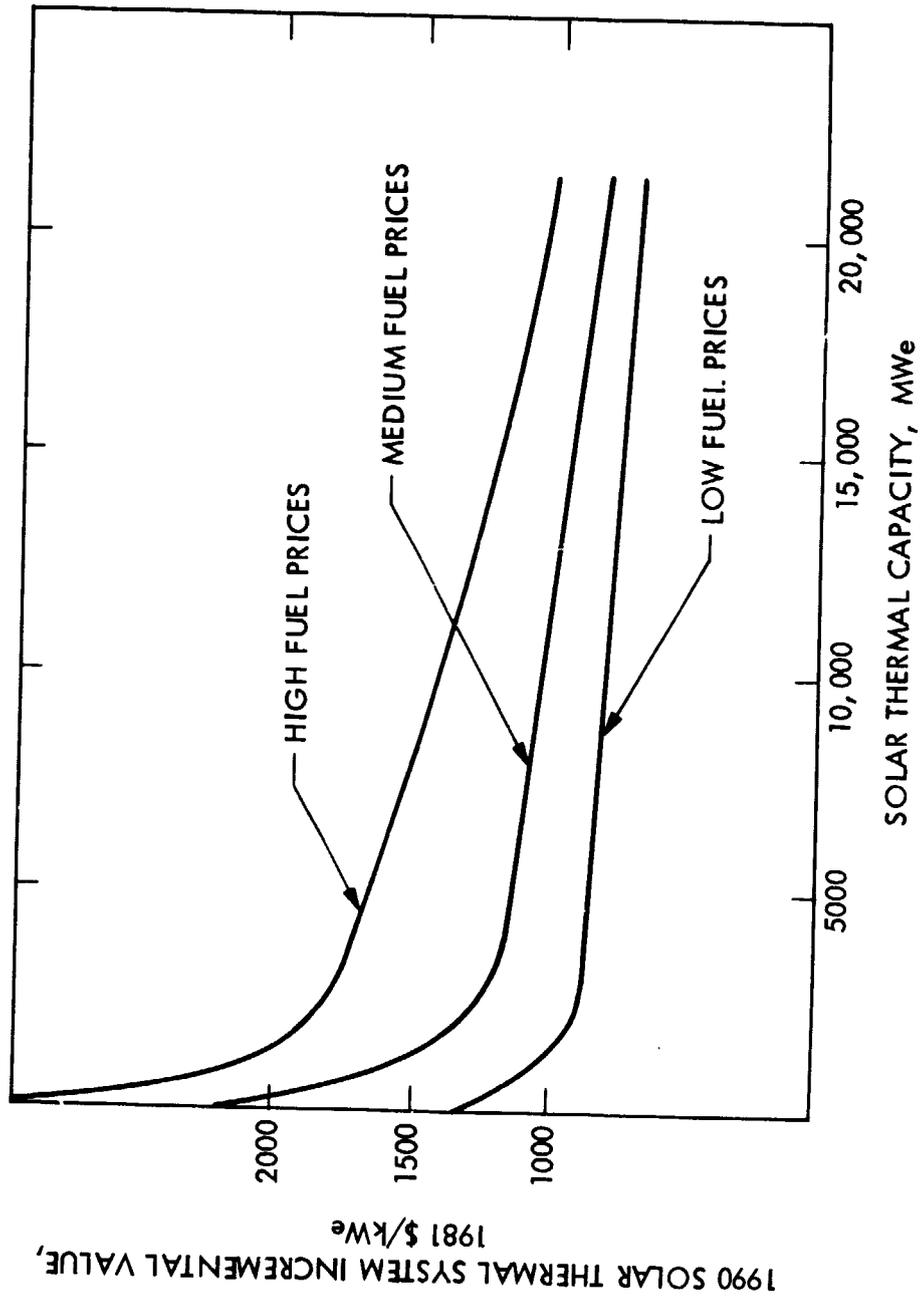


Figure 4-3. 1990 Incremental Value of Solar Thermal Electric Systems (Investor-Owned Utilities; Southwest and South Central Regions; No Storage)

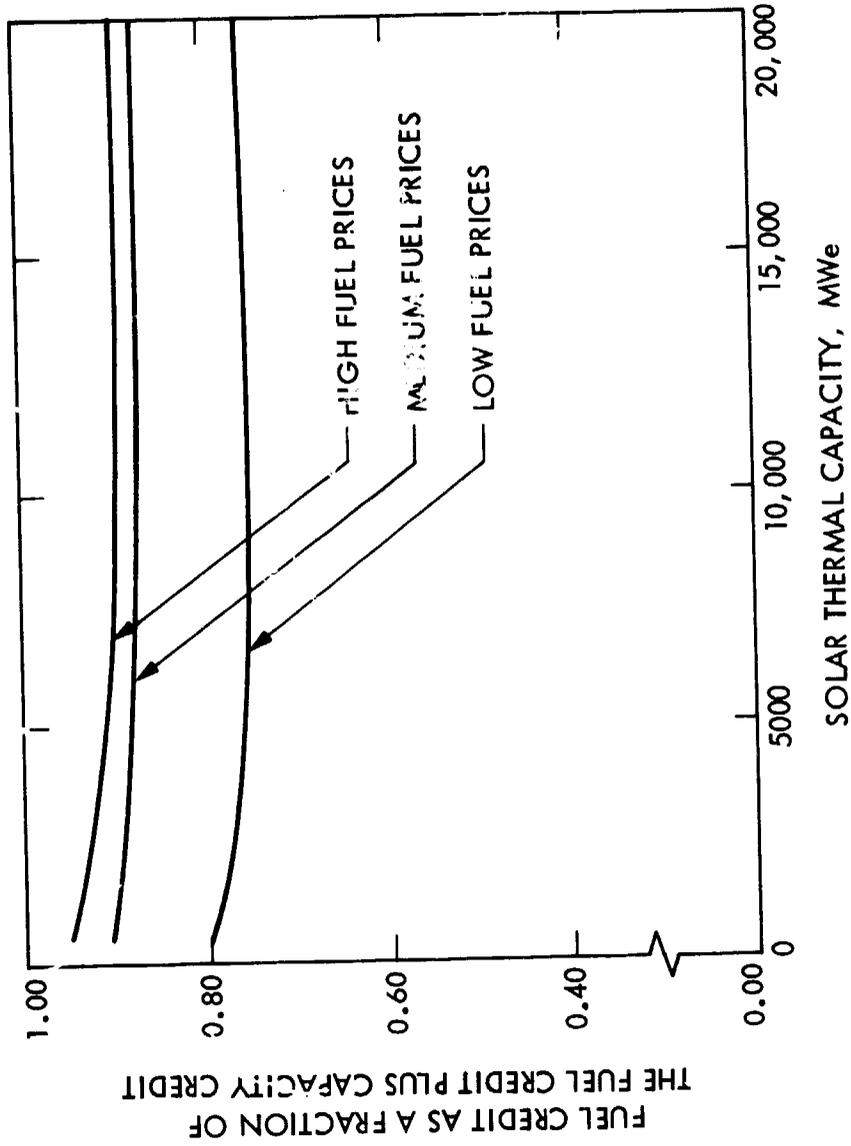


Figure 4-4. The Value of STT: Fuel Versus Capacity Credits

SECTION 5

THE COST OF STT: EVALUATION METHODOLOGY

The preceding sections of this analysis have described the methodology used to estimate a range of demand curves for STT. In addition to market demand projections, however, benefit assessment also requires predictions regarding the expected supply of solar thermal systems. Supply estimates indicate the quantity of STT that the private market can be expected to provide for alternative STT price levels. When combined with the demand analysis, these supply predictions will determine potential capacity of cost-competitive STT installations in 1990. To assess the benefits of the Federal STT Program, it is essential to first estimate the future economic market potential for STT.

The supply curve depends on STT production and installation costs. In turn, these costs depend on a variety of factors. First, production costs are sensitive to production volumes. As production volumes increase, long-run production costs per unit generally will decrease because firms can use fabrication processes that exploit potential economies of scale. Initially, the long-run STT supply curve is expected to reflect decreasing costs as annual production rates increase. Other important considerations include: the technological characteristics of alternative solar thermal systems successfully completing the R&D process; the prices of inputs used in producing STT; land and site preparation costs; balance-of-system requirements; and on-site installation activities. Many of these cost items will vary across geographic regions. Accurately estimating future STT production and installation costs requires estimating the future regional values of these factors. Because these predictions are highly uncertain, meaningful point estimates of these regional values cannot be obtained. As in the case of demand projections, a range of values has been considered.

5.1 STT COST GOALS

This analysis assumes that future STT costs will encompass the 1990 cost goal for the Federal STT Program (Ref. 25). STT cost goals have been specified for initial deployment in both 1990 and 2000 to reflect expected changes in STT systems over time. Near-term goals represent early generation technologies, while long-term goals relate to more technically advanced systems. Similarly, a range of production volumes is assumed for each year of initial deployment, with limited production volumes for first-generation technologies and increased volumes for more advanced systems. The cost goals are based on attainability to the extent that they were initially derived through detailed engineering studies for representative early and advanced technologies. They are value-based to the extent that these goals have been compared with preliminary demand estimates for STT to verify that the cost targets are sufficiently ambitious to ensure a significant future STT industry. This comparison also indicates that if these targets are achieved, the resulting

STT market potential would be adequate to support the annual production rates assumed in establishing the cost goals. Using these cost goals simplifies the cost estimation procedure described above by providing a representative STT system description and a limited but economically justifiable range of production volumes. The cost goals are national values because regional variations are insignificant relative to the uncertainty surrounding the estimates.

The 1990 cost goal for solar thermal electric systems with buffer storage is \$1600/kWe in 1980 dollars (approximately \$1750/kWe in 1981 dollars). Three alternative 1990 STT cost assumptions have been considered in this analysis: \$1300/kWe, \$1750/kWe, and \$2200/kWe (in 1981 dollars). These costs represent a range of $\pm 25\%$ around the 1990 cost goal. For reference, the year 2000 cost target for STT with buffer storage is \$1100/kWe in 1980 dollars (approximately \$1200/kWe in 1981 dollars).

SECTION 6

RESULTS: 1990 STT ECONOMIC MARKET POTENTIAL AND ENERGY COST SAVINGS

Once a range of values has been estimated for both STT supply and demand, the estimates can be combined to determine the economic market potential for STT in the year being analyzed and the corresponding energy cost savings (Figure 6-1). The demand curve represents the price that potential consumers would be willing to pay for each quantity of STT capacity. The supply curve indicates the quantity of STT capacity that manufacturers would provide for alternative STT price levels. Thus, the intersection of the supply curve and the demand curve will determine the total capacity for which STT provides a cost-effective alternative in 1990. The area bounded by the demand curve, the supply curve, and the left-hand vertical axis provides a measure of the after-tax energy cost savings.

6.1 1990 STT ECONOMIC MARKET POTENTIAL

Figure 6-1 illustrates that the size of the market strongly depends on achieving the STT cost targets and is sensitive to future fuel prices. As discussed previously, the prices that utilities would willingly pay for STT are higher at lower levels of usage corresponding to applications using the highest priced fuels in areas with the best insolation. Values decrease as the level of usage increases since STT must displace lower priced fuels in regions with less desirable insolation levels. For STT without storage, the rate of decrease is rapid at first, since the oil displacement potential is exhausted by the initial STT installations. In the medium oil price scenario, utilities would pay \$2000/kWe (1981 dollars) for the first 500 MWe of STT capacity (without storage). To achieve a market penetration of 5000 MWe, STT system costs would have to fall to \$1100/kWe (1981 dollars).

As discussed earlier, the total economic market potential for STT at a particular time is likely to exceed the actual level of STT purchases and installations. Consumers may be constrained by capital market imperfections or imperfect information, while suppliers in growing industries frequently face bottlenecks to establishing the required industry infrastructure, especially in industries experiencing a relatively rapid rate of technological change. For these and other reasons, actual purchases of STT will be less than the total projected demand for that period. Cumulative installations during the 1990s, however, will approach the total capacity for which STT is cost-competitive. This suggests the use of a dynamic approach to projecting future STT deployment decisions. Because a dynamic formulation is beyond the scope of this analysis, static estimates of total potential demand have been used.

6.2 ENERGY COST SAVINGS

The STT demand and supply curves shown in Figure 6-1 can be used to estimate the energy cost savings associated with STT installations under alternative system cost and fuel price assumptions. By construction, STT demand curves represent the after-tax incremental value to electric utilities of additional units of solar thermal electric capacity. STT supply curves

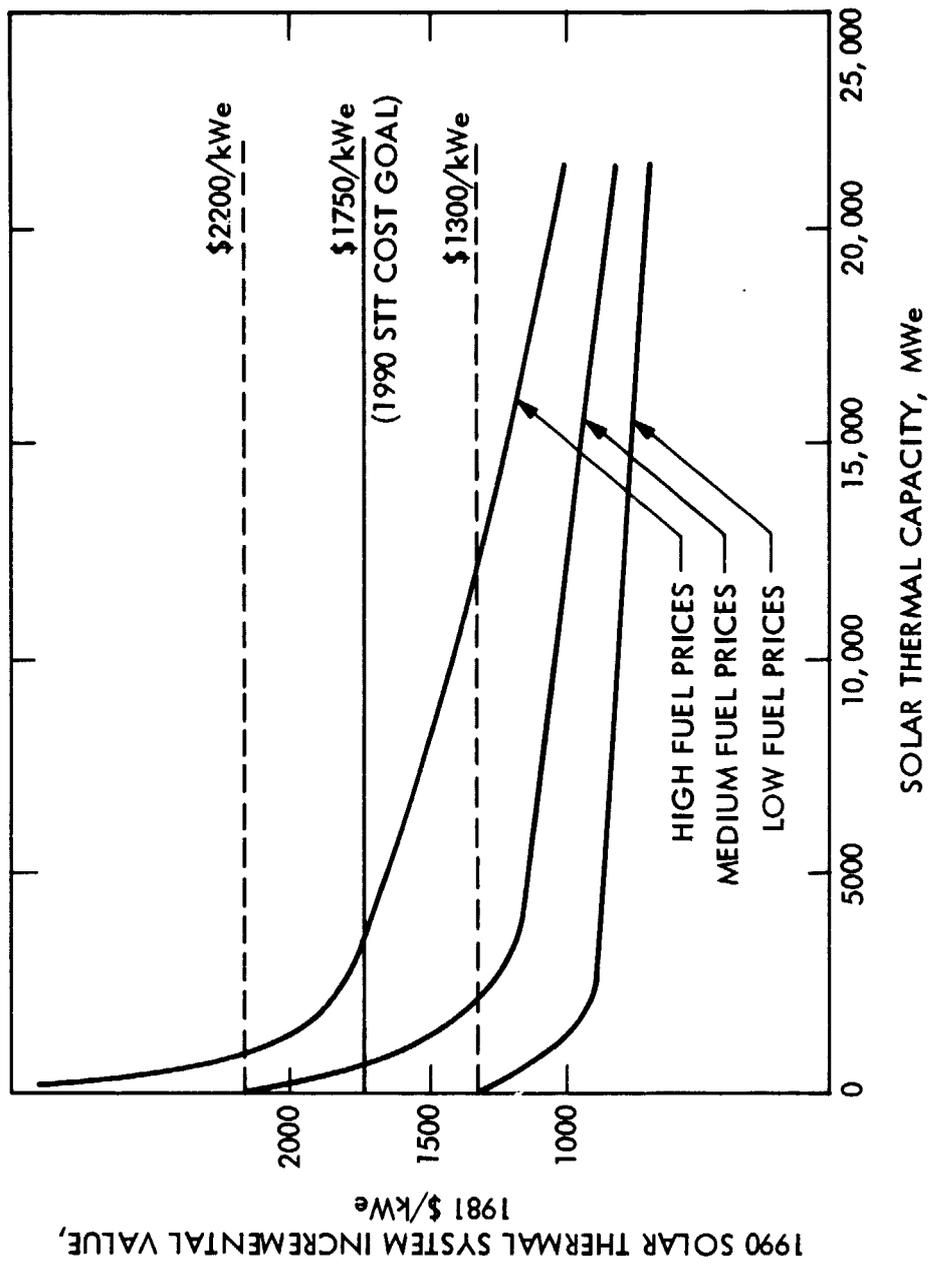


Figure 6-1. 1990 Market Potential for Cost-Competitive Solar Thermal Electric Systems (Investor-Owned Utilities; Southwest and South Central Regions; No Storage; After Tax Incremental Values)

indicate the incremental cost of producing additional units of STT capacity. The net after-tax energy cost saving is represented by the area bounded by the demand curve, the horizontal line representing the relevant STT supply curve, and the left-hand vertical axis (Figure 6-1). This area represents the energy cost savings captured by private consumers and producers of STT systems.

STT installations will also affect Federal tax revenues. Fuel cost savings reduce a utility's deductible expenses and increase Federal tax revenues. The capital expenditures associated with STT systems will result in tax credits and depreciation allowances that reduce Federal tax revenues. However, changes in tax revenues simply represent a transfer of income between the public and private sectors. If tax revenues increase, then part of the energy cost savings associated with STT installations is being transferred to the public sector. If tax revenues decrease, then society is subsidizing the STT industry. To estimate the total energy cost savings realized by the economy, changes in tax revenues must be combined with the private sector impacts discussed in the preceding paragraph.

The after-tax demand curves depicted in Figure 6-1 have been used to determine the STT economic market potential, given alternative STT system costs. Once the market potential has been determined considering the after-tax value, the relevant areas in Figure 6-1 were converted into pre-tax values to provide an estimate of the net energy cost savings captured by both the private and public sectors.¹⁷

Figure 6-2 shows the relationship between STT system costs (\$/kWe) and the value of the net energy cost savings associated with potential cost-competitive installations of solar thermal electric systems in 1990 under the medium fuel price scenario. The net energy cost savings are estimated to be in the range of \$0 to 2 billion (1981 dollars). The range reflects achievement of the high (\$2200/kWe) and low (\$1300/kWe) STT cost targets. Achieving other cost targets would result in different values for the potential net energy cost savings; e.g., Figure 6-2 shows that the \$1750/kWe cost target would result in a net energy cost savings of \$0.5 billion.

Table 6-1 summarizes the net energy cost savings for three oil price scenarios and three levels of STT costs. If STT systems cost \$2200/kWe, installations will be cost-effective only in the high energy price scenario. However, at a cost of \$1300/kWe, STT would be preferred by the utility sector under all three oil price scenarios. The net energy cost savings for the \$2200/kWe case range from \$0 to 1 billion; at \$1300/kWe, benefits vary from \$0 to 10 billion.

The values reported in Table 6-1 and Figure 6-2 are 1990 values (in 1981 dollars). In order to derive the present value of the net energy cost savings, the values must be discounted to the current period. Using the real

¹⁷The present value of the private and public net energy cost savings associated with a particular level of STT installations is equal to the sum of the corresponding fuel credit, O&M credit, and capacity credit minus the solar thermal system cost plus solar O&M costs, with all cash flows expressed in present value terms.

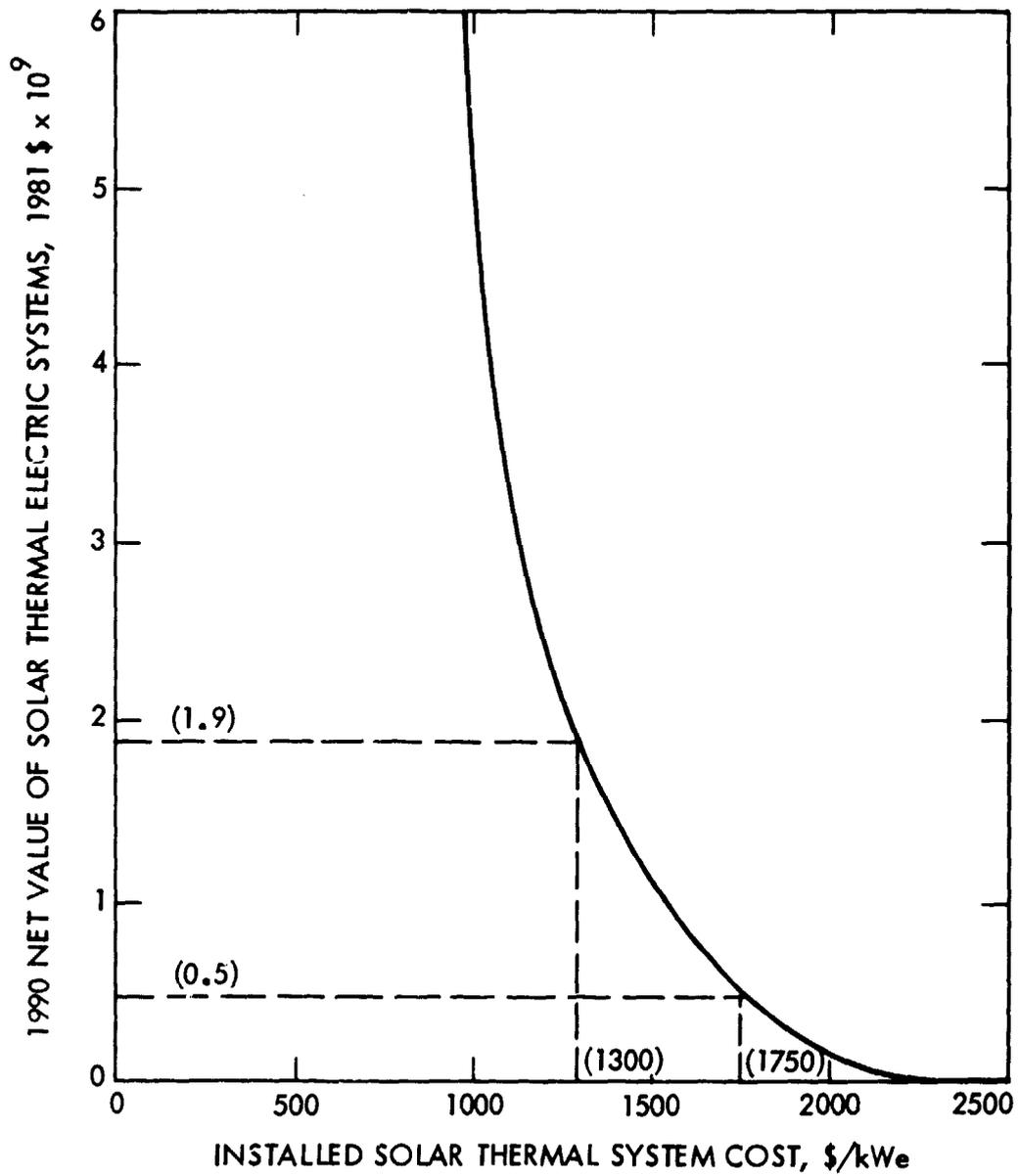


Figure 6-2. 1990 STT Net Energy Cost Savings: Medium Fuel Prices (1981 Base Year Dollars; 1990 Installation Date; Medium Oil Price Scenario)

Table 6-1. Total Net Energy Cost Savings of Solar Thermal Electric Systems (1990 Values in Billions of 1981 Dollars)

STT System Costs ^(b)	NEP-III Energy Price Scenario ^(a)		
	Low	Medium	High ^(c)
\$2200/kWe	0	0	1
\$1750/kWe	0	0 ^(d)	3
\$1300/kWe	0 ^(d)	2	10

(a) Low, medium, and high refer to the NEP-III energy scenarios based upon the 1990 imported oil price of 44, 52, 68 (1981 \$/barrel).

(b) Low, medium, and high system costs reflect varying production volumes and levels of R&D success.

(c) Energy cost savings as estimated here assume that conventional generating capacity with projected 1990 characteristics represents the best alternative technology to STT for electric applications. As discussed previously, this assumption may prove unrealistic, especially for the case of oil- and natural gas-fired capacity in the high oil price scenario.

(d) Positive values that become 0 after rounding to nearest billion.

Federal discount rate of 7% per year, as suggested by the Office of Management and Budget, the values reported herein would be reduced by approximately 40% when discounted to 1982 dollars. When comparing the net energy cost savings with the future required Federal investment in R&D, both cash flows must be expressed in dollars for equivalent years.¹⁸

Two final points deserve further discussion. First, the energy cost savings reported here represent the total values attributable to STT assuming that all cost-competitive systems as of 1990 are actually installed in that year. Due to probable manufacturing bottlenecks and imperfect consumer

¹⁸If current funding levels are maintained through FY 1990, the Federal government will invest approximately 300 million dollars in STT R&D between FY 1983 and FY 1990 (1982 present value in 1981 dollars). These expenditures address early and advanced concepts for a variety of technologies and applications. Even when discounted to 1982, the values in Table 6-1 exceed the proposed Federal expenditures for early generation solar thermal electric systems under all but a few combinations of assumptions regarding system costs and future fuel prices.

information, actual STT installations are expected to fall short of the total potential level. Thus, the values reported represent upper bounds on the actual level of benefits that will be realized by STT installations in 1990. However, if this analysis were repeated for other years, with more realistic annual sales, the cumulative benefits should be on the same scale. Secondly, the entire net benefit from successful STT development has been attributed to the Federal STT Program. If private R&D occurred without Federal participation, the Federal STT Program would merely speed the development process, limiting the benefits attributable to the Federal program to the value of obtaining cost-competitive STT at an earlier date. However, as discussed further in Section 7, private investment in R&D for the technologies currently included in the Federal STT Program is not anticipated in the absence of Federal support. The benefits of this R&D are extremely sensitive to world petroleum prices, which are largely determined through the price-setting policies of the OPEC cartel. If new energy technologies begin to displace significant quantities of imported petroleum, the OPEC cartel could lower petroleum prices to undercut the price of the new technologies. Private industry's concern for this threat, combined with their desire to avoid risking a significant possibility of losing substantial resources, is expected to be sufficient to virtually eliminate private STT R&D efforts in the absence of Federal participation. Thus, the entire benefits of STT R&D have been attributed to the Federal R&D effort.

6.3 STT, THE TRANSITION TO COAL, AND THE EPRI SYNTHETIC UTILITIES

The utility simulation in this report is designed to measure the average regional value of STT. Correspondingly, the incremental value of STT, as estimated in this analysis, reflects the value to utilities exhibiting average characteristics for each region, assuming the utility's mix of generating capacity has evolved to the cost minimizing mixture by the year 2019. Specifically, utility simulations were conducted using the EPRI synthetic utilities for the western and south central regions of the United States. The EPRI synthetic utilities are designed to provide a consistent set of utility data representing the average utility for the region in question. The EPRI data include 1990 generating capacity, operating characteristics, and electricity demand patterns. A screening curve analysis, assuming NEP-III fuel prices, was used to model the change in the utility's mix of generating capacity over time. The value of the fuel displaced by STT increases as the fuel price scenario increases. However, the impact of increasing fuel costs is partially offset by changes in the utility capacity mix. While Tables 4-4, 4-5, and 4-6 illustrate that the coal transition is extensive for all fuel price scenarios, the anticipated transition from oil- and natural gas-fired power plants to coal-fired capacity is more dramatic in the high fuel price scenario than in the low price scenario.

Taken together, the EPRI synthetic utility characteristics and the projected transition toward coal-fired power plants represent a situation that is relatively unfavorable for solar thermal electric systems (without storage). STT is forced to compete primarily with coal-fired generating capacity. As Figure 6-3 illustrates, coal represents 60% of the fuel displaced for the first 1% penetration in the low fuel price scenario. The coal displacement percentage increases as STT penetration increases. It is also higher under the medium and high fuel price scenarios.

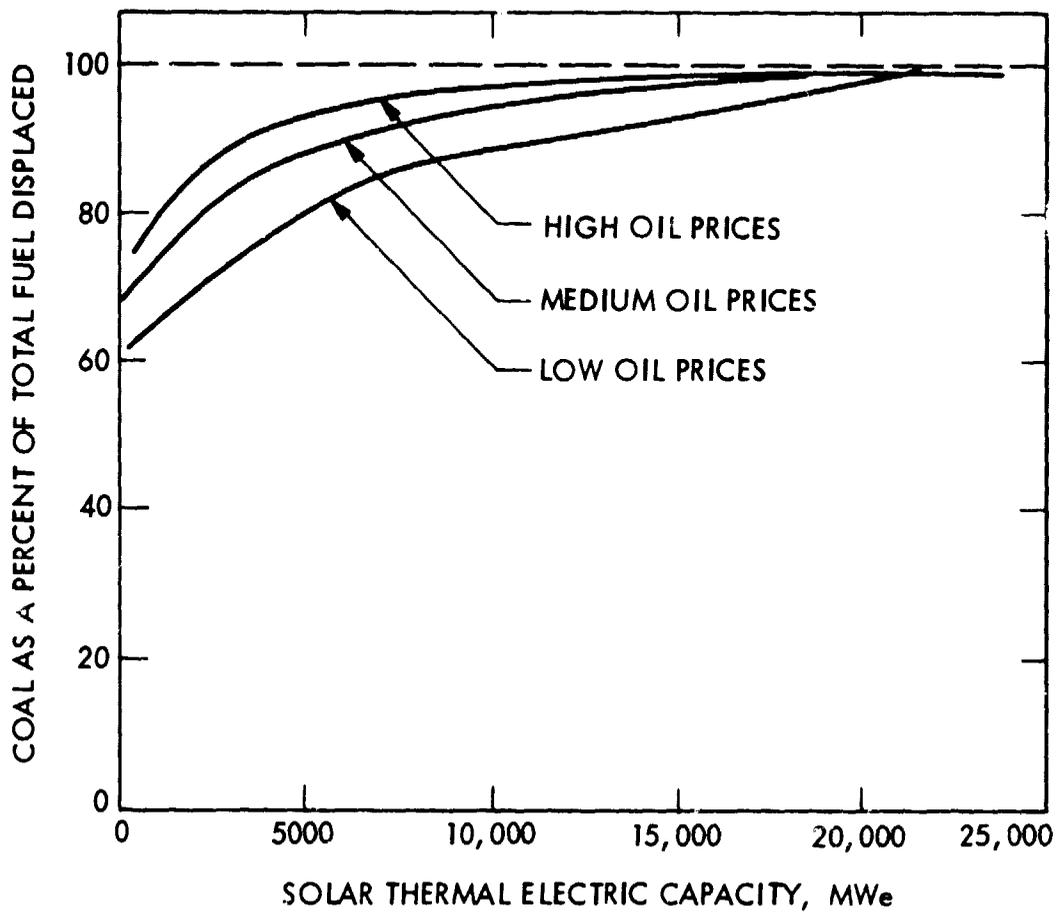


Figure 6-3. 1990 Solar Thermal Electric Capacity and Life-Cycle Coal Displacement

The high incidence of coal displacement results from two influences: the high percentage of coal-fired capacity in a utility's generation mix, and the poor correspondence between peak insolation and peak electricity demand in the EPRI electricity demand data. Because an aggressive transition toward coal is assumed in this analysis, oil and natural gas are used primarily as peak-load fuels. Base- and intermediate-load demands are satisfied by coal and nuclear capacity. As a result, STT will displace oil and natural gas only to the extent that solar energy is available during periods of peak demand. As Table 6-2 indicates, peak electricity demand in the EPRI synthetic utilities for the western and south central United States occurs in many cases during hours of the day that have poor insolation. With this capacity mix and electricity demand pattern, STT without storage is forced to compete with coal-fired capacity.

Table 6-2. EPRI Regional Utility Systems: Peak Electricity Demand (a,b)
(Ref. 6, pp B-28, B-29, B-44, B-45)

Region	Season	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Western	Spring/Fall (0.76-0.90)	2000- 2100	1000-1100 + 2000-2100 (d)	1000-1300 (d) + 2000-2100	1000-1100 (d) + 2000-2100	1000-1100 (d) + 2000-2100	1000-1100 (d) + 2000-2100	1100-1200 (d) + 2000-2100
	Summer (0.81-1.00) (c)	1200-1300 (d) + 1800-2100	1100- 1300	1400-1500 + 1700-1900 (d)	1100- 1400	1100-1500 + 1800 (d)	1200-1400 (d) + 1700-1800	1100-1300 (d) + 1800-1900
Western	Winter (0.85-0.97) (c)	1800- 2000	900-1100 + 1800-1900 (d)	1800- 1900	900-1000 + 1800-1900 (d)	900-1000 + 1800-1900	900-1000 + 1800-1900 (d)	1000-1100 + 1800-1900 (d)
	Spring/Fall (c)	0800- 1000	1000- 1100	1000- 1100	0800- 0900	0800- 1000	1000- 1100	1000-1200 + 2000-2100 (d)
South Central	Summer (0.90-1.00) (c)	1600- 1800	1400- 1500	1600- 1700	1300- 1500	1600- 1700	1500- 1700	1600- 1800
	Winter (0.65-0.75) (c)	1800- 1900	1000-1100 + 1800-1900 (d)	800-900 (d) + 1800-1900	700-800 (d) + 1800-1900	800-900 (d) + 1800-1900	700-900 (d) + 1800-1900	1000- 2200

(a) Times are based on a 24-hour clock.

(b) Dual peaks are included in table if demand for second peak is at least 95% of primary peak.
(Primary peaks are denoted by note d.)

(c) Designates range of monthly peak per season as a fraction of the annual peak.

(d) Primary peak.

SECTION 7

EARLY MARKETS FOR SOLAR THERMAL ELECTRIC SYSTEMS

Despite the high percentage of coal displacement, Figure 6-1 indicates that STT can compete, on a limited basis, in utilities that exhibit these average characteristics. As Figure 7-1 indicates, STT provides a cost competitive alternative, using Albuquerque insolation and the high fuel price scenario, as long as the coal percentage does not exceed 90% and the STT program achieves the \$1750/kWe cost target. The maximum allowable coal percentage falls to 75 and 30% in the medium and low fuel price scenarios, respectively. According to Figure 6-3, these coal percentages are surpassed after relatively low STT penetrations in coal-dominated utilities with evening and morning peaks. However, Table 6-1 indicates that the net energy cost savings associated with cost-competitive STT installations can be significant with high fuel prices and/or low STT system costs, even when coal is the primary fuel displaced.

In actuality, initial STT installations during the late 1980s and early 1990s will occur in applications where the value of STT is relatively high and they may rely on beneficial financial arrangements. Utility simulation using average regional characteristics cannot accurately reflect these favorable circumstances. Early applications include those utilities that continue to use a significant quantity of oil and natural gas, utilities that have a close correspondence between peak electricity demand and peak insolation, as well as remote sites and non-grid-connected applications (island utilities, stripper oil wells, agricultural irrigation, etc.). Stimulated by both the Federal Business Energy Tax Credit and Federal accelerated depreciation and augmented in some states by additional energy tax credits and accelerated depreciation, third party investors offer an attractive funding source through which STT can penetrate the early electric utility and remote-site markets.

7.1 FAVORABLE GRID-CONNECTED ELECTRIC UTILITIES

As discussed previously, the utility characteristics used in this analysis represent average regional characteristics. Some utilities will have characteristics more favorable to STT, while others will be less favorable. Initial STT installations during the late 1980s and early 1990s will occur in utilities where the value of STT is the greatest. This will include those utilities that continue to use a significant quantity of oil and natural gas, and/or utilities with a close correspondence between peak insolation and peak energy demand (e.g., the Southern California Edison Company). Identification of particularly favorable utilities, estimation of the economic market potential, and assessment of the corresponding energy cost savings require utility-specific case studies.

Detailed case studies are beyond the scope of this report; however, Figure 7-2 can be used to indicate the relationship between the net energy cost savings per kWe of STT capacity and the quantity of coal displaced as a percent of total fuel displacement, assuming fuel prices follow the medium price scenario and STT system costs achieve the values indicated.

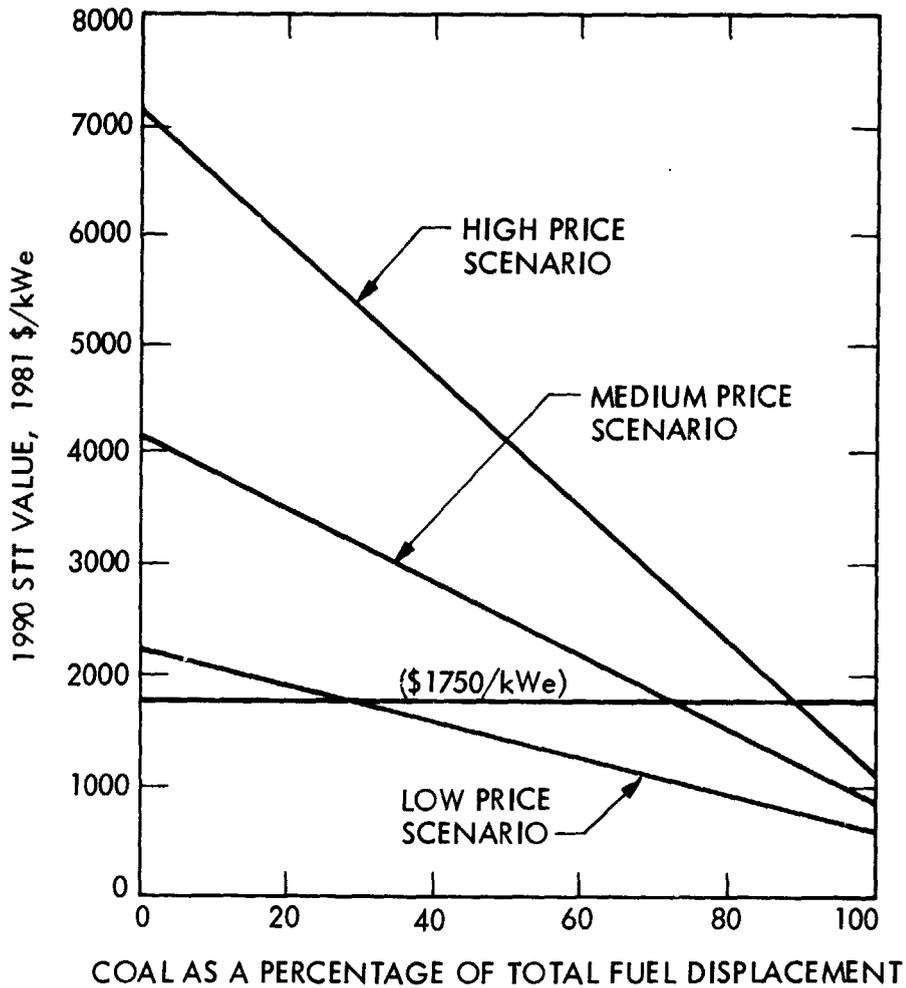


Figure 7-1. STT Value and the Percentage of Coal Displacement (Investor-Owned Utility; Two Fuels: Oil and Coal; Albuquerque Insolation; No Storage, CF (Capacity Factor) = 25%)

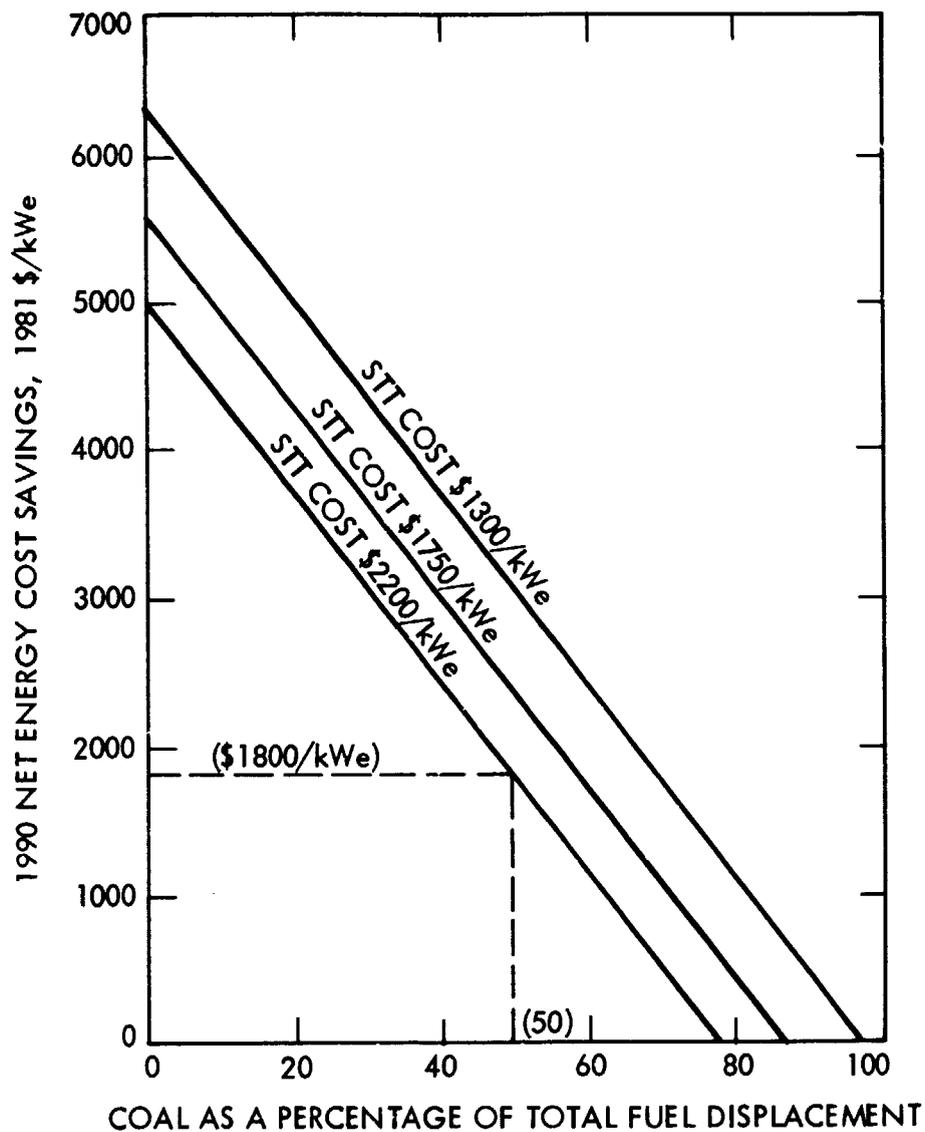


Figure 7-2. Net Energy Cost Savings and the Percentage of Coal Displacement (Investor-Owned Utility; Two Fuels: Oil and Coal; Albuquerque Insolation; No Storage, CF = 25%; Medium Fuel Price Scenario)

According to Figure 7-2, if STT penetrates a utility where it displaces 50% coal and 50% oil, the net energy cost savings will equal \$1800/kWe given STT system costs of \$2200/kWe and medium fuel prices. For a 100-MWe STT installation, the resulting energy cost savings would equal 180 million dollars. By contrast, Figure 6-1 indicates that STT systems at \$2200/kWe are not cost-competitive in the medium oil price scenario. This example illustrates that relative to the average regional utilities, STT will have a higher value in the favorable utilities which are expected to account for early STT installations. As a result, Figure 6-1 is likely to understate the actual economic market potential for early, high-cost STT systems. Similarly, the energy cost savings actually realized from early STT installations may be greater than indicated in Table 6-1.

7.2 REMOTE SITE APPLICATIONS

In addition to grid-connected electric utilities with favorable characteristics, there are other early markets for electric applications of solar thermal technologies not covered by this analysis. These early markets include remote site (non-grid-connected) electricity consumers in relatively high insolation locations. Oil-fired power plants are generally used to produce electricity at these remote sites. Island utilities (Puerto Rico, Hawaii, and the Virgin Islands), agricultural irrigation, and stripper well applications are examples of remote site applications. According to Electric World (Ref. 21), Puerto Rico, Hawaii, and the Virgin Islands had a combined 1978 oil-fired generating capacity of approximately 5700 MWe. STT (without storage) could be used to displace the petroleum consumed by the utilities on these islands during daylight hours. In agricultural applications, the 1990 economic market potential for small-scale STT systems (less than 1 MWe) has been estimated at approximately 2000 MWe (Ref. 26). Stripper well applications provide an additional market for small-scale solar thermal electric systems (Ref. 27). These early markets will further expand the 1990 economic market potential and the net energy cost savings as estimated in this analysis.

7.3 THIRD PARTY OWNERSHIP

Stimulated by both the Federal Business Energy Tax Credit and the Federal Accelerated Capital Recovery System and augmented in some states by additional energy tax credits and depreciation allowances, third party investors offer an alternative means by which STT can penetrate the electric utility and remote site markets described above.¹⁹ More specifically, the Economic Recovery Tax Act of 1981 (ERTA) allows for a five-year depreciation

¹⁹Because public utility investments are normally perceived as being secure investments, utilities generally face lower debt and equity costs than third party investors. As a result, third party investors will offer attractive early markets for STT only if they can capture tax incentives not available to public utilities. This analysis assumes that state and Federal tax incentives for third party investors are extended at least until 1990. Without these extensions, significant third party investment in STT is not anticipated.

period for STT systems owned by third party investors. The annual depreciation percentages for property placed in service after December 31, 1985 are 20, 32, 24, 16, and 8 for years one through five, respectively.²⁰ The depreciation basis is the entire capital cost of the STT system. Investor-owned utilities are allowed a 15-year depreciation period on the entire cost of the system. In addition, under ERTA both third party investors and public utilities can claim a 10% investment tax credit; third party investors are allowed an additional 15% business energy tax credit. Third party investors in the State of California can also claim an additional 25% energy tax credit and three-year straight-line depreciation on the cost of the STT system less the state energy tax credit. The relevant financial parameters for both third party investors and public utilities are given in Table 7-1.

Figure 7-3 shows the 1990 relative value of STT to investor-owned utilities and third party investors for Albuquerque insolation and the medium fuel price scenario, assuming extension of the state and Federal tax incentives.²¹ Given the financial parameters used in this analysis, third party financing provides an attractive alternative, particularly in states such as California that offer state tax incentives.²²

The Tax Equity and Fiscal Responsibility Act of 1982 (TEFRA) reduced the Federal depreciation allowances available to both public utilities and third party investors. The depreciation periods remained unchanged (15 years for public utilities and 5 years for third party investors), but the annual allowances were altered to reduce the percent depreciation claimed in the earlier years.²³ In addition, under TEFRA 50% of the Federal tax credits

²⁰See the Economic Recovery Tax Act of 1981, Act Sec. 201(a).

²¹Depreciation allowances and tax credits can be modeled as affecting either the cost of a solar thermal electric system or its value. The methodology used in this analysis is based on estimating the value of STT to a potential investor. Therefore, for the purpose of this analysis, accelerated depreciation and energy tax credits have been modeled as increasing the value of STT. (For further discussion, see Appendix B.)

²²The relative values in Figure 7-3 are very sensitive to the debt/equity ratio assumed for third party investors. This figure assumes a 50% debt fraction. If the debt fraction increases and debt and equity costs remain unchanged, the premium for third party investors increases. With medium fuel prices, if the debt fraction falls below 45%, the value of STT will be greater for investor-owned utilities except in states such as California, which provide additional tax incentives (the critical debt fraction is 50 and 35% for the high and low fuel price scenarios, respectively).

²³TEFRA actually rescinded the successively more rapid depreciation schedules proposed in ERTA for properties placed in service during and after 1985. The annual percentage allowance for 5-year property placed in service after 1985 changed from 20, 32, 24, 16, and 8 to 15, 22, 21, 21, and 21. A similar but less dramatic change occurred for 15-year public utility property.

Table 7-1. Financial Parameters: Third Party Investors and Investor-Owned Utilities

Parameter	Investor-Owned Utility	Third Party Ownership: National Average	Third Party Ownership: California
System Life, yr	30	30	30
Depreciation Life, yr			
Federal	15	5	5
State	-	-	3
Depreciation Method			
Federal ^(a)	ACRS	ACRS	ACRS
State	-	-	Straight Line
Effective Tax Rate, %	48	52	55.5
Federal Tax Rate, %	46	50	50
State Tax Rate, %	4	4	11
Federal Investment Tax Credit, %	10	10	10
Effective Energy Tax Credit, %	-	15	275
Federal Energy Tax Credit, %	-	15	15
State Energy Tax Credit, %	-	-	25
Return on Equity (Real), ^(b) %	5.6	15	15
Return on Debt (Real), ^(b) %	3	7	7
Debt Fraction, %	50	35-65	35-65
Other Tax and Insurance, % (Fraction of Capital Investment)	2	2	2
Operation and Maintenance (O&M), % (Fraction of Capital Investment)	2	2	2
O&M Escalation Rate (Real), %	1	1	1
General Inflation Rate, %	6	6	6

(a) Accelerated Capital Recovery System (ACRS) as specified in the Economic Recovery Tax Act of 1981 and modified in the Tax Equity and Fiscal Responsibility Act of 1982.

(b) Lower debt and equity costs for investor-owned utilities reflect the higher perceived security associated with public utility investments.

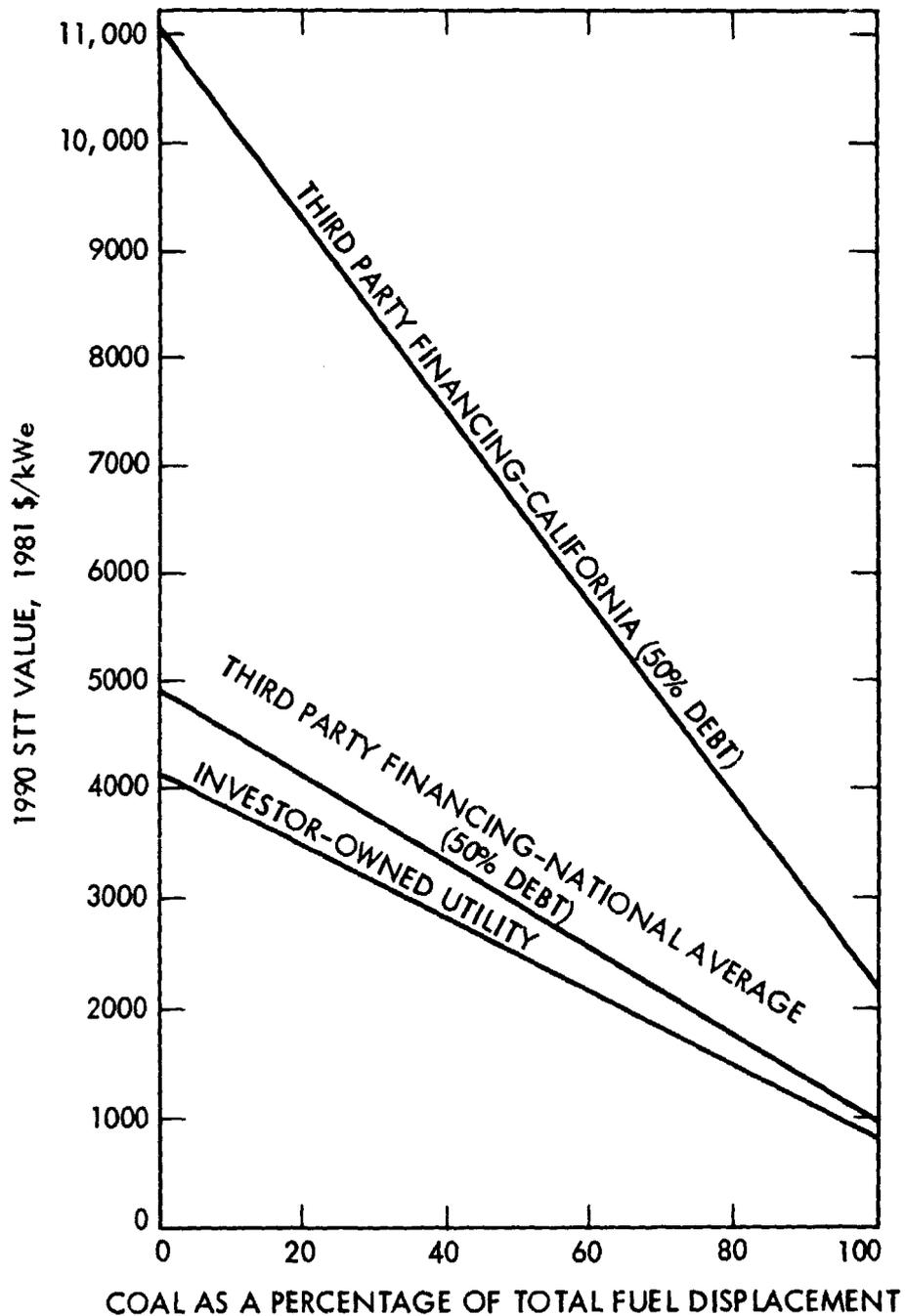


Figure 7-3. Third Party Financing Before TEFRA (Two Fuels: Oil and Coal; Albuquerque Insolation; No Storage, CF = 25%; Medium Fuel Price Scenario; Extension of Federal and State Tax Incentives)

claimed must be deducted from the capital investment prior to calculating the depreciation allowance. This reduces the depreciation base by 5% for public utilities and by 12.5% for third party investors (assuming extension of the Federal Energy Tax Credit).

Figure 7-4 shows the relative value of STT to investor-owned utilities and third party investors after TEFRA. With the financial parameters given in Table 7-1 and a 50% debt equity ratio, third party financing is more attractive than public utility ownership only in states that provide additional tax incentives. Without state measures, the debt fraction in the medium fuel price scenario must exceed 50% before the value to third party investors exceeds the value to investor-owned utilities. The critical debt fraction for the high and low fuel price scenarios is 55 and 45%, respectively. Because a debt fraction exceeding 50% is considered unlikely for third party investments in early STT installations, TEFRA has limited the potential for third party financing of early STT systems either to states offering additional tax incentives (e.g., California) or to applications with special financial arrangements (e.g., companies having a vested interest in establishing a solar thermal production capability). For reference, Table 7-2 lists the income tax incentives currently available for the states included in this analysis. Based on Table 7-2, California is the most attractive market for third party financing of solar thermal electric systems (contingent upon the extension of both State and Federal tax incentives, a prerequisite considered essential if third party investors are to finance early STT systems).

Figure 7-5 shows the relationship between the value to third party investors of an STT system coming on-line in California in 1990 and the percentage of displaced fuel, which in this case is coal. This figure assumes that the Federal and State tax incentives are extended at least until 1990 so that they can be claimed for STT installations coming on-line in 1990. Assuming 50% debt/financing and the medium fuel price scenario, Figure 7-5 indicates that early STT systems, costing up to \$3000/kWe, are cost-competitive in 1990 for electric utility applications where they displace up to 70% coal. In the high fuel price scenario, the maximum coal percentage increases to 85%.²⁴

²⁴These coal percentages are based on a 50% debt/equity ratio. If the debt/equity ratio were 65% and all debt and equity costs remained unchanged, the maximum coal percentage would increase to 100% for the high, medium, and low fuel price scenarios. For a 35% debt/equity ratio, the coal percentage would fall to 60 and 30% in the high and medium fuel price scenarios, respectively. (Third party financing is not economically viable in the low fuel price scenario.) Of course, as the debt/equity ratio increases (decreases), it is likely that the cost of debt and equity will increase (decrease) as well. This will tend to moderate the change in the maximum coal displacement percentage. Since the coverage ratios calculated for a \$3000/kWe system are approximately equal to one for 50% debt financing, even a 50% debt/equity ratio is considered optimistic.

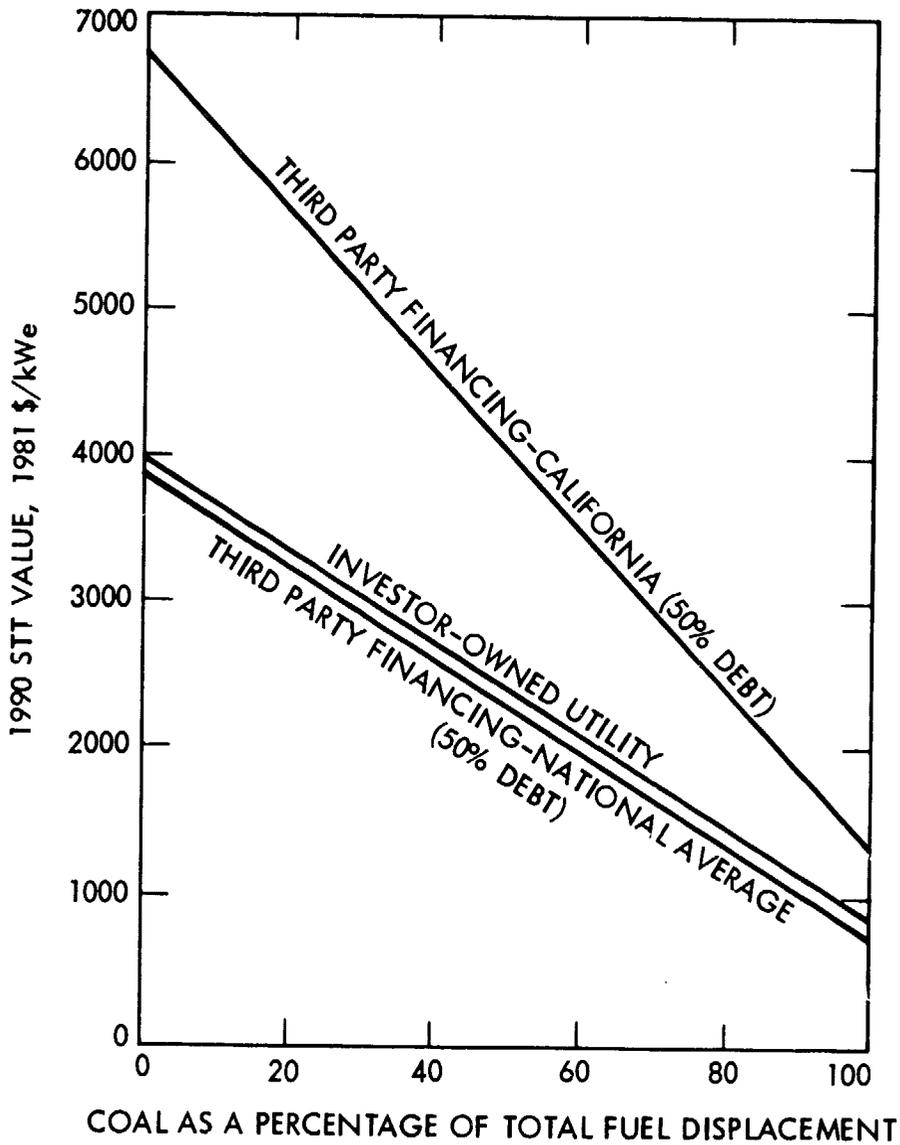


Figure 7-4. Third Party Financing After TEFRA (Two Fuels: Oil and Coal; Albuquerque Insolation; No Storage, CF = 25%; Medium Fuel Price Scenario; Extension of Federal and State Tax Incentives)

Table 7-2. State Income Tax Incentives for Solar Energy^(a)

State	Income Tax Incentives
Alabama	None
Arizona	Election of 35% credit with \$1000 maximum or 36-month depreciation
Arkansas	100% deduction
California	25% credit, depreciation over 36 months on investment less credit
Colorado	30% credit with \$3000 maximum
Florida	None
Hawaii	10% credit
Kansas	30% credit with \$4500 maximum; 60-month depreciation
Louisiana	None
Mississippi	None
Missouri	None
Nevada	None
New Mexico	None
Oklahoma	15% credit
Texas	60-month depreciation for corporations
Utah	10% credit with \$3000 maximum

^(a)Source: U.S. Office of Housing and Urban Development, Office of Policy Development and Research, "Solar Data Bank Report: Tax Breaks for Non-Residential Uses of Solar Energy," DR-121, National Solar Heating and Cooling Information Center, Franklin Research Center, Rockville, Maryland, February 26, 1981.

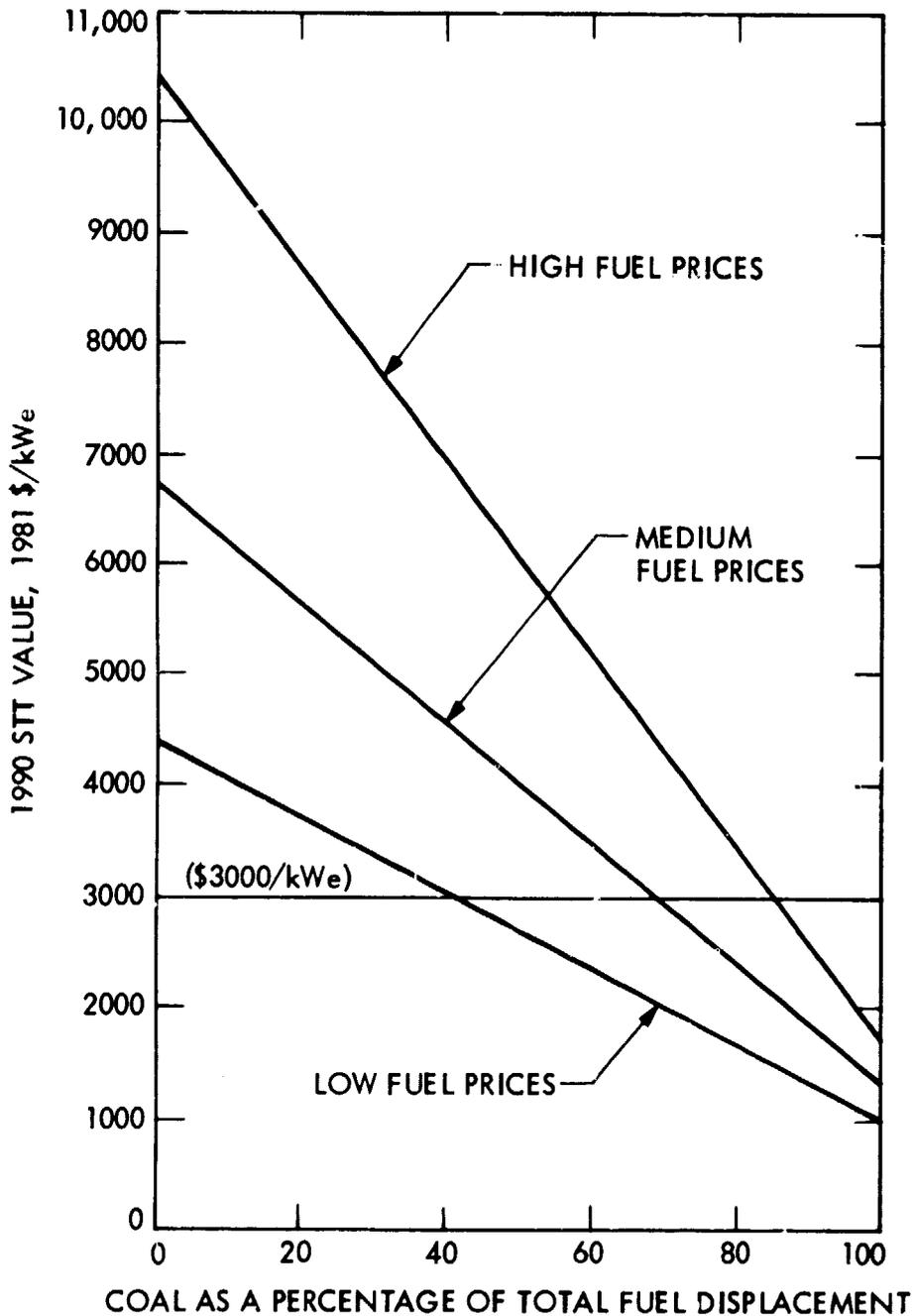


Figure 7-5. STT Value and Third Party Financing in California (After TEFRA; Two Fuels: Oil and Coal; Albuquerque Insulation; No Storage, CF = 25%; 50% Debt Financing; Extension of Federal and State Tax Incentives)

Assuming extension of the Federal and State tax incentives, third party investors in California are expected to provide a pre-1990 market for STT systems. The total economic market potential and corresponding energy cost savings will depend on the particular characteristics of the installations in question.²⁵

7.4 STORAGE-COUPLED SOLAR THERMAL ELECTRIC SYSTEMS

The addition of storage capacity can extend the flow of energy from STT beyond daylight hours. Energy collected and stored during periods of high insolation can be discharged on demand during the night. With sufficient storage capacity, storage-coupled solar thermal electric systems can potentially provide a constant flow of energy 24 hours a day. Storage enables STT to serve either base- and intermediate-load electric power applications, or peak-load applications where there is a poor correspondence between peak electricity demand and peak insolation. Thermal storage is currently the most cost-effective storage medium. The ability of solar thermal technologies to effectively utilize thermal storage makes storage-coupled STT systems a particularly attractive option.²⁶

While detailed analysis is beyond the scope of work for FY 1982, some preliminary observations regarding the impact of storage on the incremental value of STT can be provided here. The optimal storage capacity and dispatching strategy will depend both on the costs of storage and the relative time-dependent value of the energy displaced by the solar energy system. Storage capacity should be added as long as the increase in STT value (as storage capacity increases) exceeds the corresponding increase in system costs. Storage appears to be particularly valuable in regions where there is a slight mismatch between peak electricity demand and peak insolation. In these applications, a small amount of storage capacity would allow STT to

²⁵For third party owners, investments in STT must be compared with other solar investments. This comparison combined with the low coverage ratio as debt financing approaches 50 percent is expected to limit the market for third party investors to individuals or companies who have a vested interest in establishing an STT industry.

²⁶Comparisons of relative storage costs depend critically on the storage power (kWe), capacity (kWeh), and throughput efficiency. Since relative storage costs fluctuate for alternative solar thermal technologies and storage capacities, specific cost estimates are not provided here. Other published reports, however, indicate that thermal storage generally has lower costs and significantly higher throughput efficiencies than other types of storage. See for example: T. Fujita, et al, "Comparison of Advanced Thermal and Electric Storage for Parabolic Dish Solar Thermal Power Systems," Jet Propulsion Laboratory, Pasadena, California, presented at the Seventeenth IECEC, Los Angeles, California, August 8-13, 1982; and K. W. Battleson, Solar Power Tower Design Guide: Solar Thermal Central Receiver Power Systems, a Source of Electricity and/or Process Heat, SAND81-8005, Sandia National Laboratories, Livermore, California, April 1981.

displace high-cost peak-load fuels (primarily diesel oil) rather than intermediate-load fuels (typically coal). Electricity demand frequently peaks (either a primary or secondary peak) during the late afternoon and/or early evening or early morning both in the western and south central regions (recall Table 6-2). The increased value associated with using solar energy to satisfy these peak demands is expected to exceed the cost of required storage. If analysis confirms this relationship, storage will increase the economic market potential of STT and the corresponding energy cost savings. Additional storage capacity, beyond that required to satisfy peak-load demands, would increase the solar thermal capacity factor and result in a larger capacity credit. The cost effectiveness of this additional storage capacity depends on the cost of the conventional generating capacity displaced relative to the change in STT system costs as storage capacity increases.

Figure 7-6 provides a preliminary indication of the value of storage-coupled solar thermal electric systems. Figure 7-6 shows the 1990 incremental value of STT versus installed STT capacity, assuming sufficient storage capacity to shift STT power output to satisfy peak-load electricity demands. In other words, the values reflected in these curves are based on the assumption that STT displaces the highest valued fuels, regardless of the correlation between peak demand and peak insolation. For reference, Figure 7-6 also shows the incremental value curve for STT with the medium fuel price scenario and no storage.²⁷ No system costs are shown because costs depend on the storage capacity. STT incremental values with and without storage are not directly comparable because of the varying system costs; however, Figure 7-6 does indicate that storage can potentially increase the value of STT by approximately 50%. The 1990 economic market potential and corresponding energy cost savings of STT with storage will depend on the relative cost and value of storage, but Figure 7-6 indicates that storage can be expected to increase the 1990s' market for STT.

²⁷As the coal displacement percentage for storage-coupled STT systems approaches 100%, the no-storage and storage values will converge. However, due to the relatively large oil capacity remaining in the utility capacity mix during the 1990s (recall Table 4-4), this convergence is not observed for the penetration levels included in Figure 7-6.

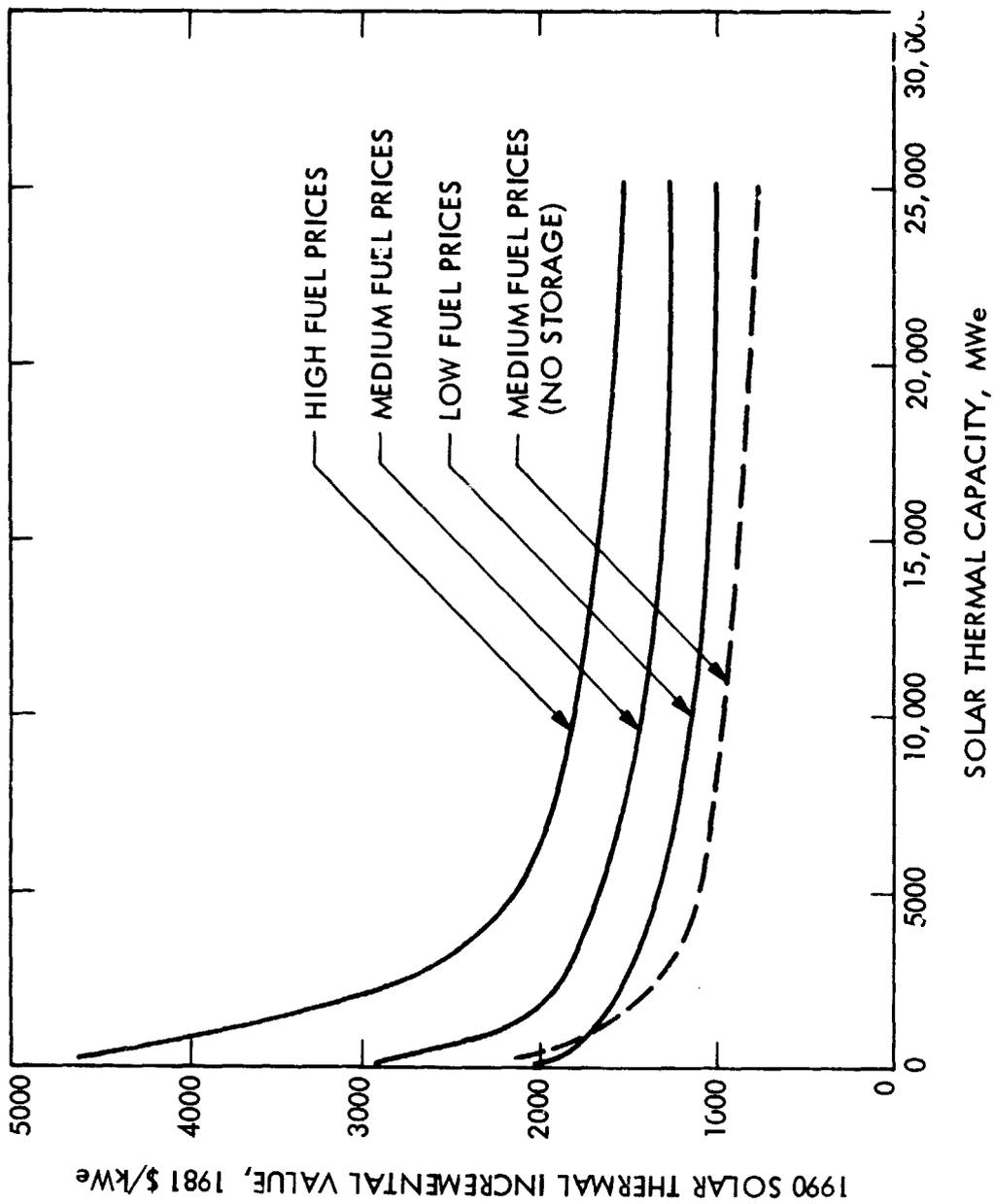


Figure 7-6. 1990 Incremental Value of STT with Storage (Investor-Owned Utilities; Southwest and South Central Regions)

SECTION 8

FEDERAL PARTICIPATION IN THE DEVELOPMENT OF STT

8.1 IMPLICATIONS FOR PRIVATE-SECTOR INVESTMENT

The potential benefits from the development of cost-competitive STT systems are significant. Figure 6-1 showed the economic market potential for solar thermal electric systems during the early 1990s under alternative assumptions regarding future fuel prices and STT system costs. Table 6-1 quantified the corresponding energy cost savings. Third party ownership, remote-site applications, favorable utility characteristics, and storage-coupled solar thermal systems are expected to further expand both the early market potential and economic benefit of STT. From Table 6-1, it is evident that the benefits are significant under plausible scenarios regarding future fuel prices and STT system costs.

8.1.1 Fuel Price Uncertainty

An important point becomes evident from examination of Figure 6-1 and Table 6-1. STT benefit projections are extremely sensitive to the level of STT system costs and future fuel prices. If system costs remain above \$3000/kWe, the market for STT will be limited. Similarly, if fuel costs follow the low fuel price scenario, the near-term market for STT will be small even if STT system costs approach the \$1750/kWe cost target. Reducing STT system costs requires investment in both R&D and solar thermal production facilities. If fuel prices follow the low price scenario, private industry faces a substantial risk that all of this investment will be lost.

Future oil price projections vary widely over time. Figure 8-1 shows the fluctuations in the oil price projections made by Data Resources, Inc., (DRI) over a four-year period. Figure 8-1 also shows the oil price forecasts used in this report. The DRI forecasts made in Summer 1979 and Spring 1980 illustrate the dramatic increase in fuel price projections that followed the 1978-79 Iranian oil embargo. Prior to the embargo, price forecasts fell between the NEP-III low and medium fuel price scenarios. After the embargo, the medium to high scenarios were considered most probable. Since Spring 1980, oil price projections have been decreasing. In particular, following the oil glut beginning early in 1982, price forecasts are once again in the range of low to medium oil price scenarios. The wide fluctuations experienced in energy price projections over the last four years illustrate the risk associated with investments in STT R&D and production facilities.

8.1.2 OPEC Control

Fuel price uncertainty is accentuated by the influence of the OPEC cartel. The OPEC nations possess a significant percentage of the lowest cost oil resources. As a result, world oil prices are largely determined through the price-setting policies of OPEC, and OPEC's influence is expected to

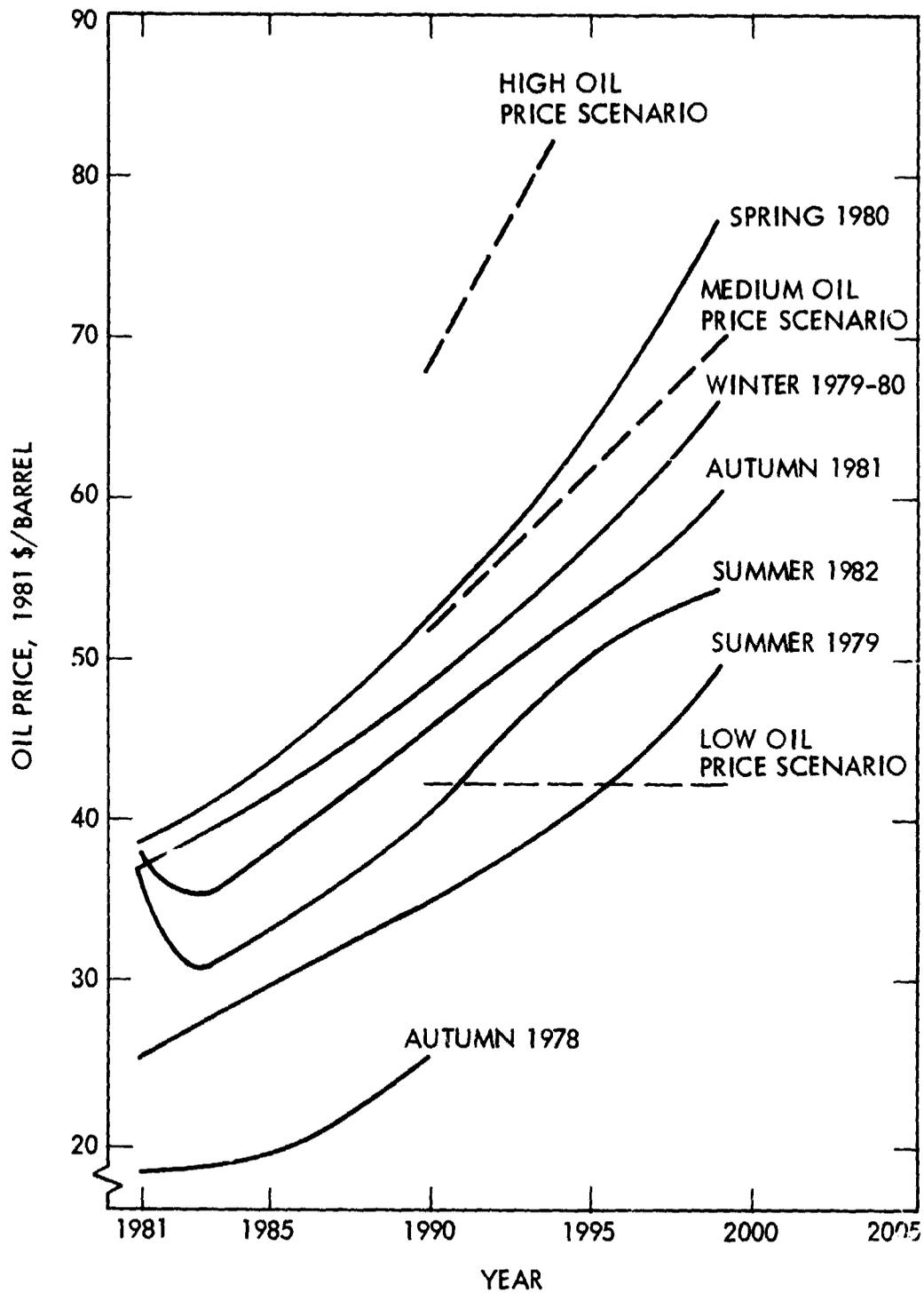


Figure 8-1. Baseline Imported Crude Oil Price Forecasts (Ref. 8)

continue in the future. If solar thermal technologies (or other alternative energy resources) threaten to displace substantial quantities of imported oil, OPEC has the ability to lower oil prices and undercut the price of the developing technologies. In other words, there may be a relationship in Table 6-1 between STT system costs and the fuel price scenario: the lower the system costs, the more likely the low fuel price scenario.²⁸ (For further discussion see Ref. 28.)

Uncertainty over future fuel prices and the potential link between alternative energy technologies and future oil prices is expected to limit private investments in both R&D and production capacity for alternative energy technologies including STT. STT benefit projections range from \$0 to greater than 10 billion. Capturing these benefits requires expenditures for both R&D and production facilities. If oil prices remain low, there is a substantial risk that all of this investment will be lost. The lack of potential markets under the low oil price scenario, coupled with concern for the threat associated with OPEC's control over energy prices, will dissuade private firms from investing in STT. Private industry cannot be expected to fund both the development of STT as well as the production facilities required to make STT cost-competitive.

8.1.3. Public Versus Private Objectives

Public objectives, however, differ from those of a private profit-making firm. The public objectives include offsetting the oil price uncertainty introduced by OPEC, protecting the economy from the disruptive influence of rapidly escalating fuel prices, and limiting the environmental consequences of oil, coal, and nuclear facilities. Private incentives for conducting STT R&D are limited due to the oil price uncertainty introduced by the OPEC cartel. From society's point of view, the values in Table 6-1 represent costs which might be incurred by not developing an STT option. In the high fuel price scenario, these costs are substantial (exceeding \$10 billion) and can be avoided if resources are devoted to STT development. In addition to the benefits associated with energy cost savings, expenditures on STT R&D would limit both the disruptive impact of future increases in world oil prices and the environmental deterioration associated with petroleum, coal, and nuclear facilities. Private industry is unlikely to fund this R&D in the presence of OPEC's influence over oil prices. Federal participation is required to offset OPEC's influence and capture the significant national benefits associated with STT R&D.

8.2 CURRENT FEDERAL INCENTIVES

One impediment to the widespread application of solar thermal electric systems is the current high system cost. As is evident from the preceding

²⁸Successful development of STT alone would probably not generate significant pressure on OPEC oil prices. If STT cost reductions reflect reductions in the costs of other alternative energy resources as well, the correlation between STT system costs and future oil prices may be significant.

discussions, the market for STT systems (currently costing in the range of \$4000/kWe) is limited given today's oil prices. Furthermore, the economic and technical uncertainties introduced by the absence of operating experience for large-scale solar thermal electric systems create additional barriers to the installation of STT. Combined with uncertainty regarding future fuel prices, these factors make private investments in STT R&D or system installations extremely unlikely. System cost reductions can be secured by two means: (1) increasing production volume to capture both scale and learning economies and (2) R&D to develop more efficient solar thermal technologies.

The Federal government can pursue a variety of alternative policies to stimulate investment in STT R&D and production facilities. Two Federal incentive mechanisms currently used include (1) Federal tax incentives to encourage STT installations and (2) direct R&D funding. Tax incentives, including accelerated depreciation and energy tax credits, subsidize capital expenditures and reduce the effective after-tax cost of STT systems. Subsidized by tax incentives, third party investors can provide early markets for STT systems. These markets would generate operating experience and reduce system costs through increased STT production volume. To attract third party investors, however, it is considered essential that state and Federal tax incentives be extended until at least 1990. Stimulated by the operating experience and cost reductions provided through third party investments during the late 1980s, STT could penetrate other favorable markets during the early 1990s (e.g., non-grid-connected electric applications, grid-connected utilities with significant oil-fired capacity and a close correspondence between peak insolation and peak electricity demand, and storage-coupled STT systems). Third party investors and favorable applications can provide the production volume and operating experience necessary to establish a viable STT industry infrastructure. Simultaneously, direct R&D funding will assist in establishing solar thermal technologies capable of meeting the 1990 cost goal and the 2000 cost goal for STT electric systems without storage, \$1750/kWe and \$1200/kWe, respectively, in 1981 dollars. As Figure 8-2 illustrates, if STT system costs (without storage) fall within this range during the late 1990s, STT (without storage) can economically compete in electric utilities dominated by coal-fired generating capacity. Thus, Federal tax incentives during the late 1980s combined with direct R&D funding are expected to develop both the solar thermal technology base and industrial production capability required to establish a self-sustaining private STT industry during the late 1990s.²⁹

²⁹There are a variety of alternative Federal policies that would have a similar impact on the STT industry. Detailed comparison of these alternatives is beyond the scope of this report. Attention here is restricted to the potential impact of energy tax credits and direct R&D funding, two Federal incentives currently in use.

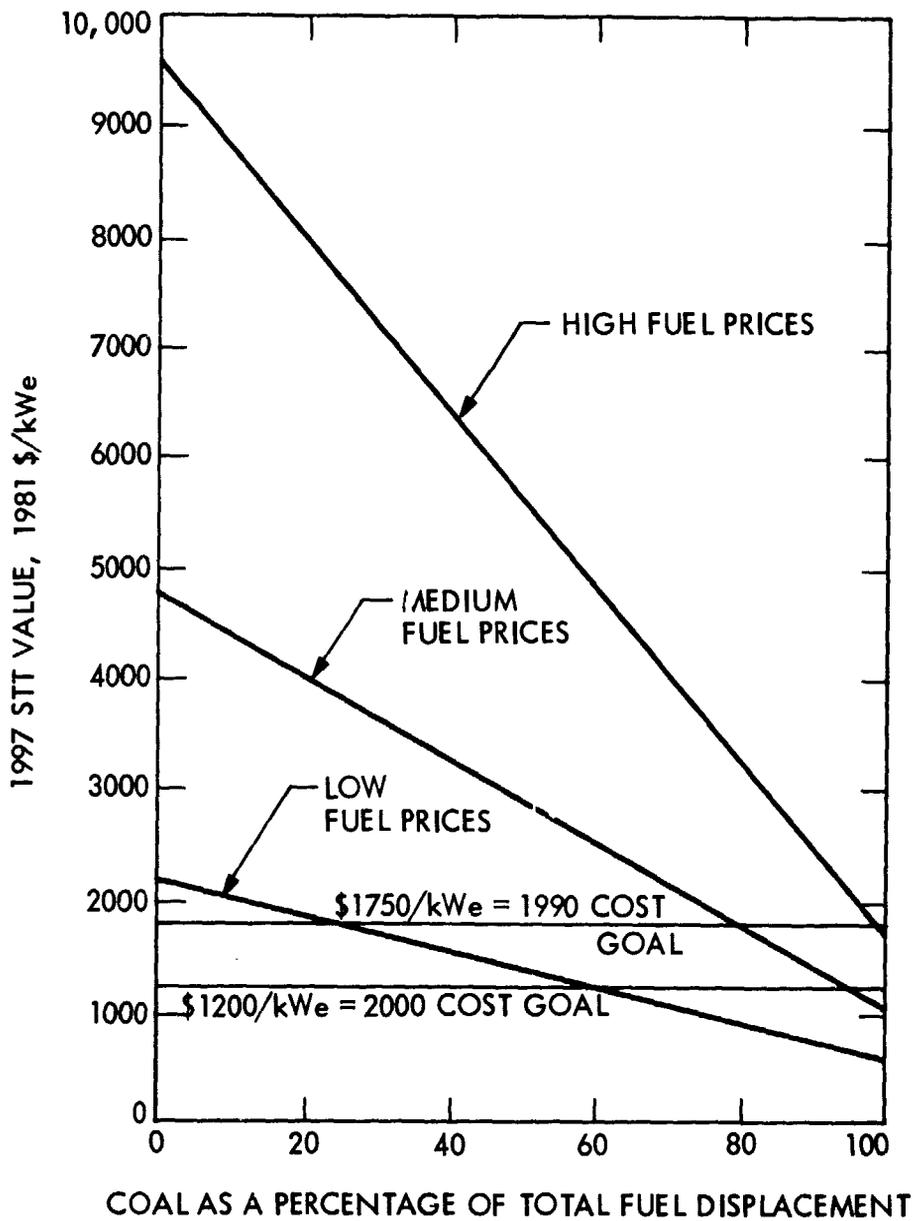


Figure 8-2. 1997 STT Value and the Percentage of Coal Displacement (Investor-Owned Utility; Two Fuels: Oil and Coal; Albuquerque Insolation; No Storage, CF = 25%; After TEFRA)

SECTION 9

CONCLUSIONS

Development of solar thermal technologies is consistent with national energy policies. Oil supply disruptions during the 1970s generated widespread public and political support for a diversified energy R&D portfolio. In the presence of technical, economic, and environmental uncertainties, a diversified R&D portfolio increases the probability of successfully developing domestic energy resources capable of satisfying a broad range of future energy demands without imposing significant environmental hazards. Avoiding excessive reliance on a single energy technology is one approach to limiting the possibility of a future energy crisis. STT provides a renewable domestic source of power capable of generating electricity, heat, or a combination of electric and thermal power. STT can be employed in a variety of economic sectors, including electric utilities, industries requiring thermal power, and in the future production of transportable fuels and chemical feedstocks. This flexibility makes STT a potentially valuable element of the national effort to diversify the energy sector.

This analysis has estimated the 1990 economic market potential and the corresponding energy cost savings associated with cost-competitive installations of STT in electric utility applications under a range of future fuel price scenarios and STT system costs. This analysis concludes that the potential benefits from Federal participation in solar thermal technology R&D can be expected to vary widely depending both on the STT system cost and on the relevant fuel price scenario. As with most R&D projects, the outcome is quite uncertain, as reflected by the range of plausible STT system costs. In the STT R&D program, however, this uncertainty is compounded by the extreme variability in expectations regarding future fuel prices. World oil prices are largely determined by the price-setting policies of the OPEC cartel, which can lower oil prices and undercut the price of developing technologies. After the 1978-79 Iranian oil embargo, fuel prices were generally expected to fall within the medium or high fuel price scenario. Since the oil glut early in 1982, the low oil price scenario appears most probable. Because fuel price expectations vary greatly, impacting the anticipated benefits from STT R&D, there is a greater-than-average uncertainty regarding STT R&D. To private industry, STT R&D represents a risky investment; private STT R&D initiatives are unlikely in the absence of Federal participation.

The Federal government, however, has a variety of concerns, including minimizing the impact of energy market imperfections, protecting the economy from the disruptive influence of rapidly escalating fuel prices, and limiting the environmental consequences of oil, coal, and nuclear facilities. Due to the energy market imperfections introduced by the OPEC cartel, private industry is unlikely to independently finance STT R&D. Expenditures on STT R&D could result in significant energy cost savings, limit the impact of oil price increases, and reduce environmental degradation associated with conventional energy technologies. Federal participation in STT R&D would help capture these significant national benefits.

The major conclusions of this analysis can be summarized as follows:

- (1) Third party investors (assuming extension of state and Federal tax incentives), non-grid-connected electric applications, grid-connected utilities with a heavy reliance on oil-fired capacity and a close correspondence between peak insolation and peak electricity demand, and storage-coupled STT systems are expected to provide early markets for solar thermal electric systems.
- (2) If STT system cost reductions are secured through Federal R&D programs and the increased production volume associated with early STT markets, solar thermal electric systems are expected to begin competing in coal-dominated grid-connected electric utilities in the mid-1990s. The economic market potential will increase as STT system costs (without storage) reach the range of \$1750/kWe to \$1200/kWe (the 1990 and 2000 cost targets, respectively, in 1981 dollars).
- (3) The energy cost savings associated with cost competitive STT installations range from \$0 to 10 billion (1990 values in 1981 dollars) depending on the scenario for future fuel prices and STT system costs. Since private investment in STT is unlikely in the absence of Federal participation, these benefits can be attributed to the Federal R&D program. If the Federal program continues at its current funding level between now and 1990, (approximately \$50 million per year), the present value of the resulting energy cost savings will significantly exceed the present value of the expenditures from early generation STT electric systems under all but a few combinations of system costs and fuel prices.

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APPENDIX A

INDIRECT IMPACTS

Solar thermal electric systems can provide a number of benefits in addition to the energy cost savings described in the text of this report. Included as additional impacts are environmental impacts and the balance of payments and national security impacts associated with reductions in oil imports. These are indirect impacts to the extent that they are not directly reflected in market prices. As such, indirect impacts do not enter private industry's decision making process.³⁰ From society's viewpoint, however, indirect impacts can have important social and economic implications. For this reason it is important to address the indirect impacts associated with the development of STT. In the presence of significant indirect benefits, the value of STT to society exceeds the value of STT to private industry. If unable to capture all relevant benefits, private industry will tend to underinvest in STT, providing additional rationale for Federal participation in STT development.

A.1 FIRST-ORDER ENVIRONMENTAL IMPACTS

Environmentally, STT provides important benefits by reducing the use of fossil and nuclear fuels in electric power generation. Reducing the use of nuclear fuels will help alleviate the problems associated with nuclear waste disposal; reducing the use of fossil-fired fuels will alleviate air pollution emissions (including SO_x, NO_x, and CO₂ buildup). Data on STT fuel displacement by fuel type can be used to indicate the extent of environmental impacts.

From the utility simulation used to derive the demand curves depicted in Figure 6-1, information is available regarding the quantity of each fuel type displaced by STT for each point on the demand curve. For assessing environmental impacts, coal and oil displacements are the relevant concerns. Table A-1 presents the average annual quantity of coal and oil displaced by STT for the three fuel price scenarios and STT system costs considered in this analysis. Considering the proposed 1990 air pollution standards, these data can be used to determine the reductions in air pollution attributable to STT for each fuel price and STT system cost combination.

Compared to the annual quantity of coal and oil consumed nationally in electric utility, transportation, industrial, commercial, and residential applications, the fuel displacements in Table A-1 are relatively insignificant. Correspondingly, the impact of STT on the national air pollution problem will also be limited.

³⁰The impacts considered as indirect benefits are equivalent to the external benefits discussed in standard economic textbooks.

Table A-1. Average Annual STT Fuel Displacement (Btu x 10¹²)

STT Cost, \$/kWe	Fuel Price Scenario					
	Low		Medium		High	
	Fuel Type					
	Coal	Oil	Coal	Oil	Coal	Oil
2200	0	0	0	0	7	3
1750	0	0	4	2	80	14
1300	3	2	45	12	250	17

Regionally, however, the environmental impact of STT can be significant. Electric power plants account for a substantial percent of the pollutants in many regional air basins. STT penetration in these air basins would reduce the capital expenditures associated with emission control technology. STT would also eliminate power plant emissions that were not controlled by emissions standards. These additional reductions in air pollution provide health benefits and reduce crop damage. Finally, STT installations would provide salable pollution offsets. Industrial growth is frequently constrained in air basins where pollution exceeds Federal standards. The creation of salable offsets through STT installations would provide the opportunity for further industrial growth. The regional environmental impacts of STT are potentially significant.

In California's South Coast Air Basin, for example, approximately 30% of the sulfur oxides and 10% of the nitrogen oxides, two important components of air pollution in Southern California, can be attributed to emissions from oil-fired power plants (Ref. 12). The major electric utility in the area, Southern California Edison Company, has a high percentage of newly installed oil-fired plants. The relatively high dependence on oil as a fuel source for electricity generation in Southern California -- and the related air pollution problems -- are not expected to change dramatically before 1990.

STT penetration in Southern California can have significant environmental impacts. As Table A-2 indicates, STT installations would reduce the capital expenditures associated with improved emissions control technology, an impact estimated to add an additional \$50 to 150/kW of installed capacity to the 1990 value of STT³¹ (Ref. 12). STT would also eliminate power plant

³¹Based on the avoided capital expenditures for improved pollution control technology as required to meet the stricter proposed emissions controls standards for 1990.

Table A-2. Savings in Expenditures for Improved Pollution Control Technologies (Savings per kWe of Installed Solar Thermal Capacity)

Control Technology	Emission Controlled	% Reduction	Contribution to Solar Thermal Value, 1981 \$/kWe
Wet Scrubbing	SO _x	90	50-150
Selective Catalytic Reduction	NO _x	90	50-100
Selective Catalytic Reduction	SO _x & NO _x	90/90	50-150

emissions that were not controlled by the proposed 1990 power plant emissions standards. As explained above, this would create health benefits, reduce crop damage, and provide salable pollution offsets. The regional environmental impacts can be significant for Southern California and other specific air basins in high insolation regions where electric power plant emissions create air pollution problems.

In addition to the first-order environmental impacts discussed above, there are a variety of second-order environmental impacts. As STT replaces power plants using fossil and nuclear fuels, environmental benefits will accrue from the reduced drilling, mining, refining, and transportation requirements associated with conventional fuel types. Partially or completely offsetting these benefits are the environmental impacts associated with STT production and installation. Detailed analysis to determine the net effect of these second-order environmental impacts is beyond the scope of this analysis. However, preliminary evidence indicates that the production and operation of solar thermal technologies does not impose any serious environmental hazards (Ref. 2, pp 17-19).

A.2 FIRST-ORDER PETROLEUM IMPORT IMPACTS

The fuel displacement data in Table A-1 can also be used to discuss the potential impact of STT on U.S. petroleum imports. Because imported oil is the highest cost source of oil in the United States, reductions in oil consumption are typically expected to translate directly into import reductions. Furthermore, due to substitution opportunities between petroleum and natural gas, a portion of any natural gas displaced is frequently expected to further

reduce oil imports. Oil import reductions will have both national security and balance of payments implications.³²

As with environmental impacts, national security and balance of payments impacts are indirect benefits that accrue to society in general. However, because they are not reflected in the market price of STT, they are external to private industry's decision-making process. If significant, petroleum import impacts provide an additional rationale for Federal participation in STT development.

Preliminary analysis indicates that the short-run impact of STT on U.S. oil imports will be limited (Ref. 29). Refining a barrel of crude oil produces a range of products including gasoline, distillate oil (diesel fuel), and residual oil. As the relative prices of refined products change, there is flexibility in the mix of products produced during the refining process. This flexibility, however, is limited in the short-run until refineries can respond by changing the technology embodied in their refining capacity. Utilities primarily consume two types of oil: Residual oil is used to satisfy base- and intermediate-load electricity demands while distillate oil is used to satisfy peak-load demands. In the short-run, little substitution occurs between residual and distillate oil in electricity generation. Early solar thermal electric installations are expected to occur in the high insolation regions in the southwestern United States, spreading later to the south central region. As Figure A-1a indicates, STT without storage primarily displaces residual oil. Distillate consumption actually increases. In the Southwest, there is currently a glut of residual oil available from refining domestic crude oil. Crude oil is imported into the Southwest in order to satisfy the transportation demand for oil (diesel fuel and gasoline). A similar situation exists in the south central U.S. Displacement of residual oil by STT in the southwestern and south central United States will not reduce oil imports to these regions in the short-run.

Residual oil consumption exceeds the supply from domestic crude on the East Coast. Displacement of residual oil on the East Coast would reduce oil imports. To use the excess supply of south central U.S. and West Coast residual oil to satisfy the excess demand for residual on the East Coast, would require that the oil be transported and further refined to lower the sulfur content. These costs make this reallocation economically prohibitive in most cases. Residual oil shipments from the Gulf Coast to the East Coast are limited. Excess residual oil in the West is exported to Japan and the Far East.

³²It is difficult to attach a value to the increased national security associated with reduced petroleum imports. One possible approach is based on the strategic petroleum reserve. Using current plans, the strategic petroleum reserve will contain 750 million barrels of oil by 1989, with a withdrawal capacity of 4.5 million barrels per day (compared to projected imports of crude oil and oil products totaling 5.75 million barrels per day; Ref. 8, Table A-8). The strategic petroleum reserve represents a 168-day supply of oil at the proposed withdrawal rate. For every barrel of imported oil displaced per day by STT, the U.S. could reduce the strategic petroleum reserve by 168 barrels and still maintain an equal level of "national security." At the oil prices used in this study, reductions in daily oil imports will have a 1990 value of \$6388, 8736, and 11,424 (1981 dollars) per barrel in the low, medium, and high oil price scenarios, respectively.

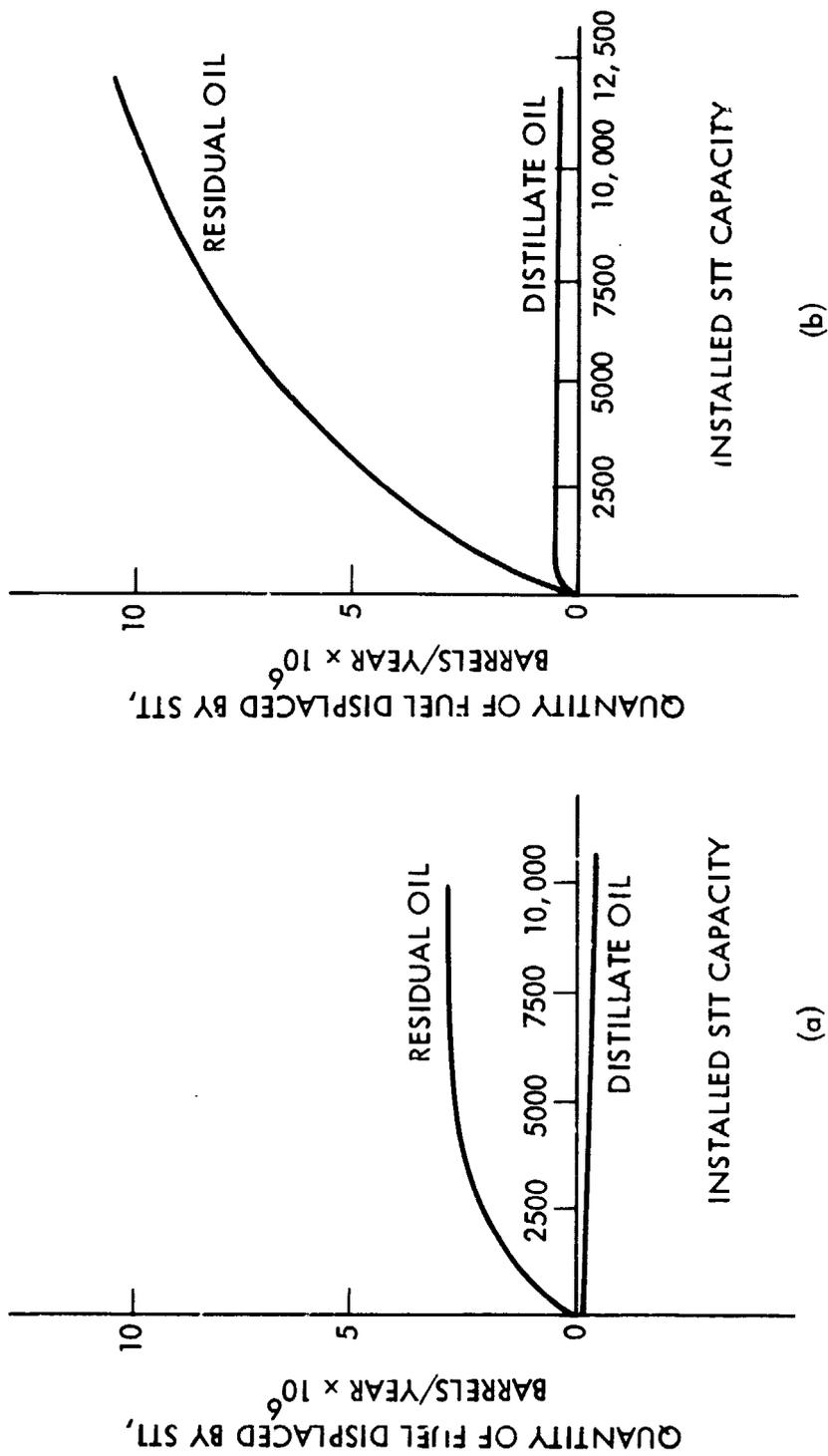


Figure A-1. Average Annual STT Oil Displacement: (a) STT Without Storage; (b) STT with Unlimited Storage (Medium Fuel Price Scenario)

The first-order impact of STT on oil imports in the short-run is expected to be small; in the long-run the impact might be significant.³³ Taken together, the tendency for STT without storage to displace residual oil, the current glut of residual oil in the western and south central United States, the prohibitive costs of reallocating excess residual to the East Coast, and the limited short-run substitution between types of oil in both refining and electricity generation all serve to minimize the short-run impact of STT on oil imports. In the long-run, competitive industries characteristically demonstrate substantial flexibility. Refinery and utility generating capacity is expected to change in response to the glut of residual oil. Substitution will occur between types of oil and between oil and other fuels. Alternative uses will be found for residual oil, some of which may reduce the demand for other types of oil. Since imported crude is the highest cost source of oil in the U.S., these changes should reduce oil imports. In addition, STT with storage does displace both distillate and residual oil (Figure A-1b). Reduced distillate consumption leads directly to reduced demand for imported crude oil in the western and south central regions. As a result, the first-order and second-order long-run impacts of STT on imported crude oil can be significant. In this case, STT would improve national security and the U.S. balance of payments.

A.3 CONCLUSIONS

This appendix has discussed preliminary measurements regarding two indirect (external) impacts associated with STT installations: first-order environmental impacts and first-order oil import impacts. Since indirect impacts are not reflected in private market transactions, private industry does not consider these impacts in their decision-making process. If the indirect benefits are significant, private industry will underinvest in STT from society's viewpoint. Significant indirect benefits provide an additional rationale for Federal participation to support the private development of STT.

Based on the preliminary analysis presented here, first-order environmental impacts are insignificant nationally, but potentially important on a regional basis. The first-order impact on oil imports, national security, and balance of payments is expected to be small in the short-run, but may increase over time.

³³A corresponding statement can be made for the impact of STT on national security and the U.S. balance of payments. To the extent that displaced residual oil is exported, however, there may be some balance of payments impact in the short-run.

APPENDIX B

DERIVATION OF EQUATIONS³⁴

B.1 THE VALUE OF SOLAR THERMAL TECHNOLOGIES IN ELECTRIC UTILITY APPLICATIONS

The methodology used to calculate the value of STT assumes that electric utility rates are set to earn utilities a predetermined return on capital investment. In other words, the net present value of all cash flows discounted at a rate equal to the utility's cost of capital is constrained to zero. Based on this assumption, the cash flow for a utility using a mix of conventional generating capacity (the no-solar case) can be expressed as follows:

$$(B-1) \quad PV \left(REV_t^{NS} + BS_t^{NS} + SS_t^{NS} \right) = PV \left(C_t^{NS} + F_t^{NS} + M_t^{NS} + SE_t^{NS} + REP_t^{NS} + INT_t^{NS} \right. \\ \left. + PDR_t^{NS} + TX_t^{NS} + OT_t^{NS} + INS_t^{NS} \right)$$

where

PV ≡ Present value operator; converts the cash flow into a present value by discounting future cash flows;

REV ≡ Revenue from sale of electricity;

BS ≡ Revenue from sale of bonds (debt);

SS ≡ Revenue from sale of stock (equity);

C ≡ Total cost of conventional generating equipment;

F ≡ Cost of fuel;

M ≡ Cost of O&M;

SE ≡ Stock earnings;

REP ≡ Repayment of equity principal;

INT ≡ Interest payment on debt;

PDR ≡ Provision for debt retirement;

TX ≡ Profits taxes;

³⁴The equations presented here are based on J. W. Doane, et al, The Cost of Energy from Utility-Owned Electric Systems, ERDA/JPL-1012-76/3, Jet Propulsion Laboratory, Pasadena, California, June 1976. This appendix revises an earlier STT value analysis presented in W. Gates Breakeven Cost Analysis for Solar Thermal Parabolic Dish Systems, Economic Research Series, Paper No. 7, Jet Propulsion Laboratory, Pasadena, California, June 1981.

OT \equiv Other taxes (property, state, sales, etc.);

INS \equiv Insurance payments.

The subscript t denotes the year while the superscript NS signifies the no-solar case.

Some of the terms defined above can be described more explicitly. In particular, corporate profits taxes can be expressed as:

$$(B-2) \quad TX_t^{NS} = (REV_t^{NS} - F_t^{NS} - M_t^{NS} - OT_t^{NS} - INS_t^{NS} - INT_t^{NS} - DEP_t^{NS})\tau - ITC_t^{NS}$$

where

DEP \equiv Depreciation allowance;

τ \equiv Effective profits tax rate. If the subscripts f and s denote the Federal and state profits tax rates, respectively,
 $\tau = \tau_f + (1 - \tau_f)\tau_s$;

ITC \equiv Effective investment tax credit. If the subscripts f and s denote the Federal and state investment tax credits, respectively, $ITC = ITC_f + (1 - \tau_f)ITC_s$.

Other terms can be specified as follows:

$INT = k_d \cdot \alpha \cdot C$, where α \equiv debt fraction
 k_d \equiv interest rate on debt.

$PDR = SFF \cdot \alpha \cdot C$, where SFF is the annual contribution to a sinking fund factor to repay the debt principal.³⁵

$SE = (k_e + h)(1 - \alpha) \cdot C$, where k_e is the average return on equity and h is the equity premium for the project in question. ($k_e + h$) is referred to as the project specific hurdle rate of return on equity and is the return required to entice equity investment for a particular opportunity.³⁶

$REP = SFF (1 - \alpha) \cdot C$.

$DEP_t = d_t \cdot C$, where d_t is the depreciation fraction in year t.

$ITC = b \cdot C$, where b represents the effective investment tax credit fraction.

³⁵For a further discussion of the sinking fund factor, see Doane, The Cost of Energy from Utility-Owned Electric Systems, pp A-12 and B-5.

³⁶For a further discussion of the hurdle rate of return, see Gates, Breakeven Cost Analysis for Solar Thermal Parabolic Dish Systems, pp 21-28.

Other taxes (OT) and insurance (INS) are assumed to be equal to a percentage of the total capital expenditure. Thus,

$$OT + INS = \beta_1 \cdot C.$$

Finally, it is assumed that the revenue generated through the sale of stocks and bonds is just equal to the utility's cost of generating capacity. Thus,

$$(B-3) \quad C_{PV}^{NS} = BS_{PV} + SS_{PV}.$$

By substituting Equations B-2 and B-3 into Equation B-1 and using the relationships discussed above, the cash flow expression can be rewritten as:

$$(B-4) \quad PV \left\{ (1 - \tau) REV_t^{NS} \right\} = PV \left\{ (1 - \tau) F_t^{NS} + (1 - \tau) M_t^{NS} + (k_e + h^{NS})(1 - \alpha^{NS}) C^{NS} \right. \\ \left. + SFF (1 - \alpha^{NS}) \cdot C^{NS} + (1 - \tau) k_d^{NS} \cdot \alpha^{NS} \cdot C^{NS} + SFF \cdot \alpha^{NS} \cdot C^{NS} \right. \\ \left. + (1 - \tau) \cdot \beta_1 \cdot C^{NS} - \tau \cdot d_t \cdot C^{NS} - b \cdot C^{NS} \right\}.$$

A similar equation can be derived for the cash flow of a utility using a mix of generating units that include STT. More specifically, define C^S as the cost of the conventional generating capacity in the solar case, and ST^S as the total cost of the solar thermal capacity. The cash flow for the solar case can then be expressed as:

$$(B-5) \quad PV \left\{ (1 - \tau) REV_t^S \right\} = PV \left\{ (1 - \tau) F_t^S + (1 - \tau) M_t^S + (k_e + h^S)(1 - \alpha^S)(C^S + ST^S) \right. \\ \left. + SFF(1 - \alpha^S)(C^S + ST^S) + (1 - \tau) k_d^S \cdot \alpha^S (C^S + ST^S) + SFF \cdot \alpha^S (C^S + ST^S) \right. \\ \left. + (1 - \tau) \beta_1 (C^S + ST^S) - \tau \cdot d_t (C^S + ST^S) - b (C^S + ST^S) \right\}$$

where the superscript S denotes the solar case.

This value analysis assumes that a utility will install STT only if it can earn the allowed return on its investment in the solar case, while supplying an equal or greater quantity of electricity at the same or lower rates as in the no-solar case. In other words, REV_t^{NS} must be greater than or equal to REV_t^S . Based on this assumption, Equations B-4 and B-5 can be used to derive the maximum amount that the utility would willingly pay for a solar thermal power plant. Assuming $h^{NS} = h^S = h$, $\alpha^{NS} = \alpha^S = \alpha$, and $k_d^{NS} = k_d^S = k_d$, Equations B-4 and B-5 can be equated and solved for ST_t^S . In this case,

$$(B-6) \quad PV \{ ST^S \} \leq$$

$$PV \left\{ \frac{(1 - \tau)(F_t^{NS} - F_t^S) + (1 - \tau)(M_t^{NS} - M_t^S) + [(k_e + h)(1 - \alpha) + (1 - \tau)k_d \cdot \alpha + SFF + (1 - \tau)\beta_1 - \tau \cdot d_t - b](C^{NS} - C^S)}{[(k_e + h)(1 - \alpha) + (1 - \tau)k_d \cdot \alpha + SFF + (1 - \tau)\beta_1 - \tau \cdot d_t - b]} \right\}$$

Equation B-6 can be further simplified by using the following relationships:

- (1) $F_t^{NS} - F_t^S = FC_t$. The difference between the fuel cost of the no-solar and solar cases is called the fuel credit.
- (2) $M_t^{NS} - M_t^S = MC_t$. The difference between the O&M cost of the no-solar and solar cases is called the O&M credit, which can be positive or negative.
- (3) $C^{NS} - C^S = CC$. The difference between the conventional capital investment in the no-solar and solar cases is called the capacity credit.
- (4) Assume all capacity credits are realized when the solar thermal system is installed: $PV(CC) = CC$.
- (5) The present value operator can be expressed mathematically as $PV(X_t) = \sum_{t=1}^T X_t (1+r)^{-t}$ where T is the STT system lifetime and r is the discount rate.
- (6) Assume the discount rate in the present value operator is approximated by the after-tax weight-average cost of capital $r = \alpha(1-\tau)k_d + (1-\alpha)k_e$.³⁷
- (7) Using the definition of r given above,

$$PV \left\{ (k_e + h)(1-\alpha) + (1-\tau)k_d \cdot \alpha + SFF \right\} = 1 + (1-\alpha)h \sum_{t=1}^T (1+r)^{-t}$$
 ³⁸
- (8) Assume all investment tax credits are realized at the end of the first year of STT plant operation: $PV(b \cdot CC) = (1+r)^{-1} b \cdot CC$.
- (9) Define $dpf \equiv \sum_{t=1}^T d_t (1+r)^{-t} = PV(d_t)$.
- (10) Assume overnight construction for the solar thermal system.

Using these relationships, Equation B-6 can be rewritten as:

³⁷For a further discussion regarding the use of the after-tax weighted-average cost of capital as the discount rate, see Gates, Breakeven Cost Analysis for Solar Thermal Parabolic Dish Systems, pp 13-28.

³⁸ $\sum_{t=1}^T (r + SFF)(1+r)^{-t} = 1$, see Doane, The Cost of Energy from Utility-Owned Solar Electric Systems, pp B-5, B-7, B-14.

$$(B-7) \quad ST^S \leq \frac{\sum_{t=1}^T (1 - \tau)FC_t (1 + r)^{-t} + \sum_{t=1}^T (1 - \tau)MC_t (1 + r)^{-t} + \rho \cdot CC}{\rho}$$

$$\text{where } \rho = 1 + (1 - \alpha)h \sum_{t=1}^T (1 + r)^{-t} - \tau \cdot dpf - b(1 + r)^{-1} \\ + (1 - \tau) \beta_1 \sum_{t=1}^T (1 + r)^{-t}.$$

Two further assumptions are used in this report. In the first place, h , the equity premium required for investments in STT, is assumed to be equal to zero. Secondly, the O&M costs associated with the solar thermal plant are expressed as a percent of the initial STT system cost (denoted β_2). In this case, MC_t represents the O&M credit associated with conventional generating capacity. Thus, Equation B-7 becomes

$$(B-8) \quad ST^S \leq \frac{\sum_{t=1}^T (1 - \tau)FC_t (1 + r)^{-t} + \sum_{t=1}^T (1 - \tau)MC_t (1 + r)^{-t} + \rho \cdot CC}{\rho + (1 - \tau)\beta_2 \sum_{t=1}^T \left(\frac{1 + e_m}{1 + r}\right)^t}$$

where $\rho = 1 - \tau \cdot dpf - b(1 + r)^{-1} + (1 - \tau) \cdot \beta_1 \sum_{t=1}^T (1 + r)^{-t}$; and e_m is the escalation rate of the solar O&M costs.

B.2 THE DIRECT IMPACT OF STT ON FEDERAL TAX REVENUES

Equation B-2 can be used to determine the impact that STT installations have on the Federal corporate profits tax paid by investor-owned utilities. According to Equation B-2 and the definitions and relationships outlined in Section B.1 above, the present value of the Federal corporate profits taxes paid by an investor-owned utility in the no-solar case can be expressed as:

$$(B-9) \quad TX_{PV}^{NS} = \left\{ \sum_{t=1}^T \left[REV_t^{NS} - F_t^{NS} - M_t^{NS} - \beta_1 C^{NS} - k_d \cdot \alpha \cdot C^{NS} - d_t \cdot C^{NS} \right] \tau_e (1 + r^g)^{-t} \right\} \\ - b \cdot C^{NS} (1 + r^g)^{-1} \text{ where } \tau_e \text{ is the effective Federal tax rate.}$$

Because state taxes are deducted from taxable income before the Federal tax bill is calculated, τ_e can be defined as $\tau_e = (1 - \tau_s)\tau_f$. The superscript g signifies the use of the Federal discount rate to evaluate cash flows to the government. The present value of the Federal corporate profits tax in the solar case can be written as:

$$(B-10) \text{TX}_{PV}^S = \left\{ \sum_{t=1}^T [\text{REV}_t^S - F_t^S - M_t^S - \beta_1(C^S + \text{ST}^S) - \beta_2 \cdot \text{ST}^S(1 + e_m) - k_d \cdot \alpha \cdot (C^S + \text{ST}^S) - d_t(C^S + \text{ST}^S)] \tau_e (1 + r^g)^{-t} \right\} - b(C^S + \text{ST}^S)(1 + r^g)^{-1}.$$

The change in the Federal corporate profits tax can be found by subtracting B-9 from B-10. Given both $\text{REV}_t^{\text{NS}} = \text{REV}_t^S$ and the definitions for FC_t^S , MC_t^S , and CC, the change in Federal corporate profits taxes equals:

$$(B-11) \Delta \text{TX}_{PV} = \text{TX}_{PV}^S - \text{TX}_{PV}^{\text{NS}} = \sum_{t=1}^T [\text{FC}_t + \text{MC}_t] \tau_e (1 + r^g)^{-t} + \gamma^1 \cdot \text{CC} - \gamma^2 \cdot \text{ST}^S,$$

where

$$\gamma^1 = \left[\sum_{t=1}^T (\beta_1 + k_d \cdot \alpha) (1 + r^g)^{-t} + \text{dpf} \right] \tau_e + b(1 + r^g)^{-1}, \text{ and}$$

$$\gamma^2 = \left[\sum_{t=1}^T (\beta_1 + \beta_2(1 + e_m)^t + k_d \cdot \alpha) (1 + r^g)^{-t} + \text{dpf} \right] \tau_e + b(1 + r^g)^{-1}.$$

If the value of Equation B-11 is positive, then Federal revenues from corporate profits taxes will increase. If B-11 is negative, Federal revenues will decrease.

Electric utility decision makers will evaluate the cost and value of STT and determine the level of solar thermal installations. Equation B-8 attempts to represent this evaluation process. The values of the fuel, O&M, and capacity credits used in Equation B-11 result from these utility decisions. Based on these credits, the impact of STT on Federal corporate profits taxes is estimated in Equation B-11.

Since Equation B-11 represents a cash flow accruing to the Federal government, the Federal discount rate is the appropriate rate to use for this analysis. This is signified by including a superscript g on the discount rate. If the Federal government is concerned with near-term budget deficits, the Federal discount rate can be quite high.³⁹ As the Federal time-horizon increases, the discount rate will decrease. If the Federal discount rate is

³⁹A discount rate in the range of 0.25 to 0.50 would restrict primary attention to a four-year period.

high, the negative revenue flows in the early years of the STT life-cycle associated with the investment tax credit (and accelerated depreciation) will tend to swamp the positive revenue flows associated with the fuel and O&M credits that accrue in the later years of the life-cycle. ΔTX_{py} will be negative for high values of r . As the discount rate decreases, the later positive revenue flows increase in importance relative to the negative flows occurring in the early years. ΔTX_{py} will increase in value as the Federal discount rate decreases. As there is no consensus regarding the appropriate Federal discount rate, a range of rates should be examined.

B.3 THE VALUE OF SOLAR THERMAL TECHNOLOGIES TO THIRD PARTY OWNERS

Third party ownership allows equity investors to capture Federal and state energy tax credits and to depreciate capital equipment over a five-year period (as opposed to the 15-year period for investor-owned utilities). In the third party ownership case, the discounted cash flow must be sufficient to earn investors their required rate of return on their equity investment. This requirement can be expressed as follows:

$$(B-12) \quad PV(P_t + BS_t) \geq PV(ST^S + M_t + INT_t + PDR_t + TX_t + OT_t + INS_t)$$

where P_t is the payment from the utility to the third party owners (assumed to be equal to the utility's net avoided fuel, O&M, and capital costs). For the third party owner, the discount rate is equal to the owner's required rate of return on equity; tax rates are personal income tax rates; and the rest of the variables have been defined previously. TX_t in this case can be written as:

$$(B-13) \quad TX_t = (P_t - M_t - OT_t - INS_t - INT_t - DEP_t)\tau^I - ITC_t - ETC_t$$

where ETC is the effective energy tax credit and τ^I is the effective personal income tax rate. Using the subscripts f and s to refer to Federal and state rates, respectively, then

$$ETC = ETC_f + (1 - \tau_f^I)ETC_s$$

and

$$\tau^I = \tau_f^I + (1 - \tau_f^I)\tau_s^I$$

Assuming $BS_t = \alpha ST^S$ and using the relationships given previously, Equation B-12 can be rewritten as:

$$(B-14) \quad PV\left\{(1 - \tau^I)P_t\right\} \geq PV\left\{(1 - \alpha^I)ST^S + (1 - \tau^I)k_d^I \cdot \alpha^I \cdot ST^S + \alpha^I \cdot SFF \cdot ST^S + (1 - \tau^I)\beta_1 \cdot ST^S + (1 - \tau^I)\beta_2(1 + e_m)ST^S - \tau^I \cdot DEP_t^I - ITC_t \cdot ST^S - ETC_t \cdot ST^S\right\}$$

Equation B-14 can be simplified as follows:

(B-15) $ST^S \leq$

$$\frac{(1 - \tau^I) \sum_{t=1}^T P_t (1 + r^I)^{-t}}{(1 - \alpha^I) + \sum_{t=1}^T \left[SFF + (1 - \tau^I) k_d^I \right] \alpha^I (1 + r^I)^{-t} + \sum_{t=1}^T (1 - \tau^I) \beta_1 (1 + r^I)^{-t} + \sum_{t=1}^T (1 - \tau^I) \beta_2 \left(\frac{1 + e_m}{1 + r^I} \right)^t - \tau^I \cdot dpf^I - (ITC + ETC) (1 + r^I)^{-1}}$$

The costs and revenues for the utility in the no-solar case are identical to those described earlier in Equation B-4. When a third party owns and operates the solar thermal system and sells electricity to the utility, the payment from the utility to the third party owner is equal to the utility's net avoided fuel, O&M, and capital costs. In the solar case with third party ownership, the utility's costs and revenues can be expressed as:

$$(B-16) \quad PV \left(REV_t^S + BS_t^S \right) + SS_t^S = PV \left(C_t^S + F_t^S + M_t^S + P_t^S + SE_t^S + REP_t^S + INT_t^S \right. \\ \left. + PDR_t^S + TX_t^S + OT_t^S + INS_t^S \right).$$

Rewriting Equation B-16 using the relationships explained earlier yields:

$$(B-17) \quad PV \left\{ (1 - \tau^U) REV_t^S \right\} = PV \left\{ (1 - \tau^U) F_t^S + (1 - \tau^U) M_t^S + (1 - \tau^U) P_t^S \right. \\ \left. + (k_e^U + h)(1 - \alpha^U) C_t^S + (1 - \alpha^U) SFF \cdot C_t^S + (1 - \tau^U) k_d^U \cdot \alpha^U \cdot C_t^S + \alpha^U \cdot SFF \cdot C_t^S \right. \\ \left. + (1 - \tau^U) \beta_1 \cdot C_t^S - \tau^U \cdot d_t^U \cdot C_t^S - b \cdot C_t^S \right\}.$$

Recalling that $PV(REV_t^S) = PV(REV_t^{NS})$, the present value of the payments from the utility to the third party owner can be found by equating Equations B-4 and B-17 and solving for P_t as follows:

$$(B-18) \quad \sum_{t=1}^T P_t (1 + r^U)^{-t} = \frac{(1 - \tau^U) \sum_{t=1}^T FC_t (1 + r^U)^{-t} + (1 - \tau^U) \sum_{t=1}^T MC_t (1 + r^U)^{-t} + \rho^U \cdot CC}{(1 - \tau^U)}$$

where, as before, $\rho^U = 1 + (1 - \alpha^U) h \sum_{t=1}^T (1 + r^U)^{-t} - \tau^U \cdot dpf^U - b(1 + r^U)^{-1}$

$$+ (1 - \tau^U) \beta_1 \sum_{t=1}^T (1 + r^U)^{-t}.$$

A number of alternative payment streams will satisfy the conditions outlined in Equation B-18. One potential payment stream assumes that FC and MC are paid in the year in which they are realized and the capacity credit is paid in equal increments over the length of the purchase agreement. In this case, P_t can be expressed as:

$$(B-19) P_t = FC_t + MC_t + \frac{\rho^U \cdot CC}{(1 - \tau^U)} \left(\sum_{t=1}^T (1 + r^U)^{-t} \right)^{-1}.$$

B.4 THE DIRECT IMPACT OF STT ON FEDERAL TAX REVENUES: THE THIRD PARTY OWNERSHIP CASE

In the case of third party ownership, the direct impact on Federal tax revenues is found by combining the tax impacts of the third party owners and the electric utility. Since the state taxes are deducted from taxable income before the Federal tax bill is calculated, the effective Federal tax rate is given by $\tau_e = (1 - \tau_s)\tau_f$. Similarly, the effective Federal energy tax credit is given by $ETC_e = ETC_f - \tau_f \cdot ETC_s$. The Federal discount rate is again the appropriate discount rate to use in evaluating tax impacts.

For the electric utility, the Federal corporate profits taxes in the no-solar case are given by Equation B-9. In the solar case with third party ownership of the solar thermal systems, the corporate profits taxes can be expressed as:

$$(B-20) TX_{PV}^S = \sum_{t=1}^T \left\{ [REV_t^S - F_t^S - M_t^S - P_t^S - \beta_1 \cdot C^S - \alpha^U \cdot k_d \cdot C^S - d_t^U \cdot C^S] \tau_e^U (1 + r^g)^{-t} \right\} - bC^S (1 + r^g)^{-1}.$$

The change in the Federal corporate profits taxes paid by the electric utility can be found by subtracting Equation B-9 from Equation B-19, which yields:

$$(B-21) \Delta TX^U = TX_{PV}^S - TX_{PV}^{NS} = \sum_{t=1}^T [FC_t + MC_t - P_t^S] \tau_e^U (1 + r^g)^{-t} + \rho^U \cdot [CC],$$

where

$$\rho^U = \left[\sum_{t=1}^T \beta_1 + k_d^U \cdot \alpha^U (1 + r^g)^{-t} + dpf^U \right] \tau_e^U + b \cdot (1 + r^g)^{-1}.$$

The taxes paid by the third party investors, given by Equation B-13, can be written as:

$$(B-22) \Delta TX^I = \sum_{t=1}^T [P_t^S] \tau_e^I (1 + r^g)^{-t} - \rho^I \cdot [ST^S]$$

$$\text{where } \rho^I = \left[\sum_{t=1}^T (\beta_1 + \beta_2 (1 + e_m)^t + k_d^I \cdot \alpha^I) (1 + r^g)^{-t} + \text{dpf}^I \right] \tau_e^I$$

$$+ (b + \text{ETC}_e) (1 + r^g)^{-1}.$$

The total Federal tax impact in the third party ownership case can be expressed by combining Equations B-21 and B-22, which yields:

$$(B-23) \Delta TX^T = \Delta TX^U + \Delta TX^I = \sum_{t=1}^T [FC_t + MC_t] \tau_e^U (1 + r^g) + \sum_{t=1}^T [P_t^S] (\tau_e^I - \tau_e^U) (1 + r^g)^{-t}$$

$$+ \rho^U \cdot [CC] - \rho^I [ST^S].$$

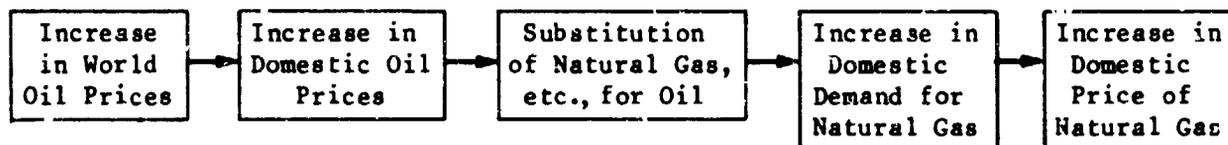
APPENDIX C

EIA FUEL PRICE PROJECTIONS: IMPACT OF WORLD OIL PRICES ON THE DOMESTIC PRICE OF NATURAL GAS

Projections of future prices for natural gas frequently exhibit a positive relationship between world oil prices and the domestic price of natural gas. This relationship is normally explained as follows (see Figure C-1): When the price of oil increases relative to other energy sources, consumers will replace their oil consumption with other relatively cheaper energy sources. Thus, the demand for alternative energy sources will increase, causing prices to increase as well. This effect is expected to be particularly important for natural gas, which is frequently considered to be a close substitute for petroleum in a variety of uses.

EIA fuel price projections⁴⁰ for the Southwest, on the other hand, exhibit a negative correlation between world petroleum and domestic natural gas prices. As world oil prices increase, domestic natural gas prices decrease.⁴¹ In explaining this seemingly counter-intuitive relationship, EIA points out that the line of reasoning represented by Figure C-1 tells only part of the story. There is an additional set of impacts that promote a negative relationship between oil and natural gas prices (Figure C-2). In particular, as world oil prices increase, the gross national product (GNP) decreases, reducing the demand for all goods and services, including natural gas. In addition, as natural gas is substituted for petroleum, any upward pressures on the price of natural gas will be at least partially offset by increased conservation efforts. In the EIA forecasts, these latter impacts dominate the former impact in the Southwest, resulting in a negative correlation between the world price of petroleum and domestic natural gas prices.⁴²

Figure C-1

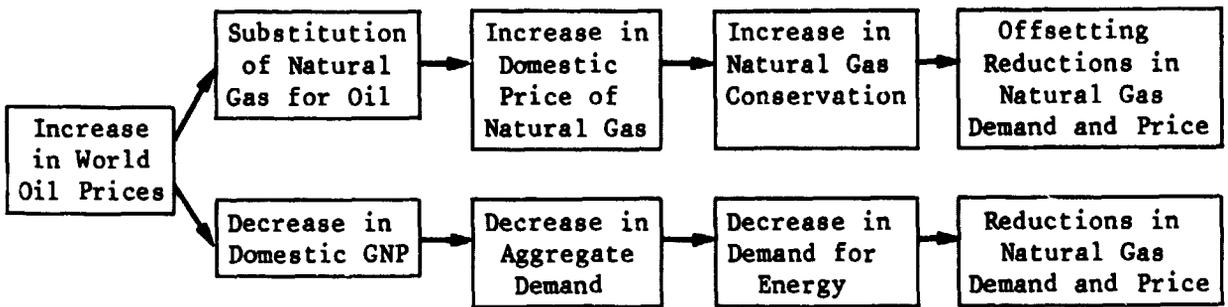


⁴⁰Energy Information Administration, 1980 Annual Report to Congress: Volume III: Forecasts, U.S. Government Printing Office, Washington, D.C., March 1981.

⁴¹Ibid., Table 3-2, p 43.

⁴²In standard economics, both conservation and the replacement of petroleum with alternative energy sources are referred to as substitution effects. As petroleum prices increase, alternative fuel sources and other factors of production will be substituted for petroleum wherever economically attractive. The relative importance of these impacts depends on the own-price and cross-price elasticities of demand. Changes in energy demand due to changes in GNP, on the other hand, are referred to as income effects. The magnitude of income effects depends on the income-elasticity of demand.

Figure C-2



EIA gives detailed explanations of both sets of relationships and of the reasons to expect gas prices to decrease as petroleum prices increase. Briefly stated, EIA assumes that GNP is relatively sensitive to changes in the world price of petroleum. Furthermore, they assume that domestic energy consumption, particularly natural gas, is strongly influenced by the level of GNP.⁴³ Similarly, it is assumed that conservation measures for petroleum and natural gas are sensitive to energy prices as well.⁴⁴ Thus, there is a strong tendency for natural gas prices to decrease as world petroleum prices increase.⁴⁵ On the other hand, as the relative price of petroleum increases, the substitution of natural gas for petroleum is limited.⁴⁶

EIA expects limited substitution between oil and natural gas for four reasons.⁴⁷ In the first place, natural gas substitution is artificially constrained by the Powerplant and Industrial Fuel Use Act. Secondly, both oil and gas are subject to strong competition from coal. As petroleum prices increase, coal may be used to replace petroleum, particularly in the industrial sector and in applications using electricity produced from coal. Thirdly, natural gas is not a good substitute for oil in many end uses (petrochemicals and transportation), or in some regions (rural areas where no natural gas transport system exists). Finally, natural gas supplies may be limited if optimistic finding-rate assumptions are not met.⁴⁸ Because of these reasons, substitution of natural gas for oil, as petroleum prices increase, is expected to occur primarily in the electric utility sector if gas usage is not constrained by the Powerplant and Industrial Fuel Use Act. Because the utility sector accounts for only a small portion of the total projected consumption of natural gas (in 1990, 3 and 12%, respectively, with and without compliance to the Powerplant and Industrial Fuel Use Act),⁴⁹ EIA expects

⁴³Ibid., IEA, pp 41, 101-104.

⁴⁴Ibid., pp 33, 39, 41.

⁴⁵In economic terms, the own-price and income-elasticity of demand are both relatively elastic (high in value).

⁴⁶In other words, the cross-price elasticity of demand is relatively inelastic (low in value).

⁴⁷Ibid., IEA, p 91.

⁴⁸Ibid., pp 39, 47-79, 95.

⁴⁹Ibid., p 46.

C-2

the substitution of natural gas for petroleum to be dominated by the GNP and secondary conservation effects. Thus, the price of natural gas in the Southwest is expected to decrease as petroleum prices increase.⁵⁰ Similarly, the supply and consumption of natural gas, in Btu's, is expected to decrease as well.⁵¹ Alternative models and regions within the EIA forecasts that exhibit a positive relationship between world oil prices and domestic natural gas prices (and consumption) implicitly assume that the substitution of natural gas for petroleum dominates the conservation and GNP impacts. (Note: There are many other secondary impacts influencing the domestic price of natural gas that were included in EIA's analysis. However, because of their relatively small effect on natural gas price projections, these secondary impacts have been excluded from this analysis.)

⁵⁰Ibid., Table 3-2, p 43.

⁵¹Ibid., Table 3-1, p 42.