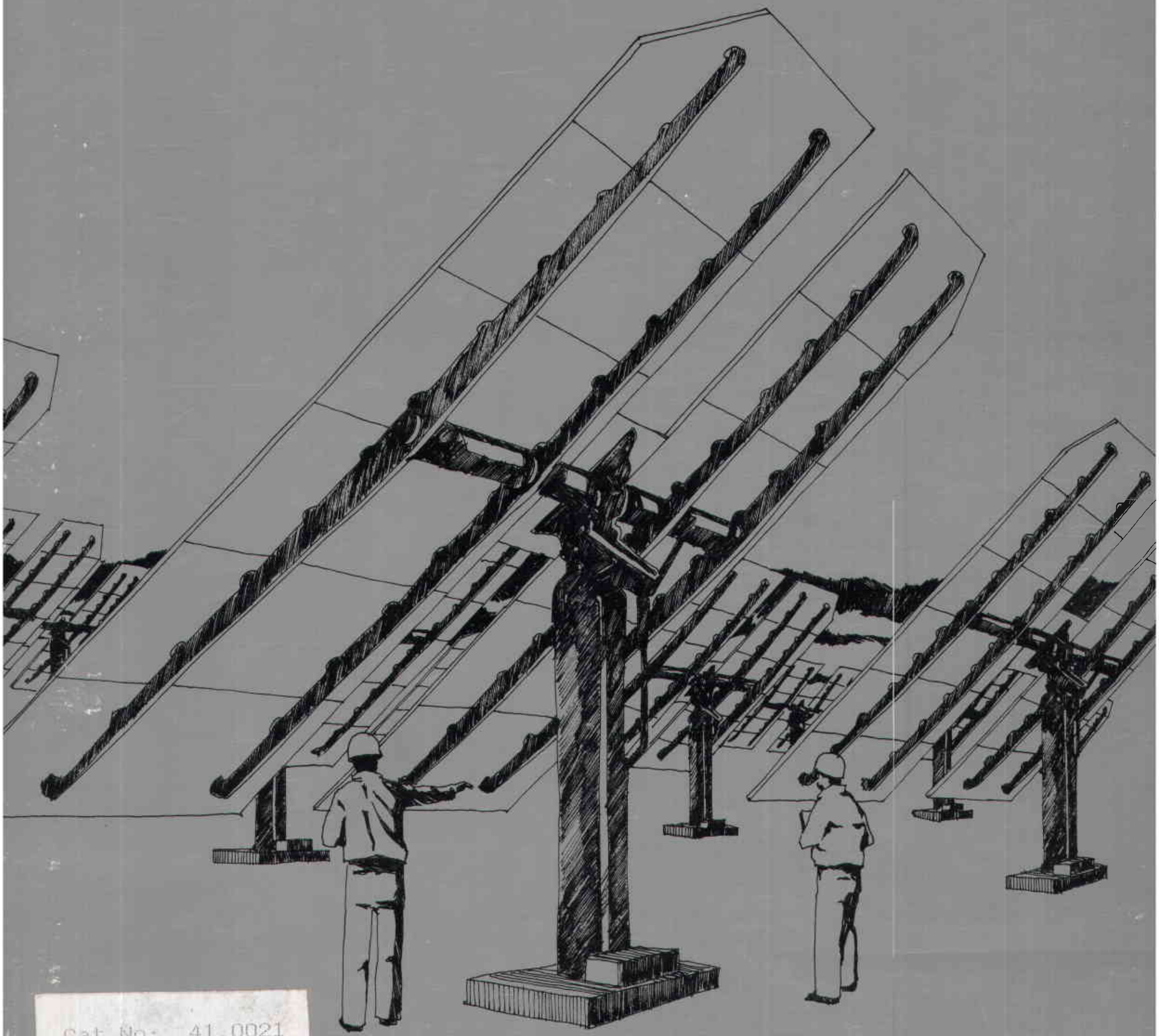
MTR-7861

SOLAR THERMAL REPOWERING

The MITRE Corporation
METREK Division



Cover—An artist's conceptual drawing of a solar thermal central receiver repowering facility. The repowered plant includes a field of tracking mirrors (heliostats) which aim the sun's direct radiation at a common target. In the receiver, elevated above the field by the tower, steam is generated and superheated to about 1000° F and 100 atmospheres pressure. On the ground, the steam is utilized by an existing power plant for production of electricity or for industrial processes. The existing oil- or gas-fueled boiler is operated to levelize the steam output and provide full power when the sun is not available.

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Solar Thermal Repowering

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ABSTRACT

A program requirements analysis and a utility survey have been conducted by Metrek to establish the feasibility of a government commitment to solar thermal repowering. Repowering involves the retrofit of existing oil- and gas-fired steam plants in the southwestern U.S. with the solar thermal central receiver ("power tower") system. This report documents the probable plant configurations, market splits by plant type, state and fuel type; geographic distribution of sites; generic development plans for the construction of the system; development of manufacturing and support facilities; capital requirements; cost estimates; labor and material requirements; net energy analysis; utility reactions to the concept; and energy production implications. One requirements scenario is analyzed to determine the actions necessary to meet a goal of 0.1 quads per year of capacity by 1985. In addition, the SPURR model was used to simulate the effects of two proposed incentives programs to estimate probable market penetration, and results of this analysis are presented and compared to a National Energy Plan scenario.

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EXECUTIVE SUMMARY

The MITRE Corporation, Metrek Division, has conducted an analysis of required Federal actions and an assessment of the availability of suitable sites needed to attain a goal of 0.1 quads per year of energy savings by 1985 through solar thermal central receiver repowering. Repowering involves the augmentation of existing oil- and gas-fired steam plants in the Southwest with solar thermal central receiver ("power tower") systems. Repowering appears to be a means to commercialize the central receiver concept earlier than heretofore expected. Federal action to support solar thermal repowering could mean that the industry would begin to form in the early rather than the late eighties. Two factors account for the possibility of early commercialization:

> The market for repowering is readily identifiable, large, and has high marginal costs with which to compete; and

> The solar thermal central receiver concept will likely have proven technical and engineering feasibility at the 10 MWe Barstow pilot plant by 1981. The Barstow facility is the key project on the critical path to repowering.

The benefits of early commercialization of the central receiver can be measured by the amount of domestic employment and investment, fuel savings, and, ultimately, cost savings for utilities and their customers.

The number of jobs and amount of domestic investment are expected to be substantial during the birth of the central receiver industry. Approximately 20 to 30 man-years per incremental megawatt are required in direct labor, with about a 3 to 4 multiplier effect for indirect and supporting (spin-off) jobs being created. This employment level is roughly double that associated with conventional generation technologies, i.e., oil, gas, and coal. With a growth rate of about 3000 MW per year (expected by the turn of the century), between 180,000 and 360,000 jobs would be created. Capital expenditures would average roughly $1200 to 1500/kilowatt (1978 dollars), resulting in expected annual capital requirements of roughly $3.6 to 4.5 billion at that time.[1]

Preliminary calculations indicate that the supporting industry which produces the heliostats (tracking mirrors) and other pertinent equipment will be profitable and self-sustaining once utility orders for solar power plants reach roughly 200 MW per year. Also, estimated busbar costs for repowering are lower than for competing technologies (oil, gas, and coal) once heliostat mass production facilities are constructed and operating at full capacity.

THE IMPACTS OF REPOWERING

Projections made using the MITRE SPURR model (System for Projecting the Utilization of Renewable Resources)(16) showed that under the National Energy Plan (which includes a 20 percent investment tax credit), free market conditions would likely preclude solar

[1] All cost estimates in this study (unless otherwise noted) are in 1978 dollars.

thermal electric generation before about 1990. Under the National Energy Plan (NEP), the energy savings for installed utility power plants using solar central receiver concepts are projected at 0.43 quads per year by 2000. If the NEP scenario is complemented by a $200 million government cost sharing program beginning in 1981 for solar thermal repowering facilities, the projected impact by 2000 is 0.90 quads per year (an incremental 0.47 quads per year). This is approximately equal to a subsidy of $0.08 per barrel equivalent for the incremental 0.47 quads per year of energy saved in 2000 (over the estimated 30-year plant life). In addition, a 30 percent investment tax credit coupled with the cost sharing program is projected to add an incremental 0.46 quads per year by 2000 to the energy savings directly attributable to solar central receiver technology.

The profitability of the supporting industry is also expected to be substantial. A cash flow analysis indicates that a three-year payback should be possible for large-scale heliostat production facilities operated at full capacity providing heliostats at a price of about $9 per square foot installed. The industry should not therefore require government subsidies to sustain itself once started. Preliminary estimates indicate that the distribution of expenditures accumulated by the time 0.1 quads per year of fuel is saved is 4 percent Federal, 17 percent industry, and 79 percent utility.

THE MARKET FACTORS

The market for repowering is estimated at 11 to 25 GWe, with an expected value of 18 GWe. The present overall use of oil and gas in steam electric plants in the southwestern United States is approximately 76 GWe of capacity (two-thirds gas and one-third oil-fired). The major limiting factor for the solar market potential is land availability. Roughly 12 GWe of the solar repowering market potential is in Texas, nearly all of which is currently gas-fired. The bulk of these facilities must convert to a fuel other than natural gas over the next 10 years if the National Energy Act is passed or be forced into retirement.(7) The temporary oil glut in the West caused by the Alaskan pipeline should last for only two more years, according to oil industry sources. Once a spur line can be built into Texas from New Mexico, oil refineries in Texas will make Alaskan oil available to the East. These developments will improve the market prospects for solar thermal repowering and for new combined solar thermal and oil-fired power plants in the Southwest.

New coal-fired facilities could be built. However, these would likely be baseload units of large (up to 1200 MWe) capacity and this would require up to six years for construction and one to four additional years for licensing, permitting and financing. The costs would be substantial, nearly as high as for projected solar capital requirements on a normalized ($/kW) basis. There are also other problems attributable to coal utilization involving environmental emissions, strip mining, and rebuilding of the railroads to deliver the larger coal shipments expected. These problems could delay coal expansion and significantly increase the cost of the coal as a fuel and the equipment that burns it.

By comparison, solar-repowered facilities could be constructed and operational two to four years after initial planning. The cost of conversion should be comparable to that for coal at this scale (less than 400 MWe, typically). Existing facilities could then continue to operate instead of being retired, using solar energy when available and small amounts of the conventional fuel when the plants are needed at other times.

Also, the acceptable cost of heliostats was computed to be $12 to $20 per square foot with repowering and $8 to $14 with storage-coupled, stand-alone solar thermal power plants. At present, estimated heliostat installed prices are in the range of $8 to $12 per square foot once heliostat mass production has been achieved, according to McDonnell Douglas, Ford Motor Company, Westinghouse, Martin Marietta, G.E., Boeing, Northrup, and Solaramics.

FEDERAL ACTION REQUIRED

To have a chance of meeting a rather ambitious goal of 0.1 quads of fuel savings per year by 1985, sixty-seven 50 MWe power plants must be constructed. The first plant should be operational by mid-1982.

Certain Federal actions are considered necessary in the near-term to begin this process of commercialization. It will be necessary for government to begin now with an aggressive parallel program to:

- Reprogram FY 79 funds to initiate funding for both heliostat production and repowering facilities
- Offer a heliostat design competition and choose the design for a production heliostat by May of 1979
- Obtain funding approval for a six-year repowering program on the order of $200 million
- Complete a site bank for all southwestern utilities
- Cost-share the first three repowering plants over the FY 79 to FY 83 period, with options for at least four additional plants
- Prepare and file a generic environmental impact statement (EIS) for the central receiver within 15 months
- Cost-share the first heliostat production facility or place a guaranteed order for approximately 25,000 heliostats.

These actions will increase the Federal solar thermal program costs over the next five years and increase the degree of programmatic risk. However, they are required to attain the goal of 0.1 quads per year of savings by 1985. Increased programmatic risks may be offset by the potential benefit of doubling the rate of solar central receiver market growth by the turn of the century.

SECTION I

INTRODUCTION

An analysis of required actions and policies and a utility applicability survey were conducted by Metrek to examine the implications of a government commitment to solar thermal repowering. Repowering involves the retrofit of oil- and gas-fired steam plants in the southwestern U.S. with the solar thermal central receiver ("power tower") system. This work was conducted for the Department of Energy, Division of Solar Technology.

This report documents probable plant configurations; market splits by plant and fuel type; geographic distribution of sites; generic development plans for the construction of the system; development of manufacturing and support facilities; capital requirements; cost estimates; labor and material requirements; net energy analysis; utility reactions to the concept; and energy production implications.

The requirements analysis in Section IV is based on estimates of what is required to achieve a rather ambitious goal of 0.1 quads per year of fuel savings by solar thermal central receiver technology by 1985.

An analysis of a scenario that includes the provisions in the National Energy Plan (a 20 percent investment tax credit and a demonstration program) is compared in Section VI to two other scenarios that include:

(1) A joint utility/government cost-sharing program (Federal share of $200 million) leading to the purchase of $3 billion of equipment, and

(2) A cost-sharing program with a 30 percent investment tax credit.

SECTION II

MARKET FACTORS

One of the key programmatic attributes of solar thermal repowering is that there is a substantial real market that is readily identifiable and could provide an early opportunity to develop commercial solar thermal central receiver systems. In the Southwest, in areas of high direct insolation, there is a capacity of over 76,000 MWe of oil- and gas-fired steam plants. About 65 percent of the fuel burned is natural gas and 35 percent is oil. This capacity exists at 197 sites where 624 boilers and turbogenerators are currently in place. The plants are owned by 65 utilities. A recent MITRE survey[7] indicates that sufficient land is available on or near these sites to repower approximately 18,000 MWe of capacity and displace 0.5 quads per year of fuels.[1] The estimated error for the survey sample is ±3,440 MWe at the 67 percent confidence level and ±6,900 MWe at the 95 percent confidence level. Thus, at least 11,000 MWe of capacity is a reasonably confident estimate of the solar repowering market potential. A more conservative estimate of about 5000 MWe market potential was made by Public Service of New Mexico,[12,15] based on more restrictive conditions for suitability: less than a 2500-foot pipe run from the tower to the existing plant; no allowance for reheat turbines; a maximum fossil plant size of 200 MW; and at least

[1]One quad=10^{15} Btus.

50 percent of the plant capacity to be repowered. By comparison, MITRE's criteria allow for a 15,000-foot pipe run (which only results in 3 percent losses), reheat turbines, a minimum fossil plant size of 25 MW, and no lower limit on the percentage of repowering when more than 150 acres (equivalent to about 25 MWe of repowering capacity) are available.

Another potential market, primarily concentrated in Texas, Louisiana and Oklahoma, is the petrochemical industry. MITRE is currently conducting a survey of potential users in this region to establish the market potential and feasibility for the repowering of existing large industrial process heat applications. Land restrictions, rate of return on investment, internally produced fuels, process compatibility and other factors will impact this sector. No firm figures are yet available for the size of this repowering market (using the solar thermal central receiver as a process steam source), but preliminary calculations indicate that this market could be as large as that for the utility sector--on the order of 0.3 quads per year repowerable.

GEOGRAPHIC FACTORS

In the Southwest, there are 10 contiguous states that might be considered for repowering:

- Texas
- Wyoming
- Oklahoma
- Arizona

- Kansas
- New Mexico
- Colorado
- Nevada
- Utah
- California

Direct insolation estimates made by Sandia(3) imply that the South and West can be divided basically into three regions. These are shown in Table I.

According to the MITRE survey, Texas has by far the greatest market potential (about 12 of 18 GWe) for repowering. California is second at 2 GWe, while the balance (4 GWe) is distributed among Oklahoma, Kansas, New Mexico, Arizona and Nevada. It was found that no site is suitable in Colorado, Utah or Wyoming. The Texas sites are generally larger than the others both in land area and capacity per site and in general have newer equipment. Furthermore, substantial new generating capacity has to be added to satisfy the growing use of electric energy in the future. According to a recent study by the National Energy Reliability Council(11), the generating capability of Southwest utilities will be increased by 62 percent in the near future (1978-1986). If planned expansion through 1985 for new combined-cycle, oil-burning facilities at new sites is included, California and Texas appear to be very large markets--1.1 GW in Texas and 4.1 GW in California. This market may expand the market potential of solar thermal repowering beyond the assumed level of 18 GW.

TABLE I

REGIONS FOR REPOWERING (BASED ON INSOLATION)

REGION I

(2400 - 3000 $kWh/m^2/yr$)

Eastern California
Arizona
New Mexico
Nevada
Western Texas (Panhandle)

REGION II

(2000 - 2400 $kWh/m^2/yr$)

Western California
Western Kansas
Colorado
Utah
Wyoming
Oklahoma

REGION III

(1600 - 2000 $kWh/m^2/yr$)

Nebraska
Montana
Oregon
Central Texas
North Dakota
South Dakota
Idaho
Central Kansas
Florida

FUEL REPLACEMENT STRATEGIES

If a utility is faced with a decision about repowering, several options can be considered:

- Retiring and replacing the plant
- Continuing to use the plant with oil and gas
- Retrofitting the plant with coal-burning equipment
- Continuing to use the plant with solar energy as a steam source with oil or gas as the backup.

The first option is not palatable simply because of the generating capacity problem that is perceived by the utilities. The trend of recent years in the region--a great influx of population and industrial activity--continually strains the available capacity. If the existing capacity were to be retired prematurely, it would have to be replaced with new capacity. The cost of replacement would have to be borne, but the new facilities would also require new permits, licenses and environmental approvals which are time consuming. It is not clear whether the cost of power to the utility would be reduced with new equipment. It is clear that if the existing plants were retired, new construction would be dramatically increased over that if the existing plants were not retired. Utilities are already strained in an attempt to meet the incremental increase in demands for electricity.

The second option is viable, but the availability and cost of oil and gas are the crucial issues. Currently, new oil contracts are signed at $11 to $16 per barrel for distillate and $8 to $12 per barrel for residual oils. Much of the oil is imported and is therefore subject to embargo. This threat is less serious in the West, however, where the Alaska pipeline has caused a temporary oil glut.[14]

Natural gas availability is a far more serious problem. Most utilities have been notified by gas suppliers that pipeline gas will either be discontinued or placed on a non-firm basis.(7) As a result, no new gas-fired capacity is planned in the region. Current new contracts for gas are signed at 16¢ to 18¢ per therm ($1.60 to $1.90 per MMBtu). However, provisions of the National Energy Act may make it illegal or more costly (up to $4 per MMBtu) to use natural gas or oil in either new or existing facilities after 1985. These additional uncertainties would make the second option a difficult choice.

The third option--conversion to coal--is an option with a proven technological basis but is a very costly and time consuming alternative. This option would require a new boiler for a facility, extensive pollution control equipment to meet current and pending EPA standards, perhaps a new turbogenerator to handle the flow conditions of the new boiler, a coal handling facility, a storage area for the coal pile, a railhead, and facilities for scrubber sludge, ash and coal waste disposal. Depending on the size of the plant to be repowered, the cost of the conversion could be relatively high. It may not be possible to build coal facilities for power plants under a 400 MW capacity because utility coal-fired boilers are no longer manufactured in this size range[13]. Capital cost estimates (adjusted to 1978 dollars) for coal plants[6] are $1000/kW at 400 MW, $910/kW at 600 MW, $850/kW at 800 MW and $800/kW at 1000 MW. Operations and maintenance costs are quite high because of the problems with the pollution control equipment. In addition, the availability of coal is uncertain because of strikes by mine workers, the poor condition of the nation's railroads, and environmental issues related to strip mining. Current costs of coal in the West range from 40¢ to 90¢ per MMBtu. Construction time is roughly four to six years, while permitting, licensing and environmental impact statement (EIS) approval could take an additional one to four years.[14] Conversion to coal is not currently considered by utilities to be a very attractive option.[7]

Option four--conversion to solar with oil and gas as backup--is one which is now considered to be technically feasible. Component tests have been successfully completed. A 1976 U.S. boiler test experiment using the central receiver solar boiler system at the solar furnace in Odeillo, France, successfully demonstrated that high pressure, superheated steam could be generated and controlled in a manner comparable to fossil boilers. Further, pilot tests of first generation heliostats at the Sandia Laboratories solar thermal test facility indicated their feasibility and structural integrity.

The engineering feasibility of a receiver of different design should be demonstrated at the proposed 10 MWe pilot plant scheduled for operation at Barstow, California in 1981. Remaining issues concern land availability, environmental impact, equipment availability, compatibility with the plant's operation, and cost.

There should be sufficient land available at roughly 100 sites to repower 24 percent of the existing capacity (about 18,000 MWe). Environmental impacts are inherently quite minor, with a reduction of plant emissions proportional to the percentage of capacity repowered (as high as 80 percent). Once heliostat manufacturing facilities are constructed, equipment should be available with a lead time of less than six months. Once control system designs are finalized for the Barstow 10 MWe plant and the first three repowering plants, virtually any petroleum-fired Rankine plant should be compatible with the central receiver system. Cost estimates for repowering are in the range of $900 to $1500 per kilowatt for capital and roughly $10 per kilowatt per year for operations and maintenance for a mature system acquisition.

Early development of an acceptable solar option could provide significant benefits to those utilities in dealing with the environmental and capacity problems associated with repowering. If sufficient land is available and the solar equipment is compatible with the plant operation at a reasonable cost, solar repowering may be a preferred option.

SECTION III

COST IMPLICATIONS

ENGINEERING COSTS

Engineering cost estimates for the central receiver have been made by JPL, MITRE, Sandia, Martin Marietta, McDonnell-Douglas, Honeywell, Boeing, and several supporting contractors including Bechtel, Black and Veatch, Sterns-Rogers, Rocketdyne, Sheldahl, and Westinghouse. Estimates made by MITRE in 1976 attempted to place all known previous estimates on a common basis for labor and materials costs, markups and fees. In addition, MITRE prepared estimates for the experience curve (cost reduction as a function of learning gained with system production) effects that can be expected for the system. These are based on a parametric study(5) that analyzed the experience curves for various materials (concrete, reinforcing bars, structural and stainless steel, float glass, insulation), components (pumps, generators, compressors), electrical and electronic equipment, and construction labor. These constitute the principal elements of solar thermal central receiver systems. The estimates of engineering costs are presented in Tables II and III in 1978 dollars, reflecting the inflation since 1976 (16.64 percent). Further adjustments were made to remove the cost of the turbogenerator and cooling system (already in place in the repowering concept) and to add the cost of plant modifications, which are expected to be

TABLE II

ENGINEERING COSTS VS. CAPACITY FOR CENTRAL RECEIVER REPOWERING PLANTS (1978 Dollars)

NUMBER OF PLANTS BUILT	ENGINEERING COST ($/kW)	CAPACITY (MWe)
1	2974	25
2	1602	75
3	1449	125
4	1312	175
5	1257	225
10	1100	475
20	1010	975
50	946	2,475
100	922	4,975
200	898	9,975
360	878	17,975

TABLE III

EXPERIENCE CURVE PARAMETERS FOR SOLAR THERMAL
CENTRAL RECEIVER (1978 DOLLARS)

MODULE	NO. REQ'D PER 50 MW PLANT	CUMULATIVE PRODUCTION (MODULES)	RATE (% SLOPE)	COST PER UNIT ($/MODULE)
HELIOSTAT	7,500	1,125 100,000 22,500,000	85 97 100	11,020 3,850 3,030
RECEIVER AND TOWER	1	1 45 10,000	85 97 100	23,650,000 9,690,000 7,640,000
CONTROLS	300	45 4,050 900,000	85 97 100	45,030 15,680 12,360
BALANCE OF PLANT	1	1	100	6,010,000

minor. Note that the ultimate engineering cost is about $900/kW at about 10 GWe of cumulative capacity. This figure is not the capital cost, but an "overnight construction cost," which does not include escalation, interest during construction, or special fees and contingencies over and above that normally considered appropriate (about 15 percent).

The operations and maintenance (O&M) costs have also been estimated at $9.33/kW/year for the operation of the solar unit alone. Maintenance and fuel costs for the existing facility are not treated, although these may be substantial if the plant is base loaded.

It has been further estimated that 25 percent of the engineering cost is expended in the first year and 75 percent in the second year of the generic development plan cycle. Extension of the cycle to three years results in an estimated distribution of 9 percent, 49 percent and 42 percent for the capital outlays in each year, respectively.

GENERIC DEVELOPMENT PLAN

Once solar thermal repowering is fully commercialized, the development cycle for plant construction should be extremely short because the system is highly modular and compatible with mass production techniques. Since the boiler, turbogenerator, electrical plant equipment and the site are already available, repowering with solar will not require the long lead times usually associated with steam plants. A generic environmental impact statement for repowering would be required to keep the development and construction cycle on schedule. There are roughly 15 activities, most of which can be conducted in parallel, that may take only two years from inception to completion.[4,5,9] In Table IV, these activities are listed along with the participants, time required for each activity, and number of months prior to plant start-up that the activity must be begun.

In Figure 1 these activities are shown on a timeline which outlines the parallel sequence of events. First generation facilities may take up to four years to complete the schedule due to delays in design, equipment availability, and financial negotiations. However, after about five years from the first plant's inception, the two-year plan may be in effect. Compared to conventional power plants, this estimated development cycle is very short. Construction periods for gas turbine systems are comparable, but new steam systems take up to 10 years for the entire development cycle.

MANUFACTURING AND SUPPORT FACILITIES

Equipment needed to complete a solar thermal central receiver includes heliostats, tracking motors, control systems, receivers, towers, piping, pumps, attemperators, feedwater heaters, valves, and special maintenance equipment. By far the most costly and most unique item is the heliostat. Before the central receiver can be commercial, the heliostat must be produced in a mass production facility. Currently, there are no mass production facilities anywhere in the world for any type of solar equipment. This issue should be

TABLE IV

GENERIC DEVELOPMENT PLAN ACTIVITY SCHEDULE

ACTIVITY	PARTICIPANTS	TIME REQUIRED TO COMPLETION (Months)	TIME REQUIRED PRIOR TO START-UP (Months)
Planning Studies	Utility	3	24-21
Preliminary Design	Utility/A/E Firm	4	21-17
Permits/Licenses	Utility/Federal, State, Local Governments	3-4	21-17
Environmental Statement	Utility/Federal, State, Local Governments	6	21-15
Site Development Plan	Utility/A/E Firm	2-3	20-18
Final Design	Utility/A/E Firm	5	17-12
Financial Negotiations	Utility/Banks/Stockholders	3	17-14
Long Lead Orders	Utility/A/E Firm/Manufacturers	3	14-11
Site Preparation	Utility/A/E Firm/General Contractors	3	13-10
Heliostat Installation	A/E Firm/General Contractors	7	11-4
Tower Installation	A/E Firm/General Contractors	4	9-5
Receiver Installation	A/E Firm/General Contractors	4	7-3
Controls Installation	A/E Firm/General Contractors	4	7-3
Shakedown Tests	A/E Firm/Engineering Firm	3	3-0
Operations	Utility	-	0

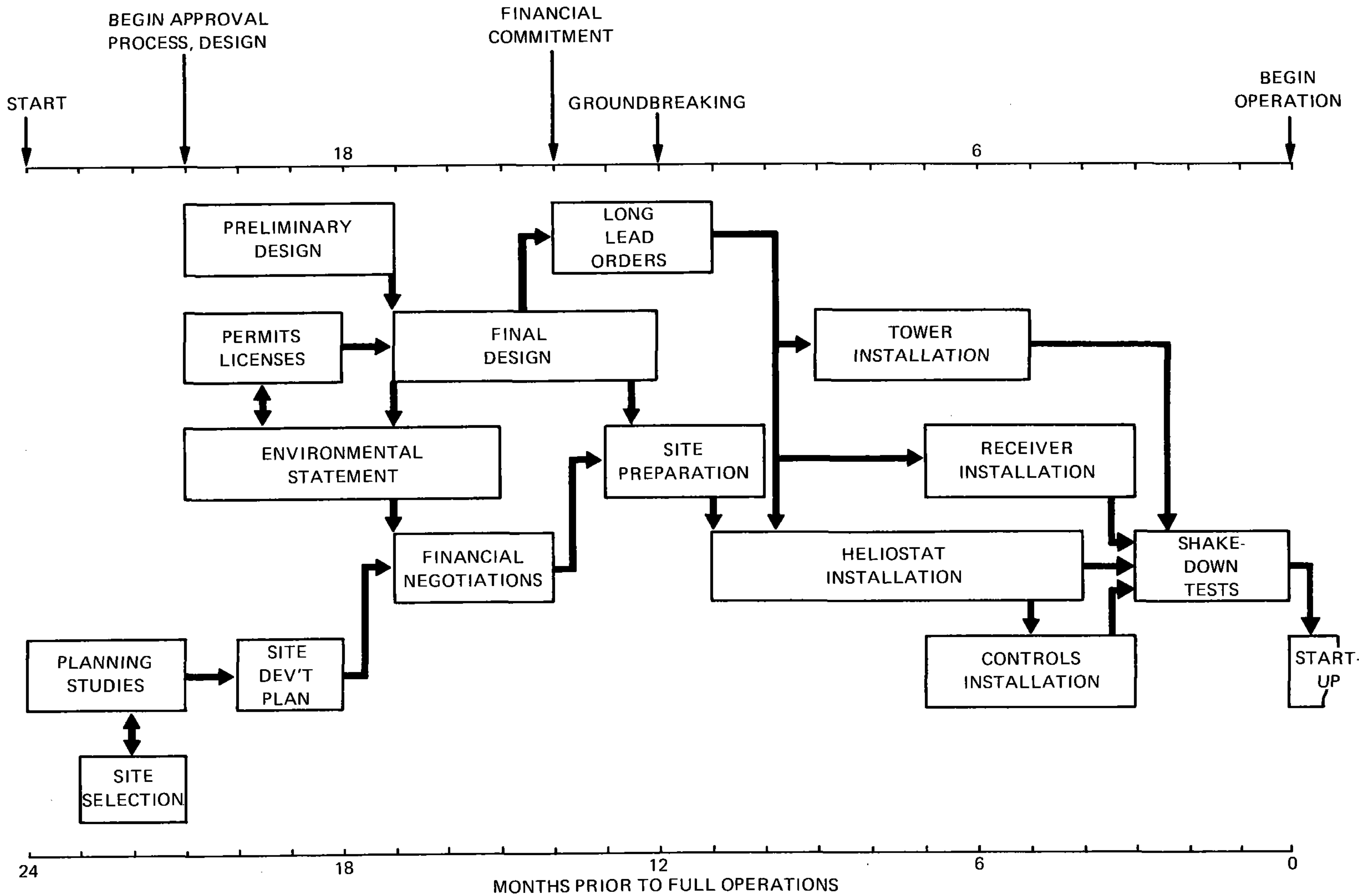

FIGURE 1
GENERIC DEVELOPMENT PLAN TIMELINE

resolved before the first generation repowering facilities are constructed if subsequent cost reductions are to be achieved. Existing boiler manufacturers could be used to provide the receivers, once a design has been finalized. General mechanical contractors or architectural/engineering (A/E) firms could handle the construction of the tower and site preparation. General utility equipment suppliers could be used for pumps, valves, piping, feedwater heaters, attemperators and fluid controls. Electronic systems can be purchased from many electronic firms and installed by electrical contractors. The heliostat and tracking motors remain as the only major new items to be manufactured.

HELIOSTAT MANUFACTURING FACILITY

Three preliminary estimates have been made for the cost of a heliostat manufacturing facility. Two estimates by Battelle are for a 50,000 unit per year capacity and 200,000 unit per year capacity facility.[1] MITRE has made an estimate for a 75,000 unit per year facility. Each unit is assumed to have roughly a 400 ft^2 area, two tracking motors, backsilvered glass, a steel frame, and a preformed concrete base. The Battelle estimates are $114 million and $230 million (1978 dollars) for each facility, respectively. MITRE's estimate is $155 million for the 75,000 unit facility.

Assuming that these estimates are reasonably correct, a cash flow analysis indicates that the heliostat individual/installed price, if mass-produced, should be very low ($8 to $12 per square foot) relative to today's cost (about $30 per square foot). Further, less than a three-year payback may be possible for the facility if full capacity could be reached in the first year.

In Table V, a cash flow analysis is presented for a 50,000 unit per year facility operating with production of 4,400 units the first year, 15,000 units for each of the second and third years, and 22,500 units in the fifth year, which would reflect demonstrations planned by the government. It is assumed that the installed heliostat price is that given in Table III, as a function of cumulative heliostat purchases. These data were derived from a previous Metrek study.(5) Further it is assumed that the $150 million (1982 dollars) facility is cost-shared, with a government share of two-thirds. Proceeds may be returned to the government as an option after 1985. It is further assumed that inflation in labor and material costs is 8 percent per year. From this analysis, one may conclude that:

- Heliostat production is labor and material rather than capital intensive
- Heliostat prices should decline sharply in mass production
- Full production capacity is not necessary to make substantial profits
- Government subsidies may not be required for further facilities.

In Table VI, a second analysis is performed for the same facility without a Federal cost share. The analysis indicates that a firm order for about 25,000 heliostats is all that is required to cover

TABLE V

HELIOSTAT PRODUCTION FACILITY CASH FLOW ANALYSIS
WITH 2/3 FEDERAL COST SHARING[1]
(Current Dollars, Millions)

	YEAR			
	1982	1982	1984	1985
GROSS RECEIPTS:	46.27	134.91	125.92	182.82
RECEIPTS FROM SALES	46.27	134.12	121.87	176.11
INTEREST INCOME		0.79	4.05	6.71
OPERATING EXPENSES:	(33.06)	(74.01)	(78.21)	(99.16)
(MATERIAL/LOGISTICS)	(11.17)	(41.14)	(44.43)	(71.98)
(LABOR)	(4.22)	(15.54)	(15.78)	(27.18)
(INTEREST)	(1.00)	(0.66)	(0.34)	-
(DEPRECIATION)	(16.67)	(16.67)	(16.66)	-
GROSS INCOME:	13.21	60.90	47.71	83.66
(TAXES)	(6.61)	(30.45)	(23.85)	(41.83)
(CREDITS)	5.00	-	-	-
NET INCOME (LOSS)	11.60	30.45	23.86	41.83
DIVIDENDS	(5.00)	(3.33)	(1.67)	-
LOAN-RETURNED TO GOV'T:	6.60	33.72	55.91	97.74
TOTAL GOV'T REVENUE (CUMULATIVE)	13.21	70.78	116.82	200.48
HELIOSTAT PRICE ($/FT^2)				
CURRENT	26.30	22.49	20.99	20.31
CONSTANT 1978	19.33	15.22	12.80	11.85
TOTAL NUMBER PRODUCED (CUMULATIVE)	7,500	22,500	37,500	60,000

[1] $150M Initial Capital ($50M Industrial/$100M Federal)
80% Equity @ 12.5% Interest (Dividend)
20% Debt @ 10% Interest
4399 Heliostats Produced in 1982

TABLE VI

HELIOSTAT PRODUCTION FACILITY CASH FLOW ANALYSIS WITH NO GOVERNMENT COST SHARING[1]
(Current Dollars, Millions)

	YEAR				
COST CENTER	1982	1983	1984	1985	1986
Receipts	46.27	134.12	121.87	176.11	365.17
Operations	(15.39)	(56.68)	(60.21)	(99.16)	(190.39)
Interest	(6.00)	(5.51)	(3.40)	(2.08)	(0.38)
Tax Depreciation	(27.27)	(24.54)	(21.82)	(19.09)	(16.36)
Taxable Income	(2.39)	45.00	36.44	55.78	158.04
Income Tax	---	(22.50)	(18.22)	(27.89)	(79.02)
Credit	---	15.00	---	---	---
Cash Flow	24.88	64.43	40.04	46.98	95.38
Dividends	(12.60)	(11.57)	(7.13)	(4.36)	(0.78)
Depreciation	(12.28)	(52.86)	(32.91)	(42.61)	(9.34)
Remaining Principal	137.72	84.86	51.95	9.34	0
Retained Earnings	0	0	0	0	85.26
Salvage Value	100.	90.	80.	70.	60.
Cumulative Heliostats Sold	4399	19,399	34,399	56,899	96,899

[1] 10 Year Sum-of-Year's-Digits Tax Depreciation
$150M Initial Capitalization; 40% Debt @ 10% Interest; 60% Equity @ 14% Interest
80% Plant Capacity Achieved for 1986 (40,000 units)

the risk for the manufacturer (i.e., the retained earnings plus salvage value equal financial exposure for the manufacturer), and the facility would be paid off in the fifth year. From another viewpoint, this is the maximum governmental risk (the cost of 25,000 heliostats, roughly $200 million) if there were to be a failure of the program at this point.

In Table VII, a third analysis performed for the same facility indicates that a three-year payback (on a net cash flow basis) is possible, even at the ultimate 1978 dollar cost of $9.16/ft^2$ for heliostats, if the facility begins operation at full capacity. This would indicate that once utility orders for new equipment come in at a rate that existing facilities cannot handle, the new facilities would be financed and paid off very rapidly. This is a key feature which projects self-sufficiency for the heliostat industry and the capability to support rapid growth. Once the industry begins to mature, the production facilities will saturate capacity very rapidly. Up to 3000 MW per year growth is likely, resulting in demand for between 600,000 and 800,000 heliostats per year. With a typical production facility size of 50,000 per year, as many as a dozen different manufacturers could join to produce the competition that would hold down prices and encourage high levels of production efficiency. In addition, general contractors would likely be used for installation and operations and maintenance activities as subcontractors to the likely larger manufacturers. The new industry

TABLE VII

ZERO INFLATION CASH FLOW ANALYSIS

FOR HELIOSTAT PRODUCTION FACILITY ASSUMED AT FULL CAPACITY[1]
(1978 Constant Dollars, Millions)

	YEAR		
	1	2	3
Revenue	183.26	183.26	183.26
Operating Expenses	128.50	128.50	128.50
Tax Depreciation	20.72	18.66	16.58
Gross Taxable Income	34.04	36.10	38.18
Income Tax	(17.02)	(18.05)	(19.09)
Tax Credit (10%)	11.40	-----	-----
Cash Flow	49.14	36.71	35.67
Cumulative Return on Investment	49.14	85.85	121.52

[1] Capital Cost: $114M
10 Year Sum-of-Year's Digits Depreciation for Taxes
Ultimate Heliostat Price: $3665/Unit ($9.16/ft^2)
Plant Capacity: 50,000 Units/Year

would not be a monopoly, but a true free enterprise complex providing thousands of domestic jobs.

In Appendix B, break-even costs are shown for heliostats used in repowered facilities and stand-alone, storage-coupled central receiver plants. It was found that the acceptable price for heliostats is $12 to 20 per square foot with repowering, but $8 to 14 per square foot with all other central receiver systems.

SECTION IV

REQUIREMENTS ANALYSIS

This section describes what must be done to achieve the rather ambitious goal of sixty-seven 50 MWe power plants (or the equivalent) on line by 1985, using 50,000 unit per year capacity heliostat manufacturing facilities, and updated insolation and market data. Costs are expressed in constant 1978 dollars.

THE GOAL

The goal of about 0.1 quad of fuel savings per year by 1985 requires that about 3350 MWe of solar thermal repowering capacity be constructed--or sixty-seven 50 MWe power plants. The aggressive schedule described later in this section could bring the first plant on line by 1982. If four additional plants could be constructed with government cost sharing during the following 18 months (by the end of 1983), the heliostat manufacturing cost may be down to a point where 13 plants (650 MW) may be added in 1984 and 50 more in 1985 without government assistance.

HELIOSTAT PRODUCTION REQUIREMENTS

The heliostat production rate required to meet this goal is 4399 units in 1982; 30,000 units in 1983; 97,500 units in 1984 and 375,000 units in 1985. This will require one production facility at 8.8 percent capacity the first year, 60 percent capacity the second year, and 100 percent thereafter. The second facility would run at 95 percent capacity in 1984 and 100 percent in 1985. Six new facilities would be required in 1985 and would operate at an average of 92 percent of capacity in that year. Each production facility would support about 300 to 350 MW per year of new repowering capacity, or 200 to 250 MW per year of storage-coupled system capacity.

ANNUAL AND CUMULATIVE CAPITAL REQUIREMENTS

The capital requirements for utilities and manufacturers would be very large to support the goal of 0.1 quads per year by 1985. In Table VIII, the requirements are estimated for both annual and cumulative expenditures by government, industry and utilities. These figures include a 45 percent contingency for the first plant, 40 percent for the second two plants, 30 percent for the next two plants, and 15 percent for all subsequent plants. Annual capital requirements in 1985 reach nearly $3 billion with a cumulative level of just over $5 billion. The distribution in 1985 of cumulative expenditures is 79 percent utility, 17 percent industry and 4 percent Federal.

It should also be noted that no additional capital spending was assumed for production facilities other than for heliostats.

BUSBAR COSTS

Busbar costs are estimated for plants built in each year in Figure 2. Busbar costs are calculated using an annualized cost procedure and the assumed capital finance structure shown in Table IX. The annualized cost is calculated in such a way as to remain constant

TABLE VIII

ANNUAL AND CUMULATIVE CAPITAL REQUIREMENTS FOR
0.1 QUAD/YEAR GOAL BY 1985
(1978 Constant Dollars, Billions)

	1981	1982	1983	1984	1985
ANNUAL CAPITAL REQUIREMENTS (10^9 Dollars)	0.180	0.191	0.273	1.501	2.863
GOVERNMENT	0.122	0.055	0.023	0	0
INDUSTRY	0.038	0	0.114	0.684	0
UTILITIES	0.020	0.136	0.136	0.817	2.863
CUMULATIVE CAPITAL REQUIREMENTS (10^9 Dollars)	0.180	0.371	0.644	2.145	5.008
GOVERNMENT	0.122	0.177	0.200	0.200	0.200
INDUSTRY	0.038	0.038	0.152	0.836	0.836
UTILITIES	0.020	0.156	0.292	1.109	3.972

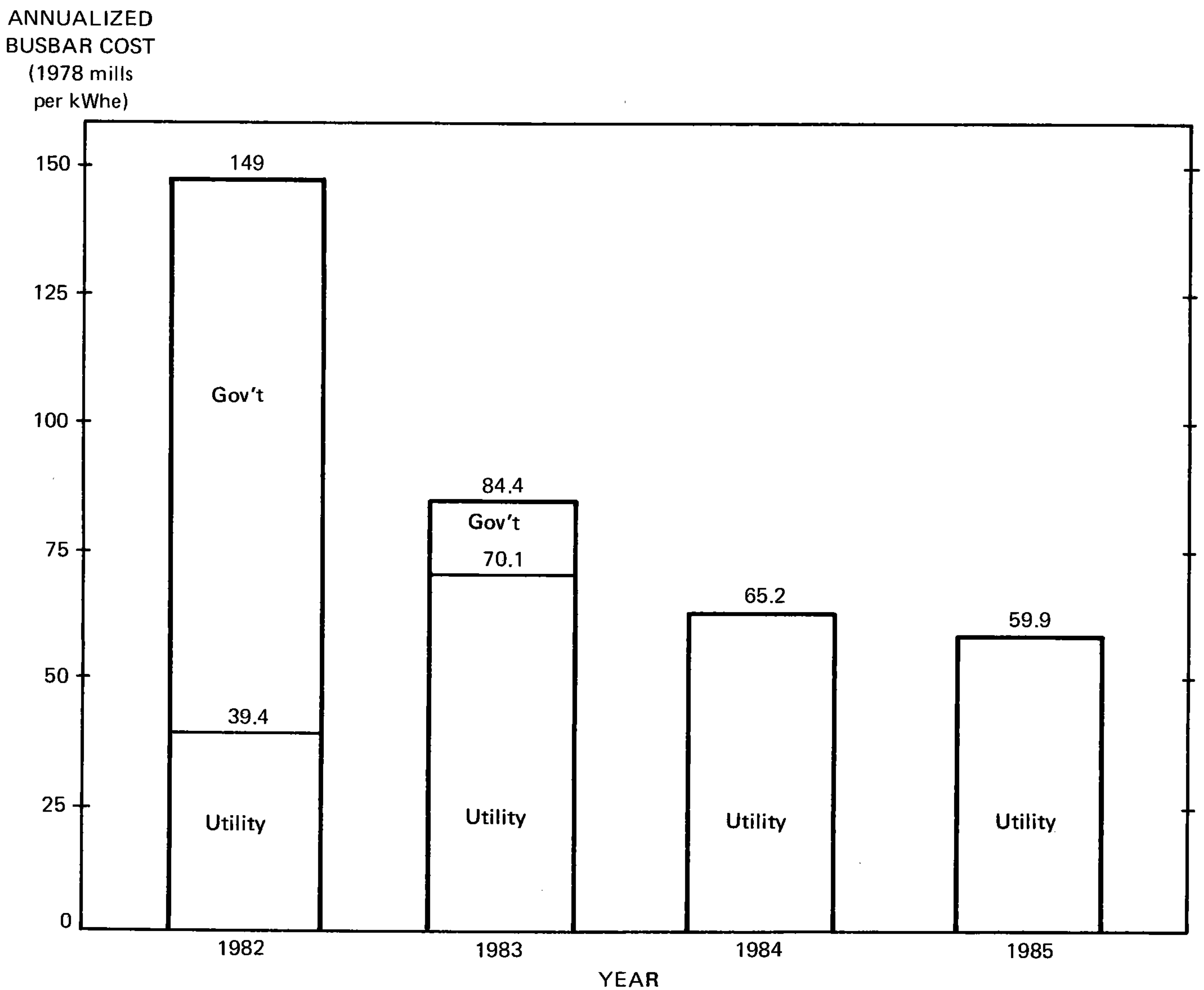

FIGURE 2
ANNUALIZED BUSBAR COST PROJECTION FOR GOAL OF 0.1 QUAD/YEAR

TABLE IX

FINANCING ASSUMPTIONS FOR BUSBAR COSTS

50% TAX RATE
7% INVESTMENT TAX CREDIT
30 YEAR FINANCIAL LIFE
22 YEAR TAX LIFE
SUM-OF-YEARS-DIGITS TAX DEPRECIATION
STRAIGHT LINE FINANCIAL DEPRECIATION
10.16% DISCOUNT RATE
35% COMMON EQUITY AT 14% INTEREST
12% PREFERRED EQUITY AT 8.5% INTEREST
53% DEBT AT 8.0% INTEREST
1.4% PROPERTY TAX RATE ON BOOK VALUE
2 YEAR CONSTRUCTION PERIOD
25%/75% SPLIT FOR CONSTRUCTION FUNDS
5.0% PER YEAR INCREASE IN O&M
9.33 $/kW/YR O&M COSTS (1978)
PLANT RATING: 50 MWe
NET YEARLY OUTPUT: 153.3 GWhe
CAPACITY FACTOR: 35%
CAPITAL COSTS AS SHOWN IN TABLE III

in time after plant start-up in terms of current dollars (similar to a simple mortgage cash flow). It should be noted, however, that the actual cash flows are quite different. It is further assumed that the average plant output is assumed to be 550 kWhe/m^2/year (153.3 GWhe/plant/yr) [see Appendix A]. The two numbers on each bar for the years 1982 and 1983 reflect the total busbar cost and apparent utility busbar cost after the government cost share.

LABOR AND MATERIALS REQUIREMENTS

The materials used to construct a generic solar thermal repowered plant are steel, concrete, aluminum, glass, insulation, chrome, molybdenum, silver and miscellaneous plastics, wood, block, etc.(10) In Table X, these requirements are estimated and put in the context of U.S. production levels in 1974. The right-hand column indicates the added capacity at which one percent of U.S. production in 1974 would be used to support such a growth rate. The 1985 growth rate of 2500 MW (50 plants) would consume 0.25 percent of the steel, 1.0 percent of the concrete, 0.5 percent of the aluminum, 5.0 percent of the glass, 2.5 percent of the insulation, 0.30 percent of the chrome/molybdenum, 2.5 percent of the silver, and a negligible percentage of other materials used in 1974. Therefore, glass, insulation and silver are the critical limiting material factors that may pose a problem after commercialization.

In Table XI, direct labor requirements are presented in terms of a normalized requirement in man-years per megawatt and in terms of

TABLE X

MATERIAL REQUIREMENTS FOR SOLAR THERMAL REPOWERING

MATERIAL	REQUIREMENT (Short Tons/Megawatt)	U.S. PRODUCTION (10^6 Tons/Yr)	MEGAWATTS/YR GROWTH AT 1% OF U.S. PRODUCTION
STEEL	150	150	10,000
CONCRETE	1000	250	2,500
ALUMINUM	10	5	5,000
GLASS	80	4	500
INSULATION	5	0.5	1,000
CHROME/MOLY	0.6	0.5	8,300
SILVER	0.014	0.0014	1,000
MISCELLANEOUS	10	LARGE	N/A

TABLE XI

DIRECT LABOR REQUIREMENTS FOR 0.1 QUAD/YEAR REPOWERING BY 1985

REQUIREMENT	1981	1982	1983	1984	1985
NORMALIZED LABOR (Man-Years/MW)	76	49	38	29	24
TOTAL LABOR WORK FORCE (Thousands of Jobs)	0.5	3.4	12	32	45

the projected annual labor force. Since the experience curves reflect a reduction in the normalized labor requirement, this reduces significantly during the 1981 to 1985 timeframe. Note that this requirement is only one-third to one-fourth the total impact since it reflects only direct labor. A multiplier effect for indirect support labor can increase the impact dramatically. This impact can be interpreted as a benefit rather than a cost for the program, since these are domestic jobs.

NET ENERGY ANALYSIS

The net energy production rate for solar thermal repowering is estimated from the expected energy production rate, the energy required to mine, mill, fabricate, assemble, ship and construct all the materials and equipment for the plant and the energy consumed by the labor force during these activities. The expected energy payback period is about 1.3 years according to the calculation shown in Table XII. As a result, the net energy production rate between 1981 and 1985 is always negative--in fact, in 1985 the net output is negative 0.1 quad/year while the gross output is a positive 0.1 quad/year. This analysis points out one of the serious problems the nation faces during the transition to renewable resources--we must make an investment of fossil fuels in order to construct the new facilities. The longer we wait, the more difficult such a transition becomes.

TABLE XII

NET ENERGY ANALYSIS FOR SOLAR THERMAL REPOWERING

MATERIAL	MMBtu/SHORT TON		MMBtu/MW
STEEL	42		6,300
CONCRETE	13		13,000
ALUMINUM	200		2,000
GLASS	39		3,100
INSULATION	40		200
CHROME/MOLY	160		100
SILVER	100		--
MISCELLANEOUS	20		200
		Total Material	25,000
LABOR	**MMBtu/MAN-YEAR**		**MMBtu/MW[1]**
DIRECT ONLY	500	Total Labor	15,000
TOTAL INPUT ENERGY			~40,000

[1]At 30 MY/MW

ENERGY OUTPUT: $0.35 \times 8760 \times 10^3 \times 10^4 \times 10^{-6} = 30{,}600 \frac{\text{MMBtu}}{\text{MW-YR}}$

Energy Output =

$$\text{Capacity Factor} \times \text{Hours per year} \times \frac{\text{kW}}{\text{MW}} \times \frac{\text{Btu}}{\text{kWh}} \text{(Heat Rate)} \times \frac{\text{MMBtu}}{\text{Btu}}$$

ENERGY PAYBACK RATE: $\frac{40{,}000}{30{,}600} = 1.3$ Years

DELAYED GOALS

A requirements scenario could also be postulated to achieve a goal of 0.1 quads per year of central receiver capacity by 1990. While this scenario goal is more plausible and more easily achieved, special government incentives would still more than likely be required. In Section VI, market simulations indicate that without these special incentives, the central receiver would not make a market entry until after 1985, leading to 0.03 quads per year of capacity by 1990. Starting by 1983 with a 25 MW repowering plant and doubling the capacity on line each year would reach 3200 MW by 1990, or about 0.1 quads per year. The growth rate in 1990 would be 1600 MW per year. The labor force would approach 30,000 direct jobs in that year. About five heliostat production facilities would be in operation at near full capacity. The same amount of capital would have been expended as in the earlier scenario, but spread out over an eight-year rather than a four-year period. Yearly material requirements would average about 40 percent less than the 1985 scenario. Net energy production would be roughly minus 30 percent of the installed capacity each year (-0.03 quads per year in 1990). This scenario goal is not only delayed in its capacity on line at a given date, but also in the rate of new additions.

Although of significantly higher risk, it would appear to be both technically and economically possible to achieve the goal of 0.1 quads of energy savings by 1985 if an aggressive Federal and utility/

industry program is initiated. The risks, however, are great to both government and industry. A major technical failure could result from lack of time to fully prove out each system concept. This could lead to a disenchantment with the concept and ultimately longer market acceptance time. The financial impacts of failure are estimated at roughly $200 million or greater.

SECTION V

IMPLEMENTATION PROGRAM

In order to get a plant on line by mid-1982, commitment to heliostat production facilities must begin by May of 1979. This implies that either:

a) The government (DOE) must reprogram FY79 funds to initiate the funding for the production facilities,

b) The design of the production heliostat must be frozen by May of 1979,

c) Approval must be obtained by FY79 for a revised solar thermal repowering plan to insure a long-term market for manufacturers and to spur serious utility involvement,

Or:

d) Large industrial entities must make the commitments of capital and resources to this option independent of government programs,

While:

e) DOE and southwestern utilities work in strong cooperation to develop a complete site bank, which requires that DOE initiate immediately acquisition of data to develop a repowering plan and the site bank, and

f) Commitments are made of FY79 through FY83 government funds to cost share the first plants until the heliostat and total plant costs are sufficiently low.

In order to achieve the utilization goal of 0.1 quad per year by 1985, the following actions must be executed in the near term:

(1) A generic environmental impact statement for solar thermal repowering must be prepared and filed. This should begin immediately and be completed within 15 months.

(2) Alternative heliostat designs must be built and thoroughly tested for performance, reliability, and expected life. They must be evaluated by production engineers for mass-reproducibility. A decision based on the above criteria must be made and the design frozen by May of 1979.

(3) A site bank of facilities in the Southwest U.S., rank-ordering the sites on the basis of available land area, system age and efficiency, insolation, terrain characteristics, and willingness of the involved utilities to repower with solar must be prepared. This should be completed by August 1978.

(4) Federal cost-sharing funds must be provided for preparation of preliminary repowering system designs for the first seven repowering sites, and advanced planning must be conducted with the utilities involved. This should begin by October, 1978.

(5) FY79 funds must be programmed to place large orders for heliostats (for the first three powerplants) by May of 1979, using the production design chosen in step (2); and a contractor must be selected from interested industrial entities.

(6) Additional funds to accomplish the above actions and to partially share the cost of construction of the first three repowering facilities must be requested within the timeframe desired.

A timeline for these activities is shown in Figure 3.

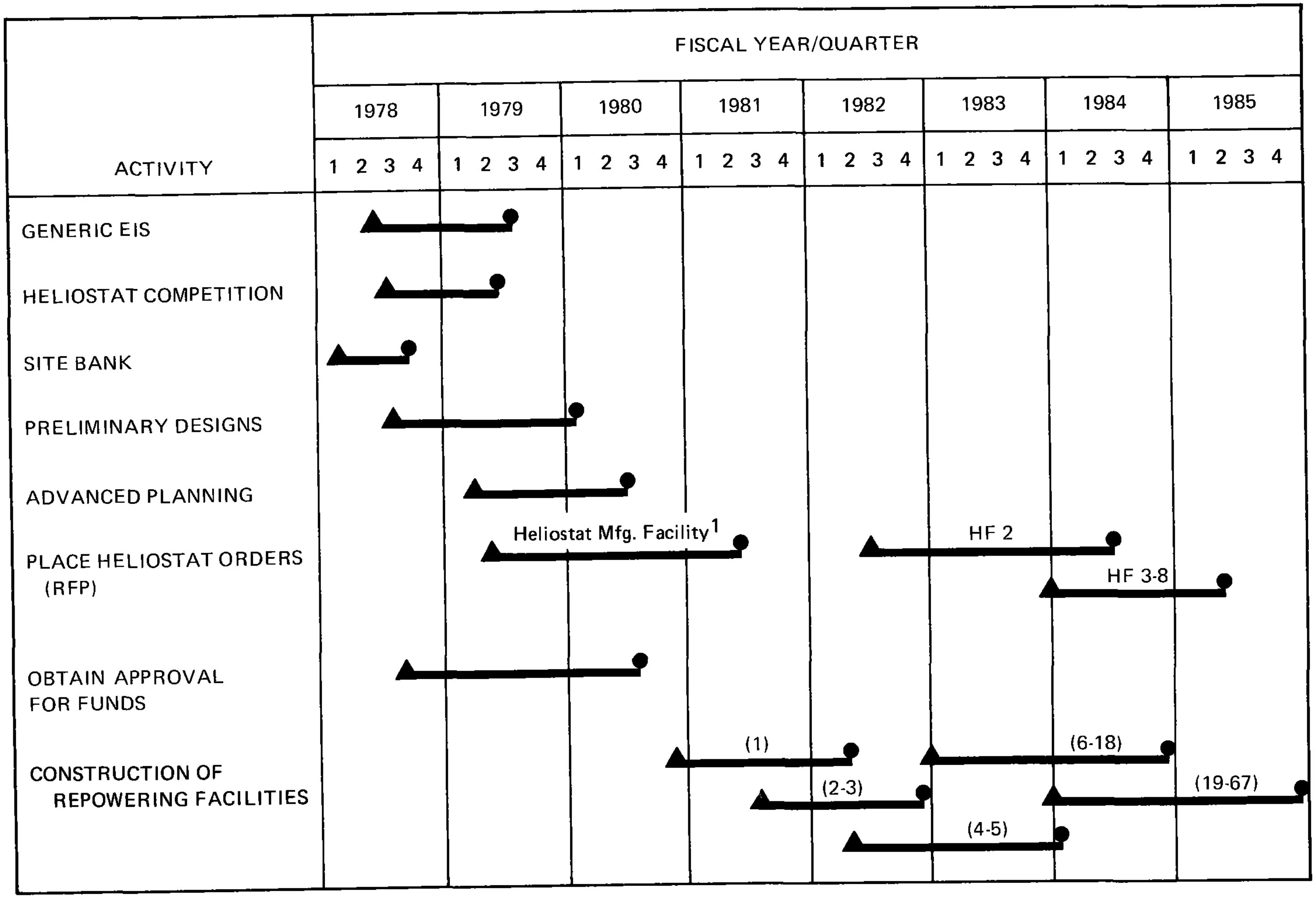

FIGURE 3
TIMELINE FOR IMPLEMENTATION OF 0.1 QUAD/YEAR SCENARIO

SECTION VI

MARKET SIMULATIONS

The MITRE/Metrek System for Projecting Utilization of Renewable Resources (SPURR) model[2,8,16] was used to simulate the market penetration for solar thermal repowering in the utility market for two sensitivity scenarios. These include all conventional technologies and applicable solar technologies to this market sector (intermediate electric utility). The conventional technologies include:

- Coal steam with flue-gas desulfurization plants
- Oil combined cycle plants.

The solar technologies are:

- Wood-burning steam plants
- Wind energy conversion system (WECS)
  - Combined with hydroelectric facilities
  - With gas turbine backup
- Photovoltaics
  - thin film flat panel
  - concentrator (gallium arsenide)
  - silicon flat panel
- Solar thermal central receiver
  - with oil combined cycle backup
  - fuel saver (no backup)
  - with three hour thermal storage
  - with six hour thermal storage
  - repowering.

The first sensitivity scenario included a 20 percent investment tax credit for all solar technologies, a $3 billion demonstration program by 1985 for first generation plants (for each generic solar technology), and the earliest possible introduction date for each technology into the commercial marketplace (1981 for repowering). The second sensitivity scenario included a 30 percent investment tax credit coupled with parallel demonstrations and streamlined permit/license/EIS approval procedures for all solar technologies. A market simulation of the NEP program with a 20 percent investment tax credit and the planned demonstration program was also performed and the results of the market penetration analysis for all three scenarios are presented in Table XIII.

Note that the market simulation for Scenario II projects the central receiver capacity at 3300 MW (0.1 quads/year of saved energy) by 1985. The energy savings (quads/year) for solar central receiver technologies are compared for Scenario I, Scenario II and the NEP with a 20 percent investment tax credit in Figure 4. The early introduction of the solar central receiver technology through repowering in Scenarios I and II results in a rapid market penetration by the year 2000. For example, the energy which is saved with the Scenario II program is more than three times that achieved under the NEP with a 20 percent investment tax credit program (1.4 quads/year vs. 0.4 quads/year).

The curve in Figure 4 indicates a "knee" about the year 2000 and a tapering-off by 2010. The spurt in 2000 is due to the introduction of cost-effective solar thermal systems as compared to the best

TABLE XIII

RESULTS OF MARKET SIMULATIONS

SCENARIO	YEAR	CUMULATIVE CAPACITY/SAVED ENERGY BY TECHNOLOGY MW/Quads per Year					TOTAL
		Repowering CF[1]=0.37	Combined Cycle CF[1]=0.37	Fuel Saver CF[1]=0.37	3 Hour Storage CF[1]=0.35	6 Hour Storage CF[1]=0.50	
NEP	1985	---	---	---	---	120/0.005	120/0.005
	1990	---	200/0.006	300/0.01	200/0.006	520/0.02	1220/0.04
	1995	---	1000/0.03	2500/0.08	1500/0.05	1720/0.07	6700/0.23
	2000	---	2000/0.06	5000/0.16	2600/0.08	3020/0.13	12600/0.43
	2005	---	4300/0.14	10300/0.33	5800/0.18	9820/0.43	30200/1.08
	2010	---	6800/0.22	19100/0.62	10600/0.32	21400/0.94	57900/2.10
	2015	---	7600/0.25	23400/0.76	16900/0.52	33500/1.47	89000/3.00
	2020	---	7900/0.26	31900/1.03	24100/0.74	49500/2.17	133000/4.20
Scenario I	1985	1850/0.06	300/0.01	---	---	600/0.03	2750/0.10
	1990	2900/0.10	1400/0.05	1800/0.06	1200/0.04	1500/0.06	8800/0.31
	1995	4400/0.14	2000/0.06	5400/0.17	2500/0.08	2700/0.12	17000/0.57
	2000	7250/0.23	2400/0.08	9400/0.30	3900/0.12	3900/0.17	26800/0.90
	2005	19250/0.62	2700/0.09	17700/0.57	10500/0.32	9800/0.43	59900/2.03
	2010	19250/0.62	3800/0.12	28700/0.93	21200/0.65	21000/0.92	93900/3.24
	2015	19250/0.62	4000/0.13	34200/1.11	30800/0.94	32000/1.40	120000/4.20
	2020	19250/0.62	4100/0.13	43200/1.40	42400/1.30	44800/1.96	153000/5.41
Scenario II	1985	2000/0.06	400/0.01	---	---	900/0.04	3300/0.11
	1990	4600/0.15	1400/0.04	2900/0.09	1500/0.05	2100/0.09	12500/0.42
	1995	9600/0.31	2100/0.07	6600/0.21	3600/0.11	3000/0.13	24900/0.83
	2000	16700/0.54	2400/0.08	10400/0.34	7400/0.23	3800/0.17	40700/1.36
	2005	19250/0.62	3300/0.11	24600/0.78	22900/0.70	18000/0.79	88000/3.00
	2010	19250/0.62	3400/0.11	40300/1.31	39600/1.21	34100/1.49	136000/4.74
	2015	19250/0.62	3600/0.12	47200/1.53	52000/1.59	47300/2.07	169000/5.93
	2020	19250/0.62	3800/0.12	61100/1.98	65600/2.01	59600/2.61	190000/7.34

[1]Capacity Factor.

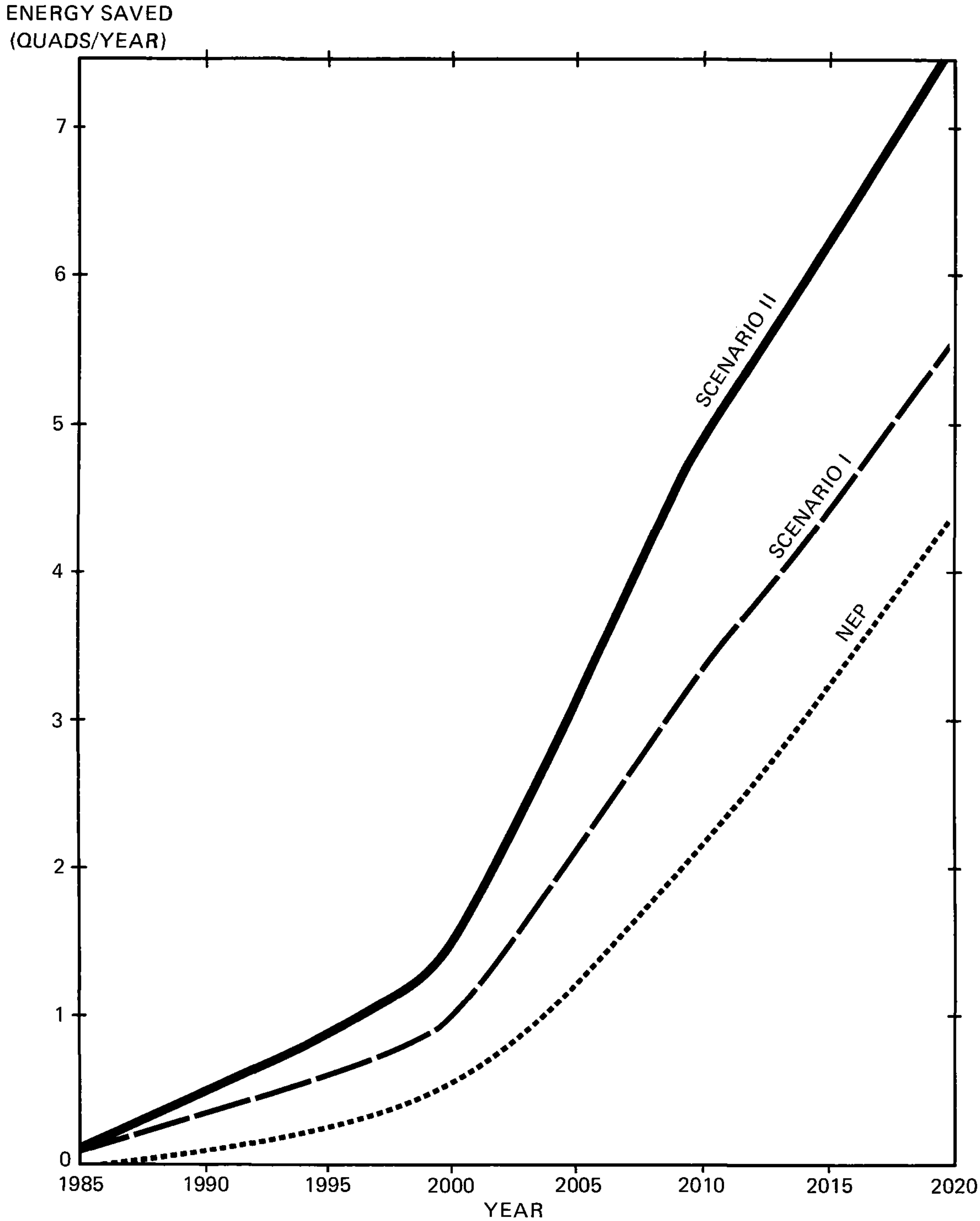

FIGURE 4
ENERGY SAVINGS FOR CENTRAL RECEIVER TECHNOLOGY

conventional alternative. The "S-curve" market penetration is characterized by a "bandwagon" effect roughly ten to twenty years after market entry. The curve ultimately saturates at some point, thus the tapering effect in 2010.

Furthermore, a significant amount of energy is saved before the turn of the century for Scenarios I and II. The same amount of energy (3 quads/ year) is saved in the year 2005 for Scenario II and in the year 2015 for the NEP. This 10 years of lead time could play a very important role during the transition towards utilization of renewable energy resources.

Energy savings due to various solar central receiver technologies are shown in Figure 5. It may be readily observed that the repowering of existing electric utilities power plants has a near-term impact and represents 40 percent (0.5 quads/year) of the total energy saved by the year 2000. After this year the market for repowering becomes saturated and other solar thermal technologies (fuel saver, three-hour and six-hour storage systems) will become more important.

Solar thermal was the most competitive of all solar technologies in the simulation in the Pacific, Mountain, and West South Central census regions, with estimated busbar costs of 30 to 50 mills per kWh versus 50 to 80 mills per kWh for all competitors.

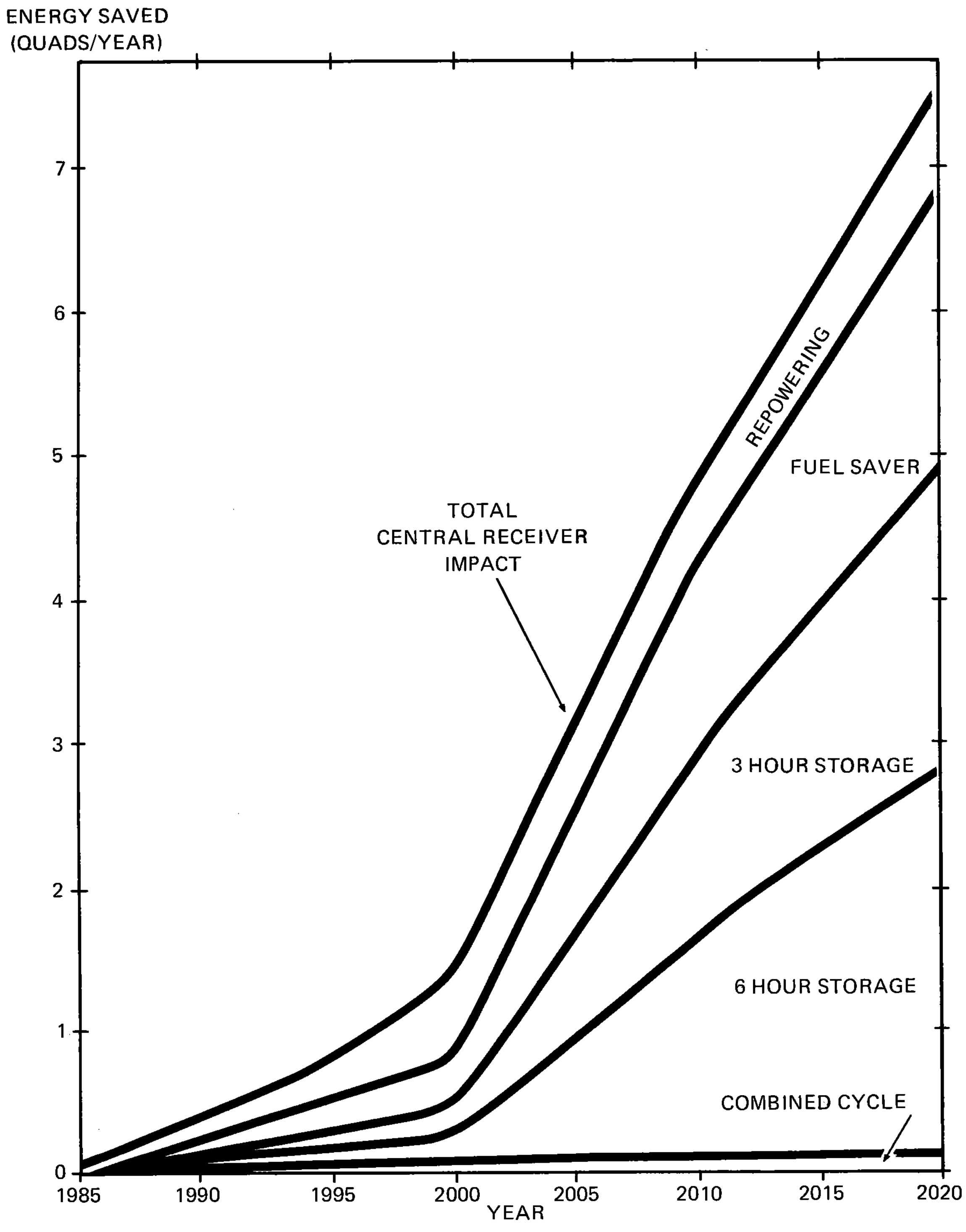

FIGURE 5
SCENARIO II: ENERGY SAVING DUE TO DIFFERENT TECHNOLOGIES

SECTION VII

CONCLUSIONS

Solar thermal repowering appears to be the solar thermal central receiver technology closest to commercialization. The repowering concept as well as the storage-coupled central receiver concept will be demonstrated with the 10 MW Barstow pilot plant which will serve as a vital source of technical information for all phases of the first repowering projects--design, construction and operations. If a solar thermal central receiver program with a major repowering element is successfully implemented during the next six years, a fast-growing and self-sustaining industry is likely to develop in support of this technology. From simulations of the future market based on a $200 million government program and a 30 percent investment tax credit for solar technologies, it also appears that it may be possible to displace up to 0.1 quads per year of fossil fuels by 1985, about 1 quad in 2000, and more than 7 quads in 2020 with the solar thermal central receiver systems. Under such a growth pattern it is expected that all potential repowering sites may be exhausted by 2005 and new solar thermal central receiver systems built after that point will be either stand-alone with storage, hybrids or fuel savers.

Government cost-shared repowering as described herein also provides a rapidly developed new market resulting in immediate cost reductions for solar thermal systems, enabling the construction of heliostat mass production facilities. As a result, the other central receiver concepts are more likely to become competitive earlier.

Material requirements may be a problem after 1990, when growth rates may exceed 3000 MW per year. The critical areas include glass, silver and insulation.

The labor force required in the new industry may reach nearly 50,000 direct labor jobs by 1985, and as many as 150,000 jobs in supporting commercial sectors. By 2000, the industry may be 10 times larger.

Capital requirements for the industry are substantial. It is not clear at this time what the total relative capital needs are going to be for all electric generation alternatives. It is likely, however, that capital availability may be a problem by the turn of the century independent of the mix of energy technologies chosen.

At least $200 million of Federal "seed" money may be required over the next five years (in addition to RD&D expenditures currently planned) to support the birth of the industry.

Certain Federal actions are needed in the near-term to begin the process of commercialization. These include:

- Reprogramming FY79 funds to initiate both heliostat production and repowering facilities
- Performing a heliostat design competition and making a production design choice by May of 1979
- Obtaining funding approval for a six-year repowering program (on the order of $200 million)
- Completing a site bank for all southwestern utilities

- Cost sharing the first three repowering plants between FY79 and FY83, with an option for an additional four plants
- Preparing and filing a generic environmental impact statement (EIS) within 15 months
- Cost sharing the first heliostat production facility or placing a guaranteed order for approximately 25,000 heliostats.

If the above actions are completed on schedule, if all of the technical systems perform as planned, and if the costs are near to that projected, then the commercialization activities may proceed as projected.

APPENDIX A

CENTRAL RECEIVER SYSTEM DESCRIPTION

APPENDIX A

CENTRAL RECEIVER SYSTEM DESCRIPTION

A solar thermal central receiver repowering system consists of a field of heliostats or mirrors that are controlled to aim direct sunlight to a common receiver mounted atop a tower. In the receiver, water is evaporated to steam and then superheated. The water is fed by a riser to the receiver and exits via a downcomer as superheated steam. The steam is then attemperated, i.e., buffered, using water injection to the required temperature and pressure conditions at the turbogenerator inlet. The turbine exhaust steam is condensed in a cooling system. The condensate is then deaerated and preheated by turbine exhaust feedwater heaters before being pumped back to the riser. When the sun is shining, the system operates on the solar loop; when it does not, the conventional plant operation is followed. The schematic shown in Figure A-1 displays the plant layout for a repowering system.

There are several potential complications for repowering regarding system design. For example, if the maximum output from the solar portion is nearly equal to the plant rating, a highly variable output could be expected during periods of intermittent cloud cover, which may require a thermal storage buffer to increase the thermal inertia of the steam supply system. The storage may be inserted directly in-line with the primary steam line. Also, many conventional steam plants employ reheat which would require intermediary heat exchangers.

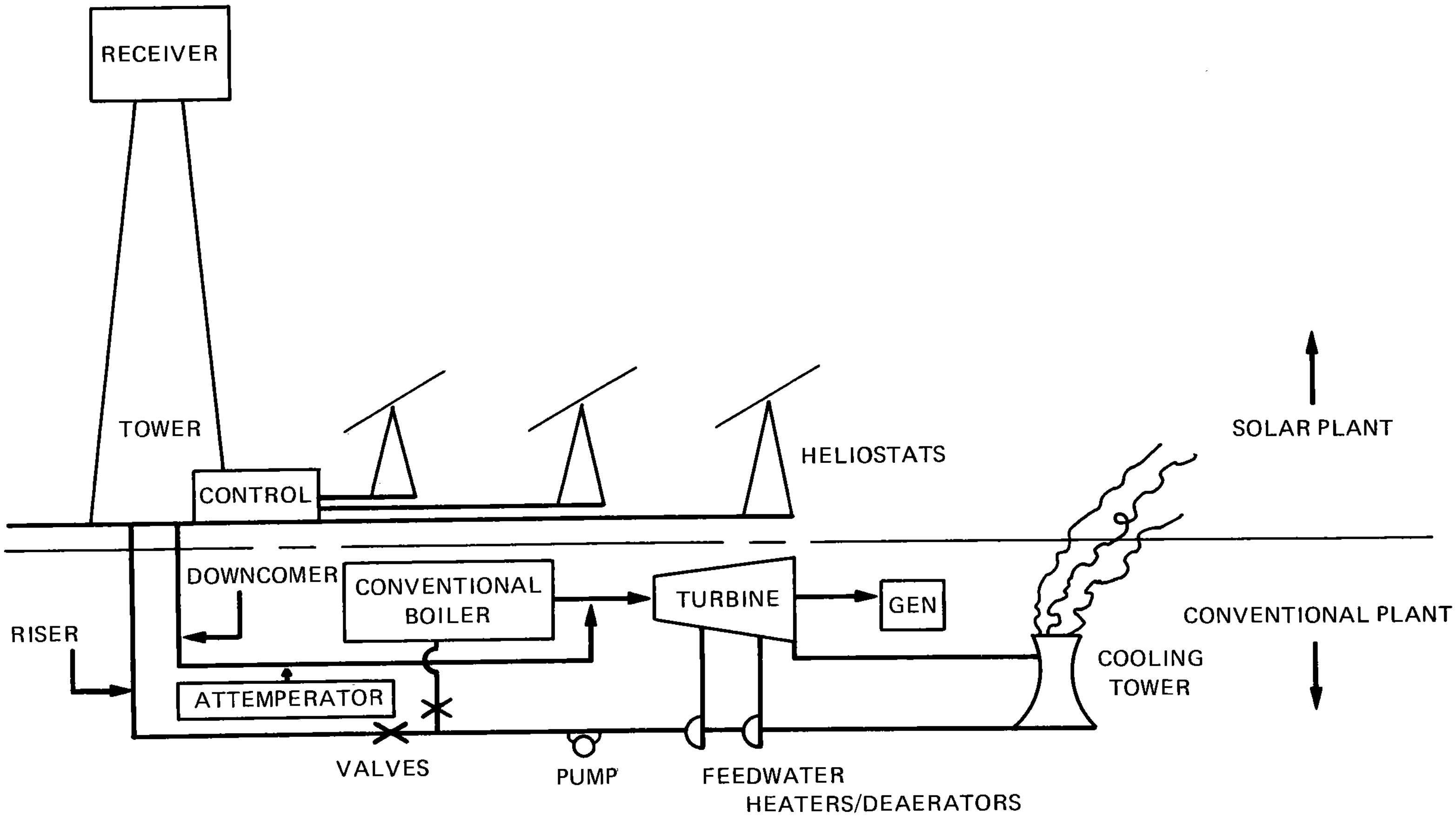

FIGURE A-1
SOLAR THERMAL REPOWERING PLANT CONFIGURATION

In about 90 percent of the sites that have been identified, the solar contribution may be less than 30 percent of the rated plant capacity, in which case the solar unit may be a primary steam source only that requires little boiler adjustment for the conventional unit. The problem of matching the two sources of steam to the turbogenerator will require a unique set of control criteria in order to assure a reliable plant operation.

The solar repowering system works on the direct component of sunlight only. Beam radiation varies from zero to 90 percent of the total insolation available, depending on cloud cover, haze, pollution and particulates suspended in the atmosphere. The beam is reflected by the heliostat to the receiver. En route, the beam is refracted, partially absorbed and scattered by the atmosphere. Also, some of the radiation is absorbed in the reflective coating on the heliostat and the glass protective layer for the coating. At the receiver, the beam is absorbed in the working fluid, some is reflected, a portion is re-radiated, some of the absorbed heat is conducted away through the walls of the receiver and the remainder is convected by the air flows from the receiver tube surfaces. Some of the heat in the working fluid is lost during the piping to the power plant. The steam produced is then expanded in the turbine and produces shaft work which drives the generator. The steam is only partially condensed in the turbine. The bulk of the heat of vaporization in the steam is removed in the condenser. A pump increases the pressure of the condensate and drives the working fluid back to the receiver whereupon the cycle continues. There are other losses in the system and requirements for auxiliary power. These include: piping losses, valve losses, losses in the attemperator and deaerator, pump and fan requirements for the condenser, power to drive the heliostat tracking motors (about 5 watts per square meter) and general power requirements for the maintenance of the power plant. In Table A-I, an estimate is made for the plant requirements and losses for a 50 MWe (200 MWth) solar repowering facility. For this system, the overall efficiency is 25 percent from sunlight to electricity at the busbar.

The yearly energy output depends strongly on the availability of sunlight and the plant operation schedule. For five different sites in the Southwest, an estimate is made of the insolation and net plant output assuming 10 percent downtime for forced and maintenance outages coupled with periods when the plant is not dispatched. These are shown below:

Location	Insolation ($kWh_{th}/m^2/yr$)	Net Plant Output ($kWh_e/m^2/yr$)	Rated Power[1] (kWe/m^2)	Potential Capacity Factor (%)
Albuquerque, NM	2600	585	0.175	38.2
Fort Worth, TX	1700	383	0.175	25.0
El Paso, TX	2650	596	0.175	38.9
Ely, NV	2420	545	0.175	35.6
Inyokern, CA	3000	675	0.175	44.0

[1]Based on 0.7 kW/m^2 mean insolation.

TABLE A-I

PLANT AUXILIARY POWER REQUIREMENTS AND LOSS INVENTORY
(50 MWe SOLAR REPOWERING FACILITY)

MODE OF LOSS	INVENTORY (kW/METER^2)		
	Input	Loss	Output
Heliostat Reflection	1.000	0.079	0.921
Tower Shadow, Shading, Blocking	0.921	0.037	0.884
Atmosphere Transmission	0.884	0.053	0.831
Effective Field Cosine	0.831	0.047	0.784
Receiver Reradiation	0.784	0.011	0.773
Receiver Conduction	0.773	0.006	0.767
Receiver Convection	0.767	0.025	0.742
Piping Loss	0.742	0.019	0.723
Attemperator Loss	0.723	0.004	0.719
Turbine Inlet Loss	0.719	0.007	0.712
Heat Engine Efficiency	0.712	0.442	0.268
Cooling Fans	0.268	0.008	0.260
Pumps/Auxiliaries	0.260	0.005	0.255
Heliostat Motors	0.255	0.005	0.250

- Backsilvered Glass
- North Facing Field
- Cavity Receiver (196 m^2 aperture or 2110 ft^2)
- Mean Beam Transmission Distance: 620 meters
- Mean Atmospheric Loss Coefficient: 1.0×10^{-4} m^{-1}
- Wet Cooling Towers
- Steam Generated at 516°C and 101.9 kg/m^2 (960°F @ 1450 psia)
- Piping Distance: 1000 m (3281 ft.)
- Tower Height: 198 m (650 ft.)
- Height to Receiver Centerline: 213 m (700 ft.)

Insolation data, based on direct beam radiation only, have been estimated for 26 locations in Reference 3. Once adjusted for the fact that a central receiver only operates once the sun is above 10° over the horizon, these data correspond to that in the table above for these five locations. About half of the potential repowering sites are in central Texas (near Fort Worth) which means that plant energy costs may be up to 60 percent higher than for the clearer areas in the Mountain states.

If storage is added to the system, the capacity factor may be increased substantially. However, the average plant efficiency also decreases while the plant rating reduces for the same array size. With three hours of storage at 70 percent of the nominal plant rating, the capacity factor may increase from 0.35 to 0.45. With six hours of storage, the capacity factor may increase to 0.52. However, the solar multiple (ratio of plant rating without storage to that with storage)[1] would increase from 1.0 to 1.4 with three hours and to 1.7 with six hours of storage.

After the construction is completed, there will be shakedown tests which may require the host power plant to be shutdown for a period of one to three months.

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[1]For example, a heliostat field and tower may be rated at 200 MWth of insolation, and produce 50 MWe without storage with direct coupling to the turbogenerator. If storage is introduced at a 1.7 solar multiple, then the turbogenerator is derated to about 30 MWe (using 120 MWth of the direct steam generated) while 80 MWth goes to charging the storage unit. Since storage input/output efficiency is roughly 70 percent, the turbogenerator may produce about 21 MWe from the stored energy. On average, 41 percent of the steam charges storage to produce 33 percent of the plant net output while 59 percent of the steam is directly used to produce 67 percent of the plant output.

APPENDIX B

BREAK-EVEN COSTS FOR HELIOSTATS

Assumptions:

- Heliostat Cost is 60 percent of Plant Cost for Repowering; 50 percent of Plant Cost for Storage-Coupled System (Stand-Alone Plant)
- Competitive Busbar Fuel Cost is 65 (± 15) mills per kilowatt-hour
- Energy Delivered is 600 kWh/m^2/yr for Repowering; 540 kWh/m^2/yr for Stand-Alone
- Operations and Maintenance Cost is \$1.50/m^2/yr for Repowering; \$2.50/m^2/yr for Stand-Alone
- Amount of capacity credit is assumed to be identical for both solar facilities, and the dispatch criteria are also identical

Findings:

	A Plant Cost (\$/m^2):	With a Heliostat Cost of (\$/f^2):	Breaks Even With (in 1985[1]):
Repowering	209.08	11.65	\$2.22/MMBtu @1% esc
	277.64	15.48	\$2.39/MMBtu @2% esc
	346.20	19.30	\$2.43/MMBtu @3% esc
Stand-Alone	173.25	8.05	\$2.22/MMBtu @1% esc
	234.96	10.91	\$2.39/MMBtu @2% esc
	296.67	13.78	\$2.43/MMBtu @3% esc

Further, if utilities believe that \$14/f^2 for heliostats will compete in the market, the stand-alone plants should compete at \$9.81/f^2 for heliostats at the same equivalent energy cost:

	A Plant Cost (\$/m^2):	With a Heliostat Cost of (\$/f^2):	Breaks Even With (in 1985[1]):
Repowering	251.16	14.00	\$2.18/MMBtu @2% esc
Stand-Alone	211.10	9.81	\$2.18/MMBtu @2% esc

[1]A heat rate of 11,000 Btu/kWh is assumed and 30 year life, fuel costs given in mid-year 1978 dollars, escalation is incremental to 5 percent general inflation rate.

REFERENCES

1. Battelle Northwest Laboratories, "Preliminary Cost Estimates for Heliostat Production Facilities," March 1978 (unpublished).

2. G. Bennington and others, Solar Energy: A Comparative Analysis to the Year 2020, MTR-7579, The MITRE Corporation, Metrek Division, McLean, Virginia, March 1978.

3. E.C. Boes and others, Availability of Direct, Total, and Diffuse Solar Radiation to Fixed and Tracking Collectors in the USA, SAND 77-0885, Sandia Laboratories, Albuquerque, New Mexico, August 1977.

4. P. Curto and G. Bennington, "Solar Thermal Repowering." Briefing presented under DOE/DST contract ET-78-C-01-2854 at Solar Energy Research Institute, Golden, Colorado, February 13, 1978.

5. P. Curto, Systems Descriptions and Engineering Costs for Solar-Related Technologies, Volume V. Solar Thermal Electric, MTR-7485-V, The MITRE Corporation, Metrek Division, McLean, Virginia, June 1976.

6. C. Kamanoff, "Power Plant Performance, Nuclear and Coal Capacity Factors and Economics," Council on Economic Priorities, 1976.

7. N. Lord and others, "Feasibility of Solar Repowering Existing Electric Generating Stations in the Southwest," WP-12875, The MITRE Corporation, Metrek Division,McLean, Virginia, March 29, 1978.

8. G. Miller, "Projected Impact of Solar Central Technologies," The MITRE Corporation, Metrek Division, McLean, Virginia, April 18, 1978.

9. "A Review of MITRE Activities in Support of the DOE Solar Technology Program." Briefing to H. Marvin (DOE/DST), The MITRE Corporation, McLean, Virginia, February 28, 1978.

10. Solar Energy Goals: Scenarios and Implications, The MITRE Corporation, Metrek Division, MTR-7389, McLean, Virginia, November 1976.

11. National Electric Reliability Council (NERC) Fossil and Nuclear Fuel for Electric Utility Generation Requirements and Constraints, 1977-1986. Princeton, NJ, August 1977.

12. Private Communications: Jerry Geist and Jack Groves, Public Service of New Mexico.

13. Private Communications: David Cox, The MITRE Corporation, Metrek Division.

14. Private Communications: William Carson, DOE.

15. Public Service of New Mexico briefing documents (unpublished), delivered at DOE Program Review, February 1978.

16. K. Rebibo and others, A System for Projecting the Utilization of Renewable Resources: SPURR Methodology, MTR-7570, The MITRE Corporation, Metrek Division, McLean, Virginia, September 1977.