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Planning and Information Project  
for the U.S. Department of Energy  
Solar Thermal Technology Division

DOE/JPL-1060-55

Distribution Category UC-62

# Solar Thermal Technologies Benefits Assessment: Objectives, Methodologies, and Results for 1981

✓ W.R. Gates

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by

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California Institute of Technology  
Pasadena, California

(JPL PUBLICATION 82-70)

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for the U.S. Department of Energy through an agreement with the National  
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## ABSTRACT

The future economic and social benefits of developing cost-competitive solar thermal technologies (STT) were assessed at JPL during FY 81. The analysis was restricted to STT in electric applications for 16 high-insolation/high-energy-price states. Three fuel price scenarios and three 1990 STT system costs were considered, reflecting uncertainty over future fuel prices and STT cost projections.

After considering the numerous benefits of introducing STT into the energy market, three primary benefits were identified and evaluated: (1) direct energy cost savings were estimated to range from zero to \$50 billion; (2) oil imports may be reduced by up to 9 percent, improving national security; (3) significant environmental benefits can be realized in air basins where electric power plant emissions create substantial air pollution problems.

STT R&D was found to be unacceptably risky for private industry in the absence of federal support. The normal risks associated with investments in R&D are accentuated because the OPEC cartel can artificially manipulate oil prices and undercut the growth of alternative energy sources. When this fact was weighed against the potential benefits of developing cost-competitive STT, Federal participation in STT R&D was found to be in the national interest.

## FOREWORD

This report documents work conducted at the Jet Propulsion Laboratory (JPL) during 1981 in support of the Department of Energy's (DOE) Solar Thermal Technology Program. The work was sponsored by Sandia National Laboratory, Livermore (SNLL), who serves as the technical program integrator (TPI) for the Solar Thermal Technology Program. Under an agreement with SNLL, JPL has ongoing responsibility for assessing the benefits and impacts associated with the successful development of cost-competitive solar thermal energy technologies. The purpose of JPL's benefit assessment task is twofold: to determine if justifications exist for federal participation in the development of solar thermal technologies; and to assist the TPI in managing the R&D effort by identifying high payoff research areas. The results of the 1981 benefit assessment task have been used in the Backup Sunset Review Document (see Ref. 1) and in the Solar Thermal Technology Program Multi-Year Program Plan (forthcoming). This report summarizes the methodologies and assumptions used in deriving the results contained in these documents.

During 1981, JPL focused on assessing the benefits and impacts associated with electric utility applications of concentrating solar thermal technologies (STT). JPL's role in the assessment of concentrating STT for industrial process heat applications was restricted to the interpretation of analysis conducted at the Solar Energy Research Institute (SERI). Discussion of industrial process heat applications is not included in this report.

Efforts are currently under way to refine these benefit assessments and to extend them to consider additional technologies (solar ponds and storage-coupled systems), applications (industrial and agricultural process heat, cogeneration, and the production of fuels and chemicals), and impacts (employment, tax revenues, and balance of payments). The refined analysis will provide information which will assist both in evaluating the federal role in STT R&D and in formulating an R&D strategy which maximizes the benefits accruing from the Solar Thermal Technology Program.

## ACKNOWLEDGMENTS

The work presented in this report was the collaborative effort of a number of individuals at the Jet Propulsion Laboratory. As task manager, Katsuaki Terasawa established the basis for the methodology used in this analysis. He directed the effort and provided insights into the interpretation of the results. John Hoag and William Gates assisted in formulating the approach and interpreting the results. Cynthia Carlson and Mike Davisson collected the required data, set up the utility simulations, and provided the analytical results that are reported here. Bob Gershman conducted the regional environmental impact analysis. E. S. Davis, Richard O'Toole, and Hamid Habib-agahi of JPL, and Patrick Eicker of SNLL, provided feedback throughout this effort which has improved the quality and clarity of the results. Susan Elrod typed the many drafts of this report and provided the figures supplementing the text; Irene Struthers edited the text and prepared it for publication. Any remaining errors, omissions, misrepresentations, or misinterpretations, of course, are the responsibility of the author.

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## 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 developed for a national energy policy designed to solve the "energy crisis" in a manner consistent with the overall objectives for the U.S. economy. One of the resulting strategies of the current national energy program is to develop a broad range of alternative energy sources. 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 OPEC cartel's control over world energy prices, private industry is unlikely to invest the required resources in the development of alternative energy systems (see Ref. 2). As a result, the Federal Government has embarked on a vigorous R&D effort to develop conservation technologies and nonconventional energy sources, including solar energy.

Solar thermal technologies (STT) represent an important component of the federal solar energy R&D program. As an alternative to oil and natural gas, solar thermal energy is renewable; free from the threat of contrived supply disruptions; and has many applications: in electric utilities as a complement to nuclear and coal-fired systems, in thermal applications, for total energy systems providing both electric and thermal power, or to produce transportable fuels and chemical feedstocks. Furthermore, solar thermal energy systems can be sized from tens of kilowatts to hundreds of megawatts. These characteristics provide STT tremendous flexibility with respect to system size requirements and ranges of application, enabling 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 process and represent near-term technologies. Other systems, such as solar thermal electric technologies, will 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 long-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, then to disseminate this data. Accomplishing these objectives will assist in forming the technological base of an STT industry founded in the national interest. Since its inception, the STT Program has supported three types of activities: R&D to reduce costs and to ensure that long-term market growth continues; systems applications experiments to enhance awareness of STT, thereby stimulating private demand which will result in further system cost reductions through volume production;

and federal financial incentives to speed the near-term deployment of STT systems. (Ref. 1 and 3.) Recently, however, with the institution of the current federal solar tax credits, as well as petroleum and natural gas price deregulation, the emphasis of the program has shifted. As directed by President Reagan,

"... it is possible to shift the focus of the Department of Energy's solar activities away from costly near-term development, demonstration, and commercialization efforts and into longer-range research and development projects that are too risky for private firms to undertake."  
(Ref. 4, page 4-16.)

In response, future federal participation in STT R&D will be limited to projects which, when compared to their expected level of benefits, exhibit excessive risks to private investors but acceptable risks to society as a whole (see Ref. 5).

This task will identify and evaluate the expected net present value of the future economic and social benefits attributable to the development of STT. We must know the expected benefits 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. Furthermore, identifying high payoff technology options early will ensure that the systems emerging from the federal R&D program will meet the requirements of those applications most likely to displace oil.

This report documents work that was conducted at the Jet Propulsion Laboratory (JPL) during 1981. 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 assessing the benefits and impacts associated with electric utility applications of concentrating solar thermal technologies. Results of this benefit assessment task have been used in the Backup Sunset Review Document (Ref. 1) and in the Solar Thermal Technology Program Multi-Year Program Plan (forthcoming). This report summarizes the methodologies and assumptions used in deriving the results found in these documents. These results, however, are considered preliminary; they are now being refined and extended to consider additional technologies (solar ponds and storage-coupled systems), applications (industrial and agricultural process heat, cogeneration, and the production of fuels and chemicals), and impacts (employment, taxes, and balance of payments).

## SECTION 2

### OVERVIEW

The JPL benefit assessment task is designed to estimate the private and social benefits expected from STT in electric utility applications. This report documents the methodology and assumptions used in assessing the benefits of solar thermal electric systems, and discusses the results of this analysis. An overview of the methodology is provided in Figure 2-1.

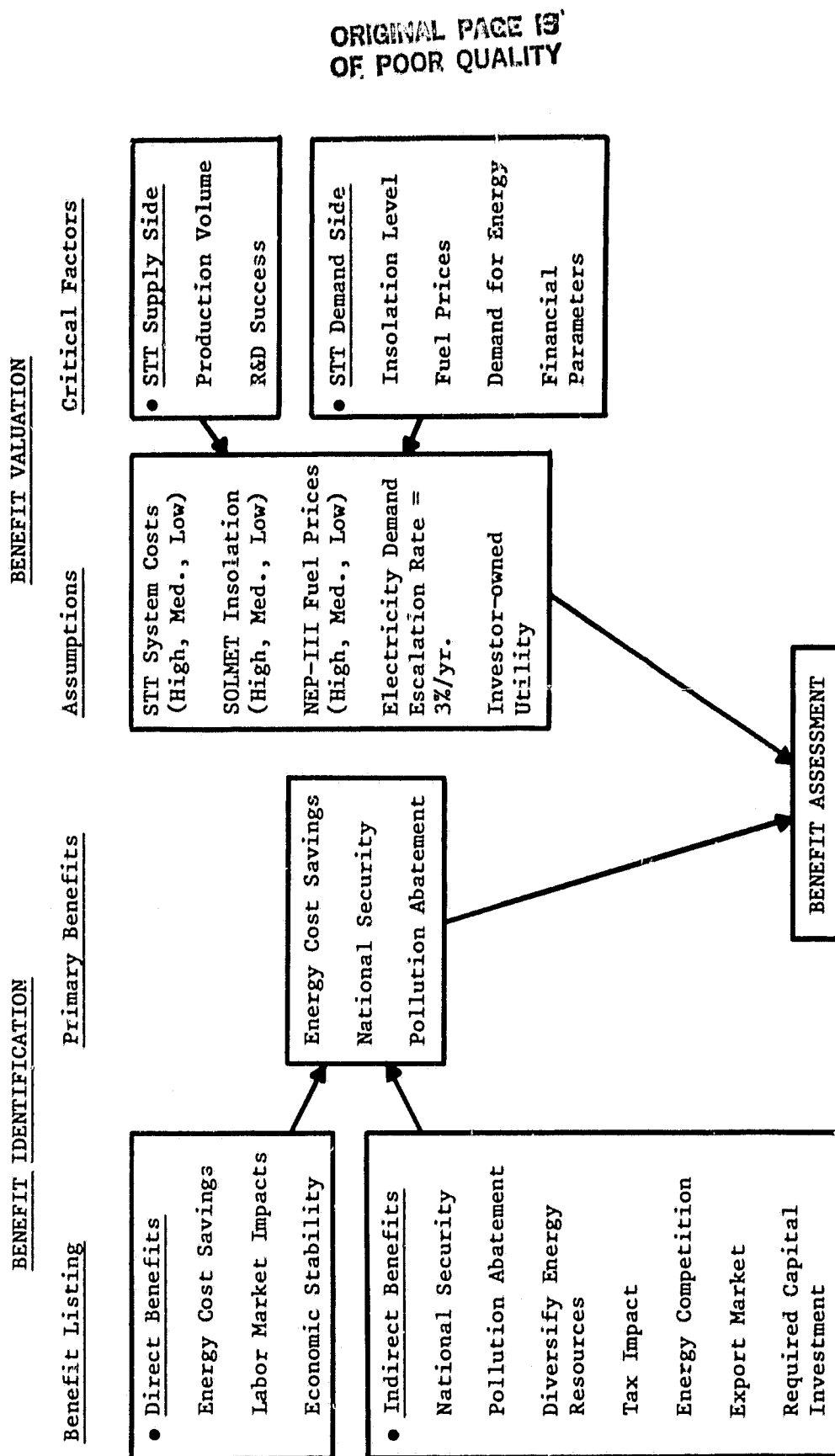
As indicated in Figure 2-1, the report first identifies the direct and indirect benefits accruing from the development and installation of cost-competitive STT systems in electric utility applications. Since assessment of the entire list of benefits is beyond the scope of this task, three benefits were selected for detailed consideration: energy cost savings, pollution abatement, and the national security implications of reduced petroleum imports.

Valuation of these benefits depends primarily on the installed capacity of STT. The capacity of economically justified STT installations is determined by two factors: the cost of producing STT (STT supply side) and the value of STT to electric utilities (STT 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, will vary from utility to utility. Many of these considerations will also vary over time. To simplify the required analysis, a single hypothetical electric utility was examined, using a single set of financial parameters which characterize an investor-owned utility. Regionally, the analysis was restricted to 16 states in the Southern and Southwestern portions of the United States. Three insolation levels were selected to reflect regional variations in solar radiation. Regional variations in fuel prices correspond to the insolation groupings. Three fuel price scenarios were used for each region to reflect uncertainty over future fuel prices. Only one time horizon was considered, 1990 STT installations.

On the supply side, STT production costs will be influenced by the success of the R&D effort, the production volume, and such regional considerations as labor and materials costs. Because estimating STT production costs is beyond the scope of this report, benefits were assessed assuming three alternative STT system costs. The range of costs reflects variations in STT production volume and R&D success, and was selected to include the STT cost goal established by the Solar Thermal Cost Goal Committee for solar thermal installations in 1990. Regional variations in STT costs were not considered.

Using these simplifying assumptions, the value of STT (demand) and STT costs (supply) were estimated for increasing levels of STT installations. Comparisons of STT costs and values indicate the economically justified market potential of STT in 1990. This information was used to assess the potential value of the benefits accruing from the installation of cost-competitive STT systems, under alternative assumptions regarding future fuel prices and STT system costs.

Figure 2-1. Benefit Assessment Overview



## SECTION 3

### BENEFIT IDENTIFICATION

To accurately evaluate the benefits of the federal STT Program, all potential benefits, both quantitative and qualitative, must be identified for each solar thermal technology, in every potential application. The benefits expected from the STT program can be divided into two broad categories: direct benefits, which are reflected in market transactions, and indirect benefits, 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 benefits include changes in employment levels and the effect of lower energy costs on other sectors of the domestic economy. Indirect benefits include positive environmental impacts, increased competition in the energy market, economic stability, and national security. Benefit assessment requires consideration of both direct and indirect benefits.

#### 3.1 DIRECT BENEFITS

The primary direct benefit of the STT Program, the savings in energy costs, will include displacement of conventional fuel and generating capacity, and potential savings in operations, maintenance, transmission, and distribution costs. Although STT can displace a variety of fuel types, the most expensive alternative fuels, petroleum and natural gas, will be most affected. Actual solar thermal installations and the corresponding fuel displacement will depend on the demand for energy and the cost of electricity from STT relative to the cost of electricity from both conventional technologies and alternative technologies other than STT.

Development of cost-competitive solar thermal technologies will also directly impact other market transactions. 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 which STT displaces. The net impact depends on both the relative capital/labor intensities and the unemployment rates of the industries involved. Furthermore, STT production techniques and labor skill requirements are similar to existing industries, and production will not be restricted to areas with the highest demand for STT. Therefore, 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 reduce the inflationary pressures on the U.S. domestic economy.

### 3.2 INDIRECT BENEFITS

Benefits in the second category are those not directly reflected through market transactions. One of the primary benefits in this category is the impact on national security. Any oil displaced due to the installation of cost-competitive STT will reduce U.S. dependence on foreign sources of petroleum, positively impacting the national security of the U.S. (see Section 7.2 and Ref. 6). 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, which in turn depends primarily upon the demand for energy and the relative cost of solar thermal systems.

STT also provides positive environmental impacts. As a replacement for conventional fossil-fuel systems, STT improves environmental quality in the short term by reducing air pollutants ( $\text{SO}_x$  and  $\text{NO}_x$ ); in the long term, STT will reduce  $\text{CO}_2$  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 Section 7.3 and Ref. 7). Furthermore, most metropolitan areas are in "non-attainment" with respect to the critical emissions associated with the burning of 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.

As a renewable domestic alternative to oil and natural gas, STT also will give the United States flexibility in responding to OPEC price increases and supply disruptions. If the price of oil and/or natural gas rises above the cost of energy produced by STT systems, or these fuels become unavailable, STT can displace oil and/or natural gas-fired systems. Thus, the price of STT systems represents a ceiling on what utilities and industry would have to pay for oil or natural gas-fired systems in the higher insolation regions of the U.S (Ref. 8). The magnitude of this benefit obviously depends on the cost of STT relative to both conventional and developing energy resources: the lower the cost of solar thermal technologies, the greater the benefit.

Because capital and fuel price expenditures are treated differently for tax purposes, STT installations will also have an impact on state and federal tax revenues. Fuel costs are considered as utility expenses and are deducted directly from the utility's taxable revenue before the tax bill is calculated. Capital expenditures, considered long-term investments, are not deducted directly, but reduce the utility's tax liability over time through depreciation allowances, investment tax credits, and deductions for interest payments.

Under most tax schemes, the present value of the reductions in taxable income associated with capital expenditures do not fully cover the present value of the capital investment. An increase in capital expenditures matched by an equal decrease in fuel expenditures would cause the utility's tax bill to increase. Cost-competitive deployment of STT in a fuel saving mode assumes that the present value of the fuel displaced by STT exceeds the present value of the capital investment in STT. Thus, STT installations can be expected to increase state and local tax revenues under reasonable assumptions regarding future tax schemes.

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 can potentially 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.

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 (see Ref. 9 and 10). 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 and contribute to the U.S. balance of payments position.

Finally, since some solar thermal technologies are highly modular, solar thermal generating facilities can be operated and expanded simultaneously (Ref. 11 and 12). This 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 THE PRIMARY BENEFITS

In this analysis, only three categories of benefits from STT are considered: energy cost savings, environmental impacts, and national security implications. As discussed previously, the list of direct and indirect benefits possible for each STT technology/application combination is extensive, and the benefits will vary in significance. Thus, once all the benefits for each technology/application option were identified, each element was examined carefully, and a limited list of primary benefits compiled. Only these primary benefits were used to assess the federal STT Program.

### 3.4 BENEFICIARIES

The benefits described in this section will accrue to a wide range of beneficiaries, who can be classified in 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 includes firms which 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 installation) 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 most 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: EVALUATION METHODOLOGY

After potential benefits are identified, their value must be estimated. In general, the benefits accruing from STT development depend 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. In electric utility applications, initial STT installations will have a high incremental value, because they will displace primarily oil and natural gas. As STT penetration increases, coal will represent a higher portion of the displaced fuel. Utilities will not be willing to pay as much for a unit of STT capacity that displaces coal as for preceding units that displaced primarily oil. Thus, the incremental value of STT will decrease as penetration increases. 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 incremental values, 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.\*

The incremental value of STT for each utility can be estimated and aggregated to determine the national demand curve. A variety of factors are involved: the demand for electricity; the current and future expected cost of energy from STT relative to the costs of other energy resources; and 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 resource availability, energy costs, energy demand profiles, and insolation levels. Relative energy costs will also be time-dependent due to differing price escalation rates. Finally, future economic conditions will be region- and time-specific. Thus, STT benefit assessments should reflect region- and time-specific variations.

This analysis has been restricted to 1990 STT electric applications in the high insolation/high energy price areas of the U.S. To approximate demand for STT in electric utility applications, potential consumers were subdivided by region. Representative consumers were selected for each region; the number chosen depends on the diversity of consumer characteristics, as well as the time, budget, and reliability requirements of the analysis. The total value of STT to the representative consumers was then determined for alternative 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 consumer in the year selected for analysis.

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

This approach approximates the demand curve for STT for each representative consumer. 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 demand for STT in electric utility applications. A range of STT demand curves were estimated by analyzing alternative future fuel price scenarios. These demand curves were used to assess the value of the benefits accruing from the federal STT Program.

#### 4.1 REGIONAL VARIATIONS

Regionally, insolation levels and fuel prices represent the primary source of variation in the value of STT systems. Regional values for both of these factors are considered in this analysis.

##### 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 (see 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 there exists a significant land area. 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

Both fuel prices and insolation levels vary across geographic regions, but fuel prices exhibit greater variability over time. Future fuel prices cannot be accurately predicted; this additional 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. Therefore, a range of possible fuel costs was considered.

There are many possible events that would affect both absolute and relative energy costs (i.e., 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. Since the demand for STT depends critically on the characteristics of the energy

Table 4-1. Regional Variations: Insolation Levels

States Considered (Grouped by Insolation Level)

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

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

\*\*Groupings based on highest insolation level for which a significant land area exists.

\*\*\*Insolation values measure average direct normal insolation and are expressed in KWh/M<sup>2</sup>/Day.

sector in which it must compete, a range of demand curves and benefits attributable to the federal STT Program was generated from several fuel price scenarios. The number of fuel price scenarios considered depends on the time, budget, and precision requirements of the analysis being conducted; scenarios must be selected to encompass the feasible range of possible outcomes.

In this benefit assessment, three energy price scenarios were selected: (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 (see Table 4-2).

Table 4-2. Fuel Price Assumptions  
(1990 Fuel Prices in 1981 \$/10<sup>6</sup> BTU)

Fuel Price Scenario	Region/ Insolation	FUEL TYPE				
		Distillate	Residual	Nuclear	Natural Gas	Coal
LOW	B: Fresno & C: Fort Worth	\$ 7.87	\$ 7.02	\$ .92	\$6.68	\$1.61
	A: Albuquerque	7.43	6.73	.92	6.98	2.34
MEDIUM	B: Fresno & C: Fort Worth	9.75	8.74	.91	6.32	1.61
	A: Albuquerque	9.23	8.37	.91	6.94	2.40
HIGH	B: Fresno & C: Fort Worth	12.61	11.30	1.00	6.57	1.81
	A: Albuquerque	12.01	10.86	1.00	7.63	2.78

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

These fuel prices correspond to the three NEP-III 1990 fuel price projections (see Ref. 13) and are based on EIA regional fuel prices for the Southwest and West regions. 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 (see Ref. 14). 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. These scaling factors are given in Table 4-3; see Ref. 15 for further discussion. Finally, three fuel price escalation rates were assumed for the post-1990 period: real annual fuel price escalation rates of 5 percent, 3 percent, and 0 percent, corresponding to the high, medium and low fuel price scenarios respectively.

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, and varies dramatically over time. For example, the medium or high fuel price scenarios were generally accepted as the most likely following the 1978-79 Iranian oil embargo; conversely, the low oil price scenario seemed most probable during the oil glut 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 later in this report.

#### 4.2 UTILITY-SPECIFIC VARIATIONS

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 to represent the regions included in this analysis 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 concerning how these mixtures will change over time, must be considered in selecting representative utilities.

Projections regarding changes in the mixture of generating capacity and fuel use patterns over time were obtained from Electric World (Ref. 16), Data Resources, Inc. (Ref. 17), DOE (Ref. 18, 19, 14), EPRI (Ref. 20, 21), the California Energy Commission (Ref. 22), and Southern California Edison (Ref. 23).

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

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

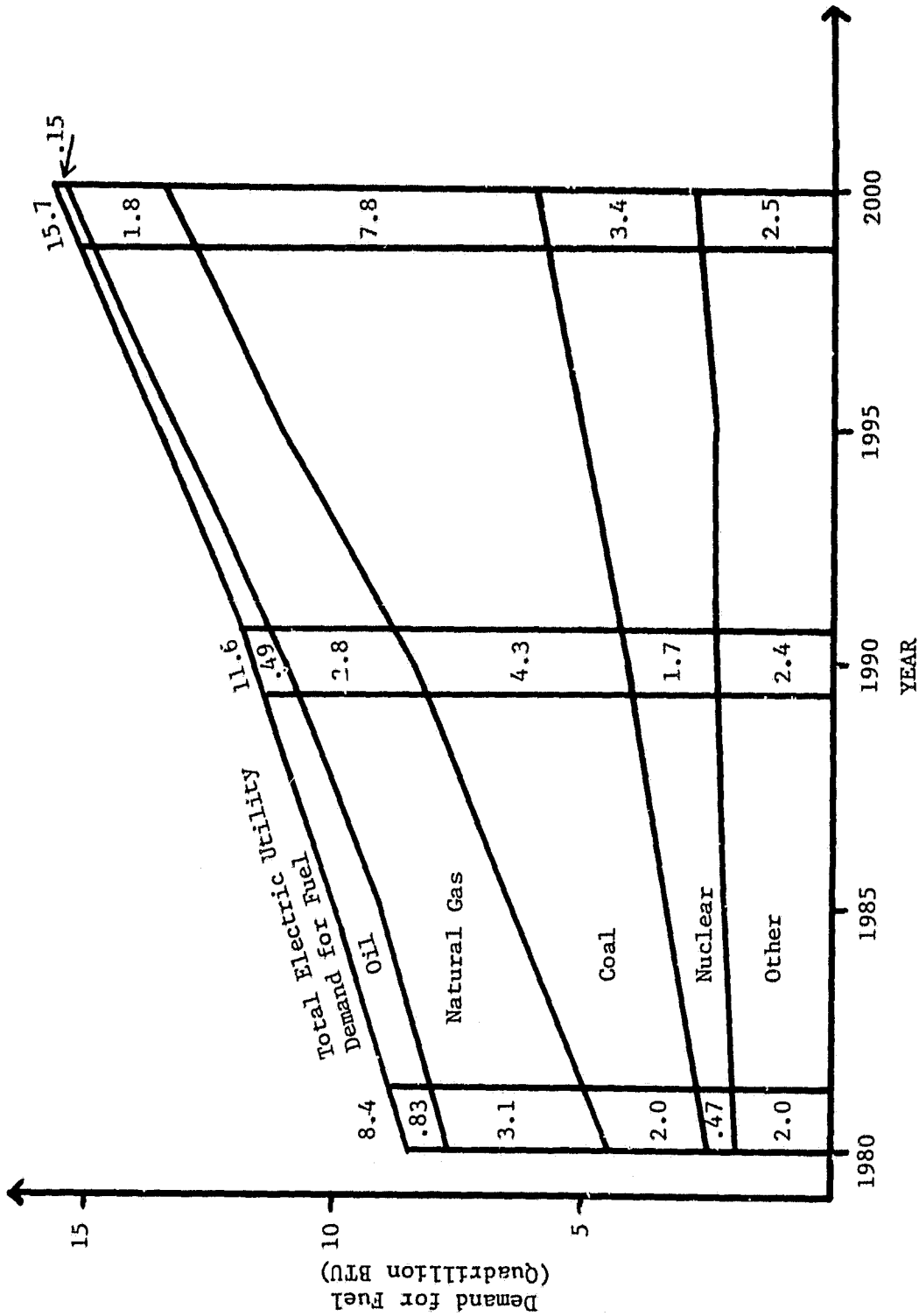
These studies all revealed a similar trend. Currently, a substantial percentage of the oil and gas burned by electric utilities is used to satisfy base- and intermediate-load demands. Nuclear and coal-fired systems are expected to replace oil and gas in these uses; oil and gas will continue to serve 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. By 1990, oil and gas will still supply some base and intermediate demands, but the transition should be virtually complete for the regions included in this study by 2000, according to Data Resources, Inc. (see Figure 4-1).

#### 4.2.1 The Representative Electric Utility

The Electric Power Research Institute (EPRI) has modeled various synthetic utilities, providing hourly load data, generating capacity mixtures, and information regarding the technical operation and maintenance characteristics for these hypothetical utilities. The data for each synthetic utility represents average values for all of a particular category of utilities in the United States (Ref. 20), thus providing a consistent set of data covering all aspects of utility power generation and energy demand. Since the peak power demand for the states included in this analysis occurs during the summer months, the summer-peaking EPRI "E" investor-owned synthetic utility was chosen as the representative utility. While no utility covered in this study actually exhibits the characteristics of the EPRI "E" utility, it is designed to represent the region as a whole.

The 1990 generation mix for the scaled-down EPRI "E" utility used in this analysis is shown in Table 4-4. This utility description was compared with the projected trends in generating capacity mixtures and fuel use patterns to ensure consistency. Heat rates, forced outage rates, scheduled maintenance, operation and maintenance costs, capital costs, and hourly load data were all derived from EPRI data (Refs. 20, 21), and are shown in Table 4-5. During the period 1990 to 2019, peak demand was assumed to grow at an annual

Figure 4-1. Projected Electric Utility Demand for Fuel by Source (Quadrillion BTU)



- Includes the following Data Resources, Inc., Regions: East South Central #2, West South Central #1, West South Central #2, Mountain #1, Mountain #3, Pacific.
- Individual fuel demands may not sum to annual totals due to rounding errors.
- Source: Data Resources, Inc., Energy Review, Autumn 1981. Tables A-6, A-60, A-61, A-62, A-63, A-65, A-66.



Table 4-4. Utility Capacity Expansion Plan (Figures in MWe)

Year	1990*	2019 (No Solar Case)**							
Unit Type	Regions A,B,C		Regions A,C			Region B			
	All Fuel Prices		High	Medium	Low	High	Medium	Low	
Nuclear	3200		16,654	16,438	16,156	16,259	16,257	16,257	
Coal	3902		164	188	98	0	0	0	
Gas	5000		490	380	170	0	317	0	
Oil	600		0	0	0	40	0	42	
Comb. Turb.	1745		4,103	4,405	4,986	5,111	4,836	5,111	

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

\*1990 generating capacity based on the EPRI "E" Synthetic Utility (see Ref. 7). Capacity mix is constant across regions and fuel price scenarios.

\*\*2019 generating capacity mix estimated using a screening curve methodology. Capacity mix varies across regions and fuel price scenarios reflecting variations in fuel prices.

Table 4-5. Generating Plant Characteristics

Generating Unit	Fuel	Heat Rate (10 <sup>6</sup> BTU/MWh)	Capital Cost (\$/kW)***	Fixed O&M (\$/kW/Y)	Var O&M (\$/MWh)	Forced Outage Rate	Sched. Maint. (Wk/Yr)
800 MW Nuclear (N)	N	10.40	960	3.25	0.82	0.15	7
800 MW Coal (WFGD)	Coal	8.31	960	2.82	2.76	0.24	5
800 MW Natural Gas (NG)	NG	9.2	450	2.25	0.37	0.24	5
600 MW Natural Gas	NG	9.4	450	2.25	0.37	0.21	5
400 MW Natural Gas	NG	9.5	450	2.25	0.37	0.13	5
600 MW Coal	Coal	9.167	1,000	2.82	2.76	0.21	5
400 MW Coal	Coal	9.27	1,070	2.82	2.76	0.13	5
400 MW Oil	OR*	9.40	450	2.25	0.37	0.13	5
200 MW Natural Gas	NG	10.05	450	2.25	0.37	0.074	3.5
200 MW Oil	OR*	9.90	450	2.25	0.37	0.074	3.5
200 MW Coal	Coal	9.785	1,190	2.82	2.76	0.074	3.5
50 MW Comb. Turbine	OD**	14.00	185	0.61	2.50	0.240	2

\*OR -- Oil Residual

\*\*OD -- Oil Distillate

\*\*\*Figures are 1990 cost expressed in 1980\$.

Source: EPRI Technical Assessment Guide, July 1979 (See Ref. 8)

rate of 3 percent, with a constant load shape. 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 (see Table 4-4). 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 capacity consists primarily of nuclear power plants and combustion turbines. The screening curve approach to utility capacity expansion typically results in this type of polarized capacity mix. If one technology has slightly lower life-cycle costs than its competitors, screening curves will indicate that the utility should install only the less expensive alternative. Nuclear was the least-cost option for all base-load and most intermediate-load applications. Thus, the screening curves indicated that nuclear power would dominate the utility's capacity mix by 2019. Although this dramatic expansion of nuclear capacity is unlikely due to regulatory and licensing constraints, the nuclear-dominated capacity was retained in this study. This will introduce a conservative bias in the estimated value of STT for electric utility applications. The bias will be limited, however, since the primary value of STT comes from oil and natural gas displacement.

#### 4.2.2 Financial Parameters

STT demand curves were estimated for each region and fuel price scenario included in this analysis, based on the value of fuel and O&M displaced by the STT system. The methodology outlined above was used with the generating capacity and load pattern data for the representative electric utility, the regional insolation levels and fuel price scenarios. More specifically, the energy output of a generic solar thermal electric power plant was estimated for a variety of system capacities using regional insolation data. System capacities were selected to represent 1, 5, 10, and 20 percent of 1990 peak power demand for the representative utility system. Assuming STT systems of these capacities were added to the original EPRI "E" generation 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. The quantity and value of fuel displaced and the O&M expense saved in each year of the analysis for each case considered can be determined by comparing the fuel and O&M requirements for each alternative STT system capacity with the fuel and O&M requirements of the conventional system base case. These yearly fuel and O&M credits were used to determine the total value of STT for each of the four system capacities considered.

The marginal value of STT to the representative electric utility was estimated based on the fuel and O&M credits described above. To derive the actual value of these credits as realized by the utility, the tax rates,

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

depreciation schedules, and financial parameters which the utility faces must be considered. These parameters may vary across utility types, and even among utilities of the same type. This analysis only considers the financial parameters of an investor-owned utility. As municipal utilities, rural electric cooperatives, and federal utilities have more favorable financial characteristics, this analysis represents conservative estimates for those utility types. The financial parameters used in this analysis, shown in Table 4-6, correspond to the parameters adopted by the Solar Thermal Cost Goals Working Group (see Ref. 24) with the exception of the fixed charge rate (FCR). The FCR adopted here is a more conservative value (0.1601 as opposed to 0.1496).\*

#### 4.3 REGIONAL DEMAND FOR ELECTRIC UTILITY APPLICATIONS OF STT

Based on the financial parameters indicated in Table 4-6 and the fuel and O&M credits described above, the total value of STT to the representative utility was determined for each system capacity considered. STT incremental values and the demand curve for STT in electric utility applications are based on these total values. The total values of STT were calculated from a methodology developed at JPL (Ref. 25). As indicated in the appendix to the referenced document, the JPL methodology is equivalent to other frequently cited methodologies. The total incremental value of an additional MWe of STT

Table 4-6. Financial Parameters for an Investor-Owned Utility

- 
- o Fixed Charge Rate = 0.1601  
(Solar Thermal Cost Goal Working Group = 0.1496)
  - o Inflation Rate = 6% (after 1990)
  - o Investment Tax Credit = 10% in first year of operation
  - o Federal Income Tax = 48%
  - o System Life = 30 Years
  - o Depreciation Life = 22 Years
  - o Depreciation Method = Sum-of-years-digits (SYD)
  - o Other Taxes/Insurance = 2%
  - o Discount Rate = 7.0% Real (1981-1990)  
= 4.3% Real (Post-1990)
- 

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\*After the analytical work described in this report was completed, the tax laws were changed to allow for a more rapid depreciation schedule (the Accelerated Capital Recovery System) which uses a 15-year depreciation life. Changing this assumption would change the Cost Goal Committee FCR to 0.1473.

capacity is calculated by determining the change in total value between successive STT capacity levels and normalizing by the change in system capacity. This change in the total 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. These curves indicate that, up to a point, utilities will prefer using solar thermal technologies to burning fuel. 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 vertical axis of these demand curves represents installed system costs.

This estimation procedure was repeated for all three fuel price scenarios in each of the three regions (see Figure 4-2 for a representative demand curve). 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. These curves represent conservative estimates of the actual 1990 demand for STT in three respects: investor-owned utility financial parameters are assumed; capacity credits resulting from the installation of STT capacity are not included; and storage capacity was not considered in conjunction with the STT system.

#### 4.4 CAVEATS

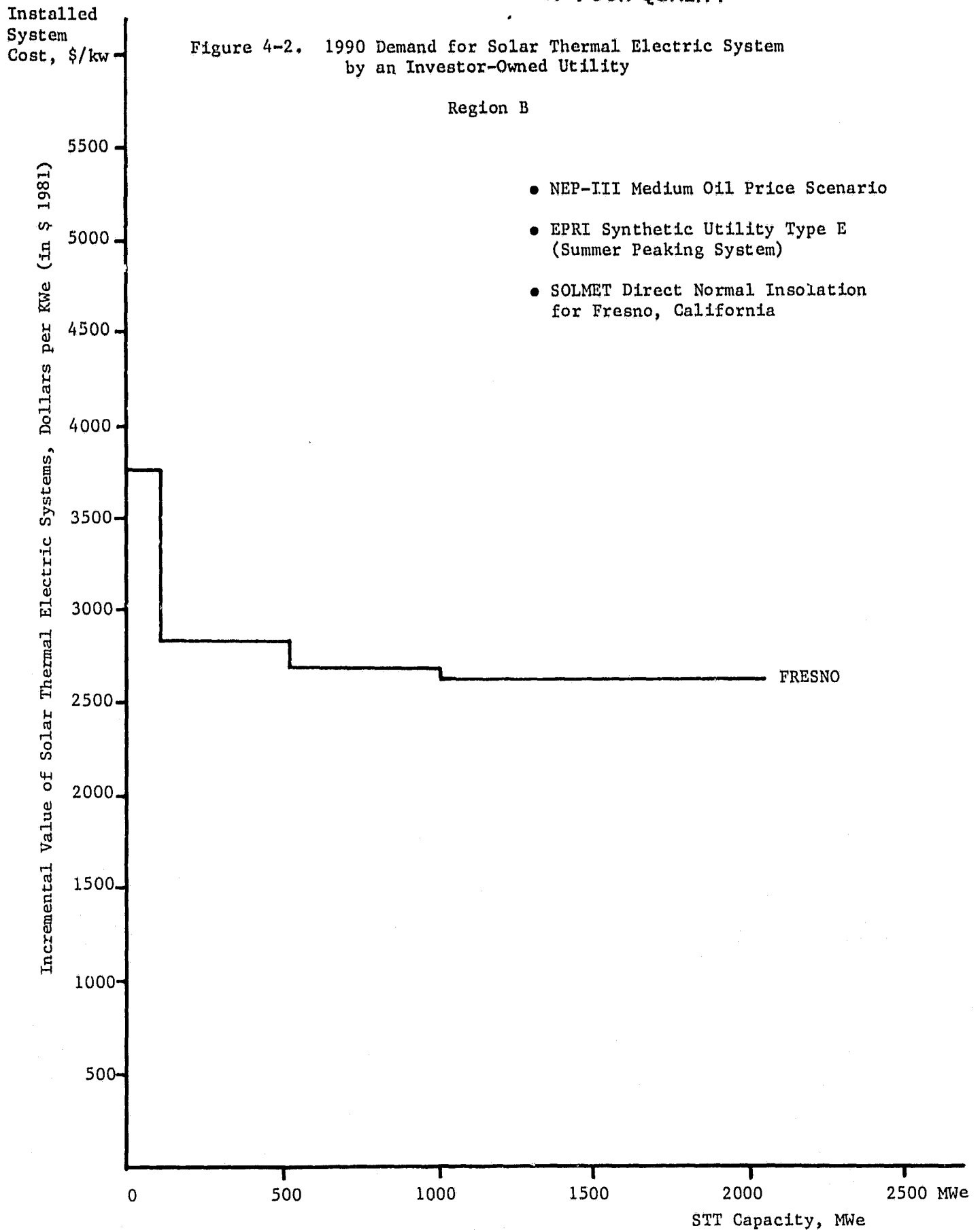
Two important assumptions implicit in this analysis should be stressed. In the methodology described here, the value of additional units of STT depends on the cost of the best alternative energy source to STT. Thus, estimating the future demand for STT requires scenarios which incorporate explicit or 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, these demand curves for STT 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. Current conventional technologies are assumed to represent the best available alternatives to STT over the years included in this analysis. This assumption becomes less realistic for the high fuel price scenario, because when oil prices are high, oil is less likely to represent the best available alternative.

A related issue concerns the static nature of the demand curve analysis in this methodology. This analysis estimates the demand for STT at a particular point in time. Implicit in these demand projections are assumptions regarding STT installations both before and after the time being examined.

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Figure 4-2. 1990 Demand for Solar Thermal Electric System  
by an Investor-Owned Utility

Region B



Many 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 in the demand curve for the year in question: prior installations reduce the demand for STT, and 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. Thus, 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.

## 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 which 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.

#### 5.1 STT COST ESTIMATES

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, 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 production techniques employed and the prices of materials 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. To accurately estimate future STT production and installation costs, the future regional values of these factors must be predicted. Because these predictions are highly uncertain, meaningful point estimates of these regional values cannot be obtained. As was the case with demand projections, a range of values has been considered.

#### 5.2 STT COST GOALS

This analysis assumes that future STT costs will encompass the 1990 cost goal for the federal STT Program (see Ref. 24). The STT cost goals combine characteristics of attainability-based and value-based targets, and have been specified for initial deployment in 1990 and 1995 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 attainability-based 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. Thus, these cost goals simplify the cost estimation procedure described in the previous paragraph by selecting a representative STT system 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. As a result, 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 used in this analysis. They are: \$1400/KWe, \$2700/KWe, and \$4000/KWe (all in 1981 dollars).

## SECTION 6

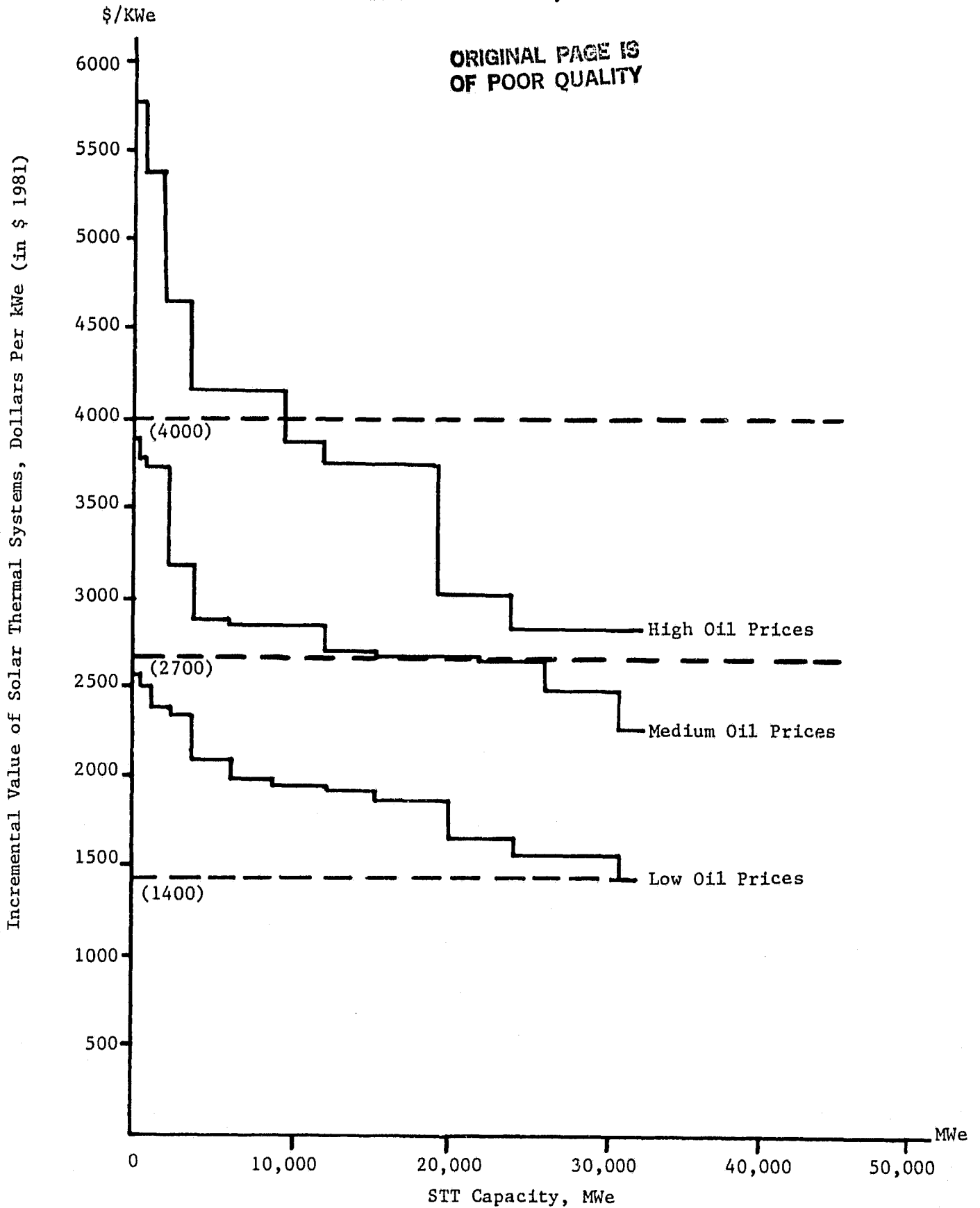
### INTEGRATION OF STT DEMAND AND SUPPLY

Once a range of values has been estimated for both STT supply and demand, the estimates can be combined to determine the market potential for STT in the year being analyzed (see 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 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.

Figure 6-1 illustrates that sufficient demand exists in the electric utility sector to support a significant STT market. The size of the market strongly depends on achieving the STT cost targets and is sensitive to future fuel prices. The demand curves depicted in Figure 6-1 indicate that, up to a point, utilities will prefer using solar thermal technology to burning fuel. 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. If the medium oil price scenario and the \$2700/KWe cost target are achieved, utilities would prefer to use 20,000 MWe of solar thermal systems rather than burning fuel. This would amount to 100 years of output from a single factory mass-producing 1,000,000 m<sup>2</sup>/yr. of STT concentrators -- a level of required output sufficient to support a competitive industry.

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 in 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 over a number of years, however, will approach the total capacity for which STT is cost-competitive. This suggests a dynamic approach to projecting future STT deployment decisions. Since a dynamic formulation is beyond the scope of this analysis, static estimates of total potential demand have been used.

Figure 6-1. 1990 Economic Market Potential for  
Solar Thermal Electric Systems



## SECTION 7

### STT BENEFIT ASSESSMENT

The curves depicted in Figure 6-1 can be used to assess the benefits accruing from the federal STT Program. As discussed earlier, three benefits are considered explicitly in this analysis: the direct benefit of the energy cost savings associated with installations of cost-competitive STT systems; and two indirect benefits -- national security implications and the environmental impacts associated with reductions in the use of petroleum and other fossil fuels in generating electricity.

#### 7.1 ENERGY COST SAVINGS

Energy cost savings can be measured by examining the STT demand and supply curves shown in Figure 6-1. By construction, STT demand curves represent the incremental value to electric utilities of additional units of solar thermal electric capacity. STT supply curves indicate the incremental cost of producing additional units of STT capacity. The net energy cost saving is represented by the area which is bounded by the demand curve, the horizontal line representing the relevant STT supply curve, and the left-hand vertical axis. These benefits have been evaluated for three fuel price scenarios (reflecting uncertainty over future price levels), and three alternative STT cost levels (reflecting uncertainty over the level of R&D success and production volumes).

Figure 7-1 shows the relationship between STT system costs (\$/KWe) and the discounted net present 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 zero to \$27 billion (1981 dollars). The range reflects achieving the high (\$4000/KWe) and low (\$1400/KWe) STT cost targets. Achieving other cost targets would result in different values for the potential benefit to the nation; e.g., Figure 7-1 shows that the \$2700/KWe cost target would result in a net energy cost savings of \$2 billion.

Table 7-1 summarizes the net present value of the net energy cost savings for three oil price scenarios and three levels of STT costs. If STT systems cost \$4000/KWe, installations will be cost-effective only in the high energy price scenario. However, at a cost of \$1400/KWe, STT would be preferred in the utility sector under all three oil price scenarios. The net energy cost savings in the \$4000/KWe case range from zero to \$10 billion; at \$1400/KWe, benefits vary from \$9 to \$50 billion.

It is important to note that STT benefit projections range between zero and \$50 billion, as shown in Table 7-1, depending on the level of R&D success and future energy prices. To capture these benefits, investment is needed in R&D and in STT component production capacity. There is a substantial risk that all of this investment will be lost, under plausible scenarios for the future price of oil. In the case of STT R&D (as with other energy-related R&D projects), this risk is accentuated due to the

Figure 7-1. Net Present Value of Solar Thermal Electric Systems

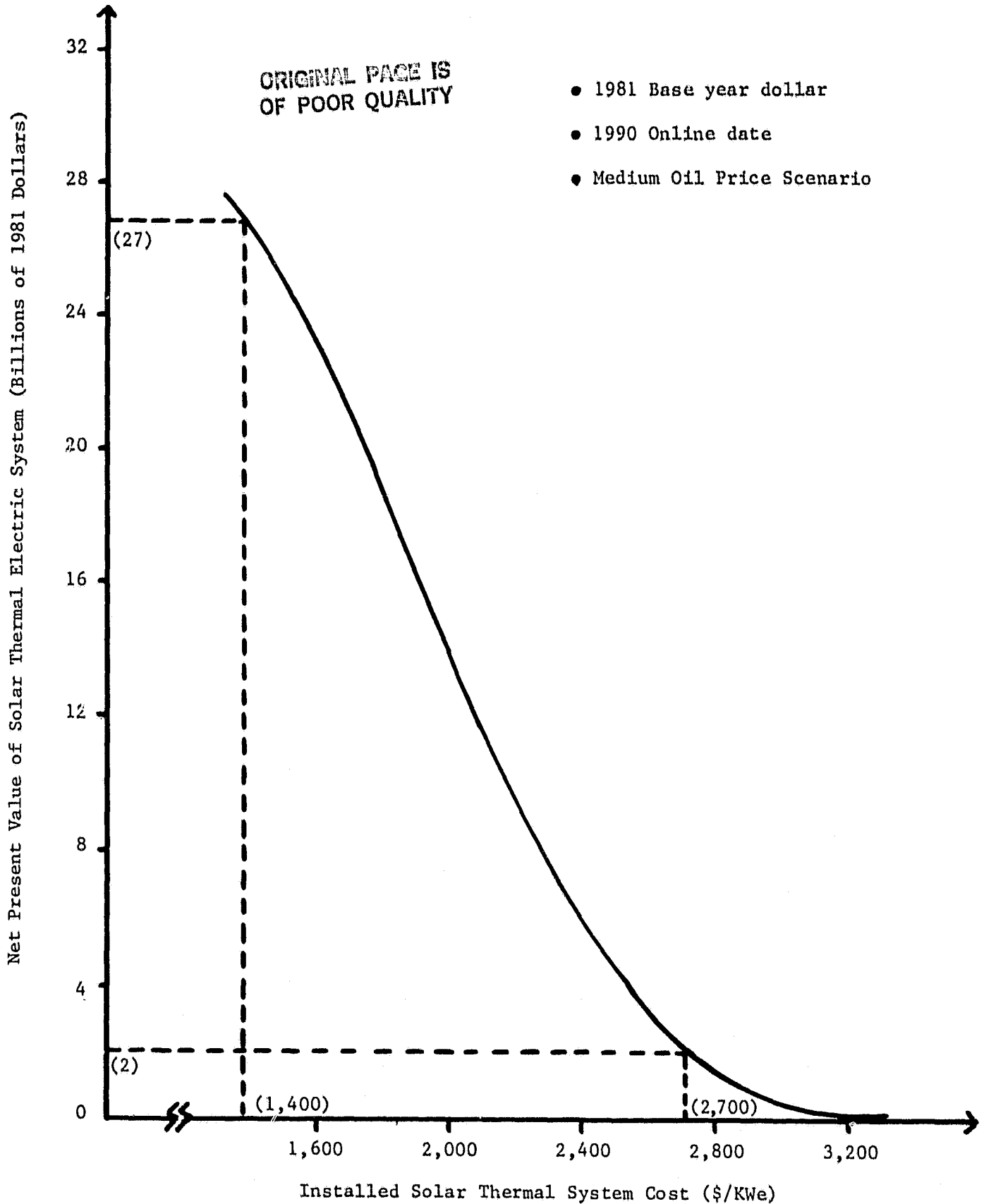


Table 7-1. Total Net Present Value of Solar Thermal Electric Systems  
(1990 Values in Billions of 1981 Dollars)

STT R&D Success**	NEP III Energy Price Scenario*		
	Low	Medium	High***
\$4,000/KW <sub>e</sub>	0	0	10
\$2,700/KW <sub>e</sub>	0	2	14
\$1,400/KW <sub>e</sub>	9	27	50

\*Low, Medium, High refer to the NEP III energy scenarios based upon the 1990 imported oil price of 44, 52, 68 (1981 \$/Barrel).

\*\*Level of success is indicated by the 1990 installed solar thermal system cost (1981 \$/KW<sub>e</sub>).

\*\*\*Energy cost savings as estimated here assume that conventional generating capacity 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.

influence of the OPEC cartel. World oil prices are not market-determined, but are primarily determined through the price-setting policies of OPEC, and particularly by Saudi Arabia. If solar thermal technologies (or other alternative energy resources) threaten to displace substantial quantities of imported petroleum, OPEC could lower oil prices and undercut the price of the developing technologies. Since private industry often seeks to minimize its maximum potential loss, the lack of potential markets under the low and medium energy price scenarios, 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 and the production facilities required to make STT cost-competitive.

Public objectives, however, differ from those of a private profit-making firm. The public objectives include 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. Private incentives for conducting STT R&D are limited due to the energy market imperfections introduced by the OPEC cartel. From society's point of view, the values in Table 7-1 represent costs which might be incurred by not developing an STT option. In the high fuel price scenario, these costs are substantial (between \$10 billion and \$50 billion), but can be avoided through STT development. Expenditures on STT R&D also would limit both the disruptive impact of future increases in world oil prices and the environmental deterioration associated with petroleum, coal,

and nuclear facilities. Despite these benefits, and the potential energy cost savings, private industry is unlikely to fund this R&D because of the market imperfections introduced by OPEC. The risks to society of not developing an STT option justify federal participation to capture the significant national benefits associated with STT R&D.

## 7.2 NATIONAL SECURITY IMPLICATIONS

The demand curves depicted in Figure 6-1 can also be used to indicate the national security implications associated with alternative STT penetration levels. The quantity of each fuel type displaced by an STT system was used in estimating the value of that system to the electric utility, so the displacement of each fuel type can be determined for each point on the demand curve (see Table 7-2). Because imported petroleum is the marginal energy source in the U.S., oil reductions will likely translate directly into import reductions. Furthermore, due to the substitution opportunities between petroleum and natural gas, a portion of the displaced natural gas may also be used to further reduce petroleum imports. Therefore, the displacement of oil and natural gas is particularly relevant to national security considerations. Table 7-3 shows the average number of barrels of oil STT would displace daily for three combinations of fuel prices and STT system costs. The average total natural gas displacement is also included in Table 7-3, expressed in equivalent barrels of oil per day. If all petroleum and natural gas displaced by STT were used to reduce oil imports, the sum of the values in Table 7-3 would indicate the average impact on daily oil imports. Crude oil imports are projected to be 3.64 million barrels per day in 1990 (see Ref. 17, Table A-8, page 165). The maximum potential reduction in oil imports attributable to STT ranges from zero percent to 9 percent, depending on the fuel price and STT system cost scenario. The actual impact is likely to be significantly smaller than the maximum potential values indicated in Table 7-3. It is unlikely that there will be perfect substitution between displaced natural gas and petroleum, especially in the higher fuel price scenarios where significant substitution for petroleum has already occurred. Additionally, some of the petroleum displaced is likely to be domestically produced oil. Even partial substitution between imported petroleum and the oil and natural gas displaced by STT, however, would contribute significantly toward reduced reliance on imported petroleum. Thus, an STT industry would reduce dependence on imported petroleum, diversify the nation's portfolio of domestic energy resources, and positively impact the nation's security.

## 7.3 ENVIRONMENTAL IMPACTS

Environmentally, STT provides important benefits by reducing the use of fossil and nuclear fuels in electrical 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. Data on STT fuel displacement by fuel type (from Table 7-2) can be used to indicate the extent of the environmental impacts. Reductions in air pollution levels can be determined for alternative combinations of fuel prices and STT system costs, assuming that the proposed 1990 air pollution standards are satisfied. Table 7-4 provides sample pollution abatement estimates, which

Table 7-2. STT Total Life-Cycle Fuel Displacement  
(Quadrillion BTU)

Fuel Price Scenario	LOW					MEDIUM					HIGH				
	Nuclear	Coal	Gas	Oil	TOTAL	Nuclear	Coal	Gas	Oil	TOTAL	Nuclear	Coal	Gas	Oil	TOTAL
Fuel Type STT Cost (\$/KWe)															
4000	0	0	0	0	0	0	0	0	0	0	1.2	1.0	3.2	3.1	8.5
2700	0	0	0	0	0	1.4	1.2	3.8	3.9	10.3	6.1	5.0	12.1	8.6	31.8
1400	5.0	4.7	11.8	11.0	32.5	5.4	4.7	11.9	9.8	31.8	>6.1	>5.0	>12.1	>8.6	>31.8

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OF POOR QUALITY



Table 7-3. Average Daily STT Displacement of Oil and Natural Gas  
(in Equivalent Barrels of Oil)\*

STT Cost (\$/KWe)	Fuel Price Scenario					
			LOW	MEDIUM	HIGH	
4000	Oil:	0	Oil:	0	Oil:	50
	Natural Gas:	0	Natural Gas:	0	Natural Gas:	50
2700	Oil:	0	Oil:	60	Oil:	135
	Natural Gas:	0	Natural Gas:	60	Natural Gas:	185
1400**	Oil:	170	Oil:	150	Oil:	135
	Natural Gas:	180	Natural Gas:	180	Natural Gas:	185

\*Figures expressed in  $10^3$  barrels of oil per day.

\*\*For the \$1400/KWe STT cost case, average daily oil displacement is greater in the low fuel price scenario than in the high fuel price scenario. This reflects the fact that in the higher fuel price scenarios, significant substitution for oil has already occurred. As a result, there is less oil for STT to displace in the higher fuel price scenarios.

represent reductions in air pollution in excess of those achieved in meeting the anticipated 1990 pollution standards. These pollution reductions are relatively insignificant on a national scale, so the impact of STT on the national air pollution problem is likely to be limited.

Regionally, however, the environmental impact of STT can be substantial. In many air basins with significant air pollution problems, a substantial percent of the pollutants can be attributed to the operation of electric power plants. In the Southern California air basin, for example, approximately 30 percent of the sulfur oxides and 10 percent of the nitrogen oxides, two important components of air pollution in Southern California, can be attributed to power plant emissions. Southern California Edison, the major electric utility in the area, has a high percentage of newly installed oil-fired plants (see Ref. 7). This relatively high dependence on oil as a fuel source for electricity generation in Southern California is not expected to change dramatically before 1990.

Table 7-4. STT Pollution Reduction for Selected Emissions  
(Improvement over best available control technology -- 1990)

- Low Sulfur Coal (.5%)
- Coal Heat Content: 13,000 BTU/lb.
- Low Sulfur Petroleum (.5%)

Oil Price Scenario	LOW			MEDIUM			HIGH		
	CO <sub>2</sub> (10 <sup>6</sup> tons/yr.)	SO <sub>x</sub> (10 <sup>3</sup> tons/yr.)	NO <sub>x</sub> (10 <sup>3</sup> tons/yr.)	CO <sub>2</sub> (10 <sup>6</sup> tons/yr.)	SO <sub>x</sub> (10 <sup>3</sup> tons/yr.)	NO <sub>x</sub> (10 <sup>3</sup> tons/yr.)	CO <sub>2</sub> (10 <sup>6</sup> tons/yr.)	SO <sub>x</sub> (10 <sup>3</sup> tons/yr.)	NO <sub>x</sub> (10 <sup>3</sup> tons/yr.)
STT Cost (\$/KWe)									
4000	0	0	0	0	0	0	20	4	14
2700	0	0	0	9	2	6	75	12	50
1400	80	13	55	80	12	50	80	12	50

STT penetration in Southern California can have significant environmental impacts. STT installations would reduce the capital expenditures associated with emission control technology, an impact estimated to add up to \$100/KW<sub>e</sub> to the 1990 value of STT as estimated in this analysis (see Ref. 7). STT would eliminate power plant emissions that were not controlled by the 1990 power plant emissions standards. Health benefits and reduced crop damage are among the social impacts of reduced air pollution. Finally, STT installations would provide salable pollution offsets. Industrial growth in the Southern California air basin is constrained because pollution exceeds federal standards, so creating salable offsets would allow further industrial growth.

The federal STT program should provide significant benefits in air basins, such as California, with air pollution problems associated with power plant emissions. Southern California offers an especially favorable market for solar thermal systems. High insolation in the Southern California deserts, combined with high fuel prices for oil-fired electric power plants, make this a promising region for early STT installations.

#### 7.4 CAVEATS

From the STT demand curves derived in this analysis, many benefits associated with the federal STT Program, besides the three assessed here, can be evaluated. Detailed discussion of the benefits is beyond the scope of this document, but two final points deserve discussion. First, these benefits, with the exception of the regional environmental impacts, represent the total values attributable to STT assuming all cost-competitive systems as of 1990 are actually installed in that year. Due to probable manufacturing bottlenecks and imperfect consumer information, actual STT installations are expected to fall short of the total potential level. Thus, the values reported here represent upper bounds on the actual level of benefits which 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. Second, the entire net benefit of 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, 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.

## SECTION 8

### CONCLUSIONS

This analysis has assessed three primary benefits associated with cost-competitive installations of STT in electric utility applications under a range of future fuel price scenarios and STT system costs:

- (1) The present value of the energy cost savings, expressed in 1981 dollars, is expected to vary between zero and \$50 billion, depending on the fuel price scenario and STT system cost.
- (2) Imports of foreign petroleum can be reduced by up to 9 percent, depending on the fuel price scenario, STT system cost, and the substitution between imported petroleum and the oil and natural gas displaced by STT.
- (3) Environmentally, STT can have a significant impact in air basins where electric power plant emissions create substantial air pollution problems.

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 the relevant fuel price scenario. As with most R&D projects, the outcome is quite uncertain, as reflected by the range of 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 through 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. Then during the oil glut early in 1982, the low oil price scenario appeared most probable. Because fuel price expectations vary so greatly, which impacts the anticipated benefits from STT R&D, there is a greater-than-average uncertainty over STT R&D. To private industry, STT R&D represents a risky investment, so private STT R&D efforts 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. These social benefits would far exceed the costs of the federal R&D program. Therefore, federal participation to capture these significant national benefits is justified.

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