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VOLUME I — EXECUTIVE SUMMARY

SOLAR THERMAL ENHANCED OIL RECOVERY (STEOR)

Final Report for the period October 1, 1979 - June 30, 1980

by
Dr. Eugene Elzinga
Dr. Charles Arnold
Dr. David Allen
Robert Garman
Patrick Joy
Paul Mitchell
Dr. Henry Shaw

November 1980
Work Performed Under Contract No. DE-AC03-79CS30307

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1. EXECUTIVE SUMMARY

Thermal enhanced oil recovery is widely used in California to aid in the production of heavy oils. Steam injection either to stimulate individual wells or to drive oil to the producing wells, is by far the major thermal process today and has been in use for over 20 years (1-1). Since steam generation at the necessary pressures (generally below 4000 kPa (580 psia)) is within the capabilities of present day solar technology, it is logical to consider the possibilities of solar thermal enhanced oil recovery (STEOR). The general concept of STEOR and its feasibility have been described in a number of recent reports (1-2), (1-3) and will not be repeated here.

The present project consisted of an evaluation of STEOR by a team from various Exxon affiliates, Foster Wheeler Development Corp. and Honeywell Inc. The study was done for the Department of Energy (Contract number DE-AC03-79CS30307) during the period October 1, 1979 to June 30, 1980.

The results of the study are presented in three volumes. Volume I contains the executive summary. Volume II contains Sections 2 through 8 together with Appendices A through K and in essence is the response to the original contract statement of work. Volume III summarizes the additional work performed to evaluate STEOR as a privately financed commercial venture at Exxon's Edison Field near Bakersfield, California.

1.1 Program Objectives

The program objectives were to:

(1-1) Interstate Oil Compact Commission, Secondary and Tertiary Oil Recovery Processes, 1974, Oklahoma City.

(1-2) DeLeon, P., Brown, K.C., Margolis, J.W., Nasr, L.H., Solar Technology Application To Enhanced Oil Recovery, Dec. 1978, SERI/TR-352-392.

(1-3) Bergeron, K.D., Solar Enhanced Oil Recover: An Assessment Of Economic Feasibility, 1979, Sandia Laboratories, 79-0787.

1. Assess the technical, economic and environmental feasibility of using line focusing distributed solar collectors as a heat source for thermal enhanced oil recovery at Exxon's Edison Field.

2. Estimate the potential market for solar equipment which could result, if STEOR is used where possible in domestic heavy oil fields.

3. Determine the merits of a demonstration of STEOR technology at the Edison Field.

The DOE limited the evaluation to a single technology, line focusing distributed collectors, on the basis that this was the only high temperature solar technology which had been adequately demonstrated. A further DOE constraint was that the project should be capable of producing energy which was at least equivalent

VIEW TO SOUTHWEST FROM CENTRAL LOCATION IN EDISON FIELD
FIGURE 1.1

to one third of the annual average output of one 7.32 MW (25 x 10^6 BTU/hr) oil field boiler i.e. 2.44 MW (8 x 10^6 BTU/hr). However, when the project was considered in the context of the conditions existing at the Edison Field, the degree of technical risk and the probable return on investment to Exxon further constraints were necessary. These constraints will be discussed in this summary.

1.2 The Edison Field

Exxon's Edison Field is located at the southern end of California's San Joaquin Valley about 16 km (10 miles) southeast of Bakersfield. The Kern County area which surrounds Bakersfield contains much of the country's heavy oil reserves. Although the Edison Field is relatively small (180 producing wells on (4 x $10^6 m^2$) (1000 + acres), its producing operations are typical of those used throughout the area.

The surface of the Edison field is nearly level with a gentle slope to the southwest which provides adequate drainage (Figure 1-1). The field's surface land, like much of the San Joaquin Valley, is irrigated and is under intensive agricultural production. The cost of taking this land out of crop production and the effect of particulates generated by the intensive agricultural activity on the collection of solar energy were site specific parameters which had to be considered.

Further site considerations were the close proximity of an active geologic fault which bounds the northeast side of the field, the economic life of the oil reservoir (estimates range from 15 to 30 years) and the apparent relatively high pressure required for steam injection into the Edison wells. (Pressures at the well head in excess of 6300 kPa (915 psia) have been measured for some wells). The STEOR system, however, has been designed to produce 5960 kPa (865 psia) steam which should be delivered at pressures in excess of 5510 kPa (800 psia) at the well head. This is believed adequate for the majority of wells.

1.2.1. DEVELOPMENT PLANS FOR EDISON FIELD

Exxon has been the principal operator at the Edison Field (Main Area) since 1965 and controls more than 50% of the wells. Steam stimulation has been used since 1965 to maintain total production from the Exxon leases in the range of 191 to 238 m^3 (1200 to 1500 barrels) of oil per day. Steam is produced by two portable Struthers Wells boilers of 6.44 MW (22 x 10^6 BTU/hr) and 7.32 MW (25 x 10^6 BTU/hr) capacity. These units are moved from well to well so that all of the most active wells are steamed every 12 to 18 months. A typical steaming cycle consists of injecting 1590 m^3 (10,000 barrels) of water as 80% quality steam into a well during a seven day period. After a soaking period of four days, the well is then put back into productive service for 12 to 18 months. This cycle is repeated from five to seven times for each well, that is until the response no longer justifies continued steaming. At this point the well is left to produce oil at a low rate, is abandoned or is reworked.

The quantity of steam needed to produce a barrel of oil on a field wide basis is increasing with time. Currently one barrel of oil is burned as boiler fuel for every six barrels of oil produced. Over the next several years this ratio is expected to increase to one barrel burned for three barrels produced. Thus if the current production level is to be maintained additional steam capacity will be required.

The Edison Field is believed to be typical of other heavy oil fields in most respects. However, the indicated pressure requirements for Edison are higher than for most fields.

Reservoir analysis, performed in conjunction with the present STEOR evaluation, indicated the need for a steam drive test to determine the production rates and recovery under this mode of operation. The analysis also indicated that the life of the Edison Field should be greater than 15 years with continued steaming. Based on this, project economics have been calculated for both 15 and 20 year periods.

1.2.2. SITE SOLAR DATA

The solar equipment proposed for this project uses only the direct component of solar radiation (that fraction of the solar flux which arrives at the earth's surface from the direction of the sun). Long term systematic measurements of either total horizontal or direct normal solar radiation are not available for Bakersfield.

The closest weather station where continuous radiation data has been taken for a long period of time is at Fresno. Fresno is located 161 km (100 miles) to the north of Bakersfield and is also in the San Joaquin Valley. Total radiation measurements have been taken since 1929 and from these the direct component has been computed. The radiation and other meteorological data are available on magnetic tape for a so-called typical meteorological year (TMY). This tape was used in the performance estimates for this study.

A weather station measuring total horizontal and direct normal radiation has been in operation at Edison since January 1980. The measured direct and total components were in good agreement with values from the Fresno TMY tape for the winter months, but a significant deviation has become apparent as the year progressed (Table 1.1). At present the reason for this anomaly is unknown. The apparent 10% average lower direct normal radiation for Edison compared to the TMY tape has been included in system performance and cost sensitivities.

TABLE 1.1

INSOLATION DATA FROM EDISON COMPARED TO TMY TAPE

Mean Daily Insolation, Kwh/m^2-Day (BTU/ft^2-Day)

Month	Measured At Edison Total Hor.	Measured At Edison Direct	From Fresno TMY Tape Total Hor.	From Fresno TMY Tape Direct
January	2.0 (634)	2.0 (634)	2.1 (666)	2.3 (731)
February	3.7 (1174)	5.1 (1618)	3.3 (1047)	3.7 (1174)
March	4.6 (1459)	6.1 (1935)	5.0 (1586)	5.7 (1808)
April	5.1 (1618)	4.9 (1554)	6.7 (2125)	7.0 (2220)
May	6.0 (1903)	5.4 (1713)	7.9 (2506)	8.1 (2569)
June	7.7 (2443)	8.9 (2823)	8.6 (2728)	9.2 (2918)
Average	4.8 (1523)	5.4 (1713)	5.6 (1776)	6.0 (1903)

It should also be pointed out that the annual average insolation at Fresno varies only by ± 8% from that for the TMY. Therefore, a similar year to year variation in system performance can be expected.

1.3 System Studies

System studies consisted of: (1) system selection based upon a balance of needs and technological risk, minimization of costs and operational consideration; (2) trade off studies to optimize cost and performance; (3) preliminary design for the selected system.

1.3.1 SYSTEM SELECTION

Five system configurations were considered in varying degrees of detail during this project. In all cases, the solar subsystem interfaced with a conventional oil fired boiler so that steam was always available from the system. This avoided the present technical and operational uncertainties associated with diurnal steaming which would occur with solar only systems and recognized the current unavailability of an economically feasible high temperature storage system.

The five alternative systems were:

- An indirect boiler concept in which a heat transfer oil is heated in the solar collectors and then used to generate steam in an indirect boiler. This concept was rejected because the temperature required to generate steam at sufficient pressure for the Edison Field could cause degradation of the selective surface on the solar collector receivers.

- Direct boiling in the solar collector receiver tubes was the least expensive of those techniques involving generation of steam. However, the concept was rejected, because of the time required to develop and demonstrate the technique.

- A flash boiler concept in which water under pressure is circulated through the receiver tubes followed by pressure reduction to allow a portion of the hot water to flash to steam. The separated water plus make-up water is recycled to the collectors. This concept was judged to be of acceptable technological risk. However, it was not the economically optimum concept.

- A flash boiler with preheat and hot water storage concept in which sufficient water is preheated in a portion of the collectors to supply preheated water to the collectors used in conjunction with the flash boiler and for 24 hour operation of the oil fired boiler. This concept was judged to be the lowest cost and to have the least technological risk of those concepts satisfying the DOE requirement for supplying at least 1/3 of the energy developed by a 7.32 MW (25 x 10^6 BTU/hr) boiler. For this reason it was examined in considerable detail and was the basis for the tradeoff studies described in Subsection 1.3.2 and some of the preliminary design studies in Subsection 1.3.3.1. However, this concept did not result in the minimum cost of solar heat and yielded a marginal return on investment.

- Boiler preheat with storage concept in which sufficient feed water is preheated and stored during the day to supply a 7.32 MW (25 x 10^6 BTU/hr.) boiler with preheated water for 24 hours of continuous operation. Although it is possible in theory to preheat the water to a high enough temperature so that 1/3 of the heat needed to generate steam is supplied by solar, it is extremely difficult to efficiently interface with present day boilers with water at this temperature, 232°C (450°F). Furthermore, the cost of storing water at this temperature and corresponding pressure causes a significant increase in the unit cost of solar energy. For these reasons the preheat temperature was limited to 121°C (250°F) which yields a solar input of about 15%. A preliminary design for this concept is described in Volume III.

1.3.2 TRADE OFF STUDIES

Trade off studies were made using the flash boiler/preheat with storage concept as a basis. The factors which were considered included: collector orientation, collector spacing, well spacing, location of collectors outside the operating area of the field, and steam pressure requirements. Other variables such as collector string length, footing design and insulation thickness were also studied but in less detail.

The results from the trade off studies are summarized in Table 1.2. Comparing the amount of annual heat delivered and its relative cost shows that the off field location has a slight advantage due to lower system costs and that there is also a small advantage for lower pressure operation. If the oil field is drilled to 1619 m^2 (0.4 acres) per well spacing however, the off field advantage becomes very large. The principal benefits of lower pressure operation will be to reduce technical uncertainties associated with the effect of high temperatures on the solar receiver's selective coating and the temperature and pressure effects on flexible hoses. These benefits should be reflected in greater system availability and reduced corrective maintenance expenses at the lower operating pressures.

TABLE 1.2

RESULTS OF TRADE OFF STUDIES FOR FLASH BOILER/PREHEAT-STORAGE

SYSTEM WITH 23,226 M^2 (250,000 FT^2) OF COLLECTOR AREA

Variable Changed	Delivered Annual Energy 10^6 Kwh/Yr.	GBTU/Yr.	Relative Cost Of Delivered Energy
Base Case (1)	19.6	(66.9)	1.00
Collector Orientation (East-West)	17.4	(59.2)	1.13
Collector Spacing			
5.3m - (17.5 ft.)	19.9	(68.0)	1.00
2.3m - (7.5 ft.)	17.6	(60.1)	1.09
Well Spacing			
20,234 m^2 (5 acre)	19.8	(67.7)	0.97
1,619 m^2 (0.4 acre)(2)	16.2	(55.3)	1.74
Off Field Location (3)	19.1	(65.1)	0.96
Lower Pressure Steam 2755 kPa (400 psia) (4)	21.0	(71.8)	0.92

Notes

(1) For north-south collector orientation, 3.8m (12.5 ft.) collector spacing, 4,735m^2 (1.17) acre well spacing and 5957 kPa (865 PSIA) steam pressure.

(2) 6.1m (20 ft.) collector string vs 24.4m (80 ft.) collector string for other cases.

(3) 762m (2500 ft.) distance from collector field to oil wells.

(4) Pressure level in high temperature collectors is 3202 kPa vs. 7128 kPa (465 psia vs. 1035 psia) for base case. Maximum receiver temperature is 243°C vs. 296°C (470°F vs. 565°F) for base case.

1.3.3 PRELIMINARY DESIGNS

Two preliminary designs were prepared during this program. The first design was based on a flash boiler/preheat with storage concept which had a total collector area of 23,226 m^2 (250,000 ft^2). The second design was limited to a preheat with storage concept which had a total area of 9,290m^2 (100,000 ft^2).

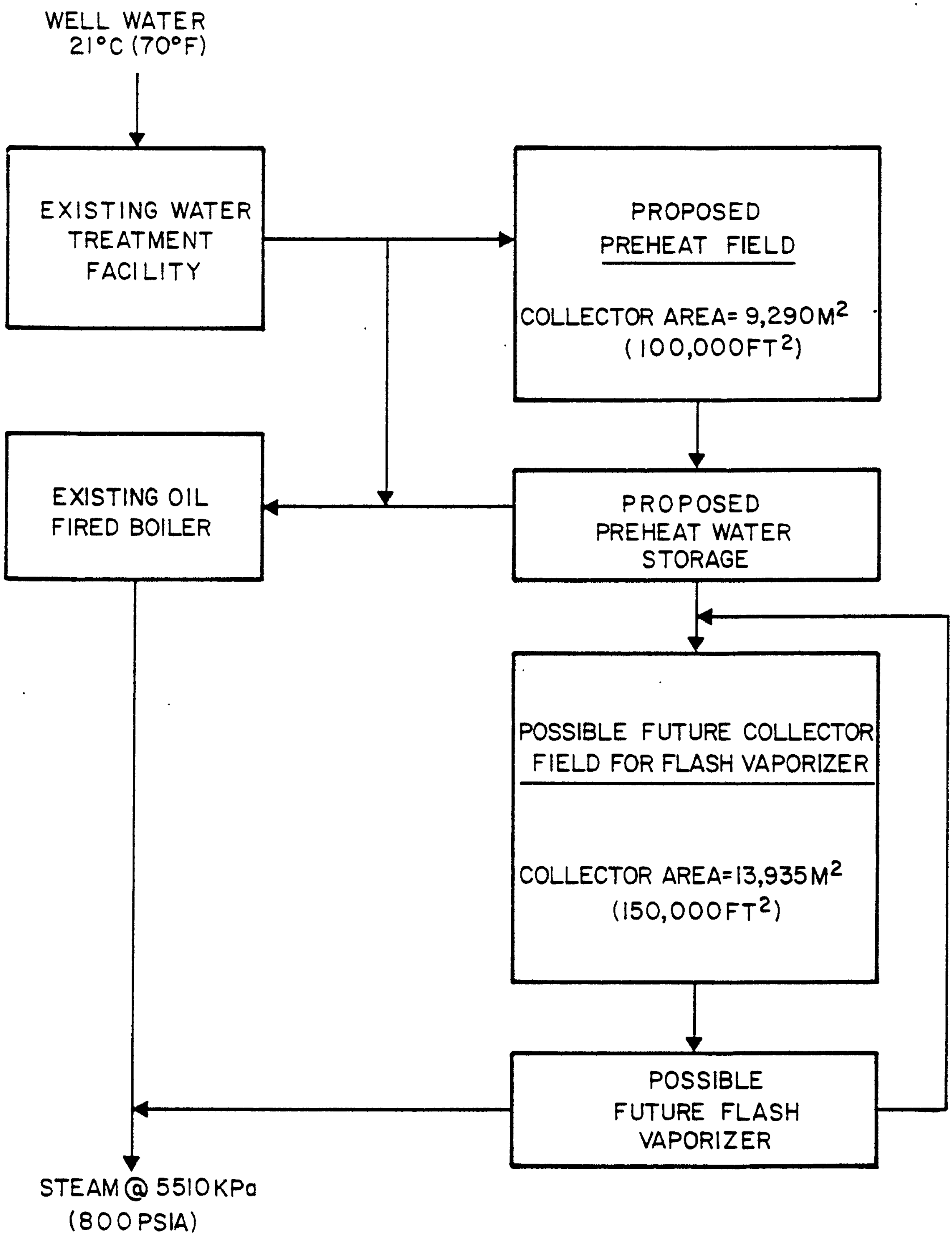
1.3.3.1 Flash Boiler/Preheat With Storage

Figure 1.2 is a schematic diagram showing the flash boiler/preheat with storage concept. Briefly stated, this system preheats sufficient treated well water to 121°C (250°F) to feed both the solar powered flash boiler and the oil fired boiler during the day and the oil fired boiler during the night. Sufficient hot water is stored during the day to satisfy the night time operation.

The major technical uncertainty with this system was in the operating temperature and pressure of the flexible hoses used to connect the trough collectors to each other and the manifolds. These operating conditions exceed the limits recommended by the manufacturer (Table 1.3). Furthermore the collector receiver temperature exceeds the current upper limit 288°C (550°F) imposed by the degradation of the selective coating.

1.3.3.2 Preheat With Storage

The preheat with storage concept is also indicated on Figure 1.2. It performs the preheat and storage functions using about 9290 m^2 (100,000 ft^2) of trough collectors to supply 121°C (250°F) water for 24 hour operation of an oil fired boiler. Since its pressures and temperatures are lower than the flash boiler concept's, it greatly reduces the technical uncertainty associated with flexible hoses and receiver coating (Table 1.3). It is anticipated that a solar steam raising section could be added to the preheater, when and if justified by technology advancement and economics.



FLASH BOILER/PREHEAT WITH STORAGE CONCEPTS
FIGURE 1.2

115-641

Table 1.3

MAXIMUM PRESSURE AND TEMPERATURE CONDITIONS VS MANUFACTURE'S RATINGS

Design Conditions	Flash Boiler/Preheat With Storage Concept		Preheat With Storage Concept		Manufacturer's Ratings
Flex Hose Pressure, kpa (PSIA)	7128	(1035)	723	(105)	6,646 (965) (1)
Flex Hose Temperature, °C (°F)	282	(540)	121	(250)	282 (540) (1)
Receiver Temperature, °C (°F)	296	(565)	135	(275)	288 (550) (2)

(1) For Anaconda's 3.18 cm (1 1/4") ID Stainless Steel Flex Hose Catalogue No. BW21-2H

(2) Larson, L.M., FY78 Annual Progress Report: Midtemperature Component And Subsystem Development Project, Sandia 79-0800.

1.4 System Economics

An economic analysis was performed on the two preliminary designs. The preheat plus storage design had the more favorable economic benefits. Using the measure of Net Present Value (i.e. present worth) of the cash flows, the economic variable with the greatest degree of sensitivity was the level of tax incentives.

The Net Present Values for solar investments were based upon fuel saved as a result of supplying solar heat. The assumed project life was 20 years and oil prices were assumed to rise at 3% per year above inflation (G.N.P. deflator). Comparisons with conventional fuels were made on the basis of levelized energy costs.

1.4.1 RELATIVE ECONOMIC ADVANTAGE OF THE PREHEAT PLUS STORAGE SYSTEM DESIGN

As previously mentioned the reliability of flexible hoses operating at the temperature and pressure required to raise steam is a concern. However, the major factor favoring the preheat plus storage concept was the levelized cost of delivered energy. As can be seen in Table 1.4 there is a significantly lower cost of delivered energy for the preheat only system. The primary reason for this is the higher collection efficiency of the collectors in the preheat system due to their lower average operating temperature.

TABLE 1.4

COMPARISON OF STEOR CONCEPTS
(20 YEAR LIFE BASIS)

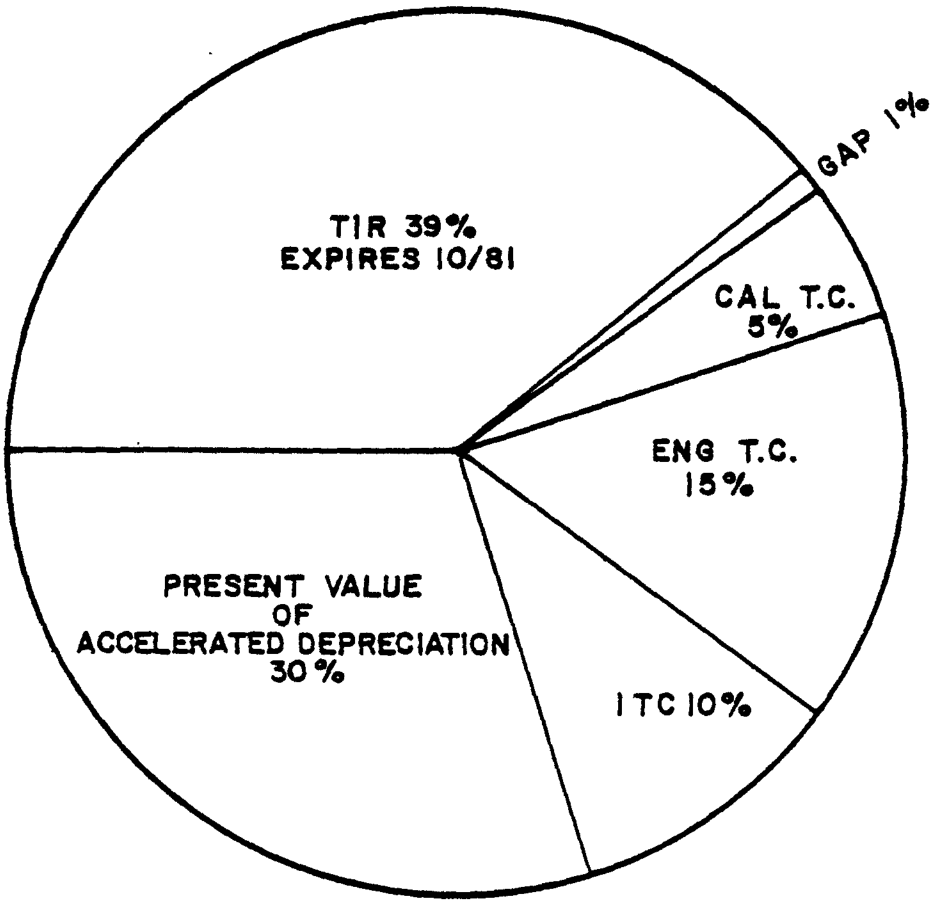
	Flash Boiler/ Preheat & Storage		Preheat & Storage	
Collector Area, m^2 (ft^2)	22,822	(245,655)	9,632	(103,680)
Annual Energy Delivered, kwh/m^2 (kBTU/ft^2)	801	(254)	1,060	(336)
Relative Investment	1.0		0.99	
Relative Levelized Energy Cost (at 15% discount)	1.0		0.93	

1.4.2 INCENTIVES AVAILABLE FOR STEOR

Current costs for solar equipment and installation cannot be economically justified by fuel savings. As a result incentives are required to encourage investments in the early years of the industry. As one subsequent analysis in this report has shown, given certain assumptions, a relatively small dollar amount would appear to be involved to bring the solar line focus industry to the point where it can develop without the large incentives now in existence.

Figure 1.3 summarizes the percentage of initial investment which can be recouped by various incentives. As can be seen greater than 90% of the investment may be recovered through a combination of accelerated depreciation deductions against other income (available on any investment), federal and state investment and solar tax credits and Tertiary Incentive Revenue (TIR). TIR allows a producer to recoup 75% (before income taxes) of his investment, net of windfall profits tax, by increasing the price of otherwise price controlled oil to market clearing levels. To take full advantage of TIR, payments for construction must be completed by September 30, 1981 when all oil will be decontrolled.

At this time it does not appear that sufficient solar equipment could be produced and installed under TIR to reduce installed solar system costs to the competitive level. Therefore, for STEOR to grow after TIR expires, appropriate additional incentives would need to be enacted to continue to encourage both oil producers and solar equipment manufacturers.



TAX AND E.R.A. INCENTIVES RECOUP
99% OF CAPITAL COST
(PRESENT VALUE BASIS)
FIGURE 1.3

1.5 Market Analysis

A preliminary market analysis was completed to explore the factors which could influence the future market, if any, for STEOR. These factors included: future increases in the use of steam for enhanced oil recovery; projected value of heavy oil, availability of economic incentives and financing arrangements, environmental factors, the projected price and performance of solar equipment and the competitive merits of alternative technologies and fuels. Although much more market analysis remains to be done, the preliminary analysis indicates that some of the factors are consistent with the potential for developing a very large market in STEOR related activities.

1.5.1 FUTURE VALUE OF HEAVY OIL

The economic benefit from STEOR depends first of all on the value of the fuel oil replaced. In the near term this is most likely to be lease crude (the alternatives of coal and gas are discussed in Section 1.5.4). The pricing information for the analysis which was obtained from available public documents (1-4, 1-5, 1-6) is not and should not be interpreted as either an Exxon forecast or an Exxon endorsed forecast. The factors which control the future value of heavy oil are: future increases in world oil prices adjusted for taxes and royalty; future increases in the domestic production of heavy oil; and refinery capacity for heavy oil.

(1-4) Projections of DOE's Mid Term Energy Forecast System as reported in 10 CFR 436, Federal Energy Management and Planning Programs; Methodology and Procedures for Life Cycle Cost Analysis (45 FR 5620 et seq 1/23/80).

(1-5) National Petroleum Council Enhanced Oil Recovery: An Analysis of the Potential for Enhanced Oil Recovery from known Fields in the United States - 1976-2000 Washington, 1976.

(1-6) Bonner & Moore Associates, Inc. 1985 California Oil Scenario Study, Houston, 1980.

World oil prices have become increasingly difficult to predict. For example, during the course of this study world oil prices have already increased to a value equal to the high forecast of NEP-II(1-7) for 1990. As a result we have used a 1980 base world oil price of $30/BBL and increased this at about 3.0% per year above inflation in agreement with DOE's Mid-Term Energy Forecast System. Since heavy oils are of lower quality (less light distillate and higher sulfur) there is a "quality debit" which must be applied. For Edison in 1979 this debit was on the order of $3/BBL but with short term gaps as high as $10/BBL during periods of rapid price escalation. To simplify the treatment of this debit we assumed a 1980 quality debit value of $3/BBL and inflated this at 3%/yr. above general inflation. Royalty payments and ad valorem taxes will vary. However, for Edison the net effect is to reduce the value of fuel by an additional 14%. Finally, the Windfall Profits Tax will further reduce the value of fuel. The net effect is presented in Table 1.5.

TABLE 1.5

FUTURE VALUE (CURRENT YEAR DOLLARS) OF HEAVY OIL AS BOILER FUEL

Year	World Oil Price, $/BBL	Less Tax, Quality And Royalty Debits, $/BBL
1980	30.00	18-21 *
1985	48.32	27-33 *
1990	77.81	41-54 *
1995	125.32	99
2000	201.82	159

*Depends On Whether Produced Oil Is Classified As Tier 2 Or Tier 3 Under The Windfall Profits Tax. Assumes Windfall Profits Tax Phases Out Between 1991 & 1995.

(1-7) National Plan for Energy Research, Development and Demonstration: Creating Energy Choices for the Future, Plan II, Washington 1979.

A recent, 1979-1980, cooperative study (1-6) by California State officials and refiners estimates a 400,000 BBL/day increase in California oil production including heavy oil from 1978 to 1985. The study concludes that there should be no refinery capacity constraints for an increase of this magnitude. Assuming no further increases in heavy oil production then there should not be a refinery capacity limitation on a future STEOR market.

1.5.2 FUTURE STEAM REQUIREMENTS

A preliminary screening of California heavy oil fields was undertaken to determine an upper limit for STEOR applicability based on a predetermined set of criteria. The study was limited to California because it contains 60% of the known domestic heavy oil reserves and currently produces over 95% of the domestic oil now produced by steam stimulation or steam drive techniques. The screening study was conducted by interviewing oil field operators and visiting selected sites.

Assumptions used for the screening study were:

(1) Solar derived steam for a field is limited to the smaller of:

- o one third of the estimated maximum eventual steam generation capacity
- o Total future anticipated increment of steam generation capacity

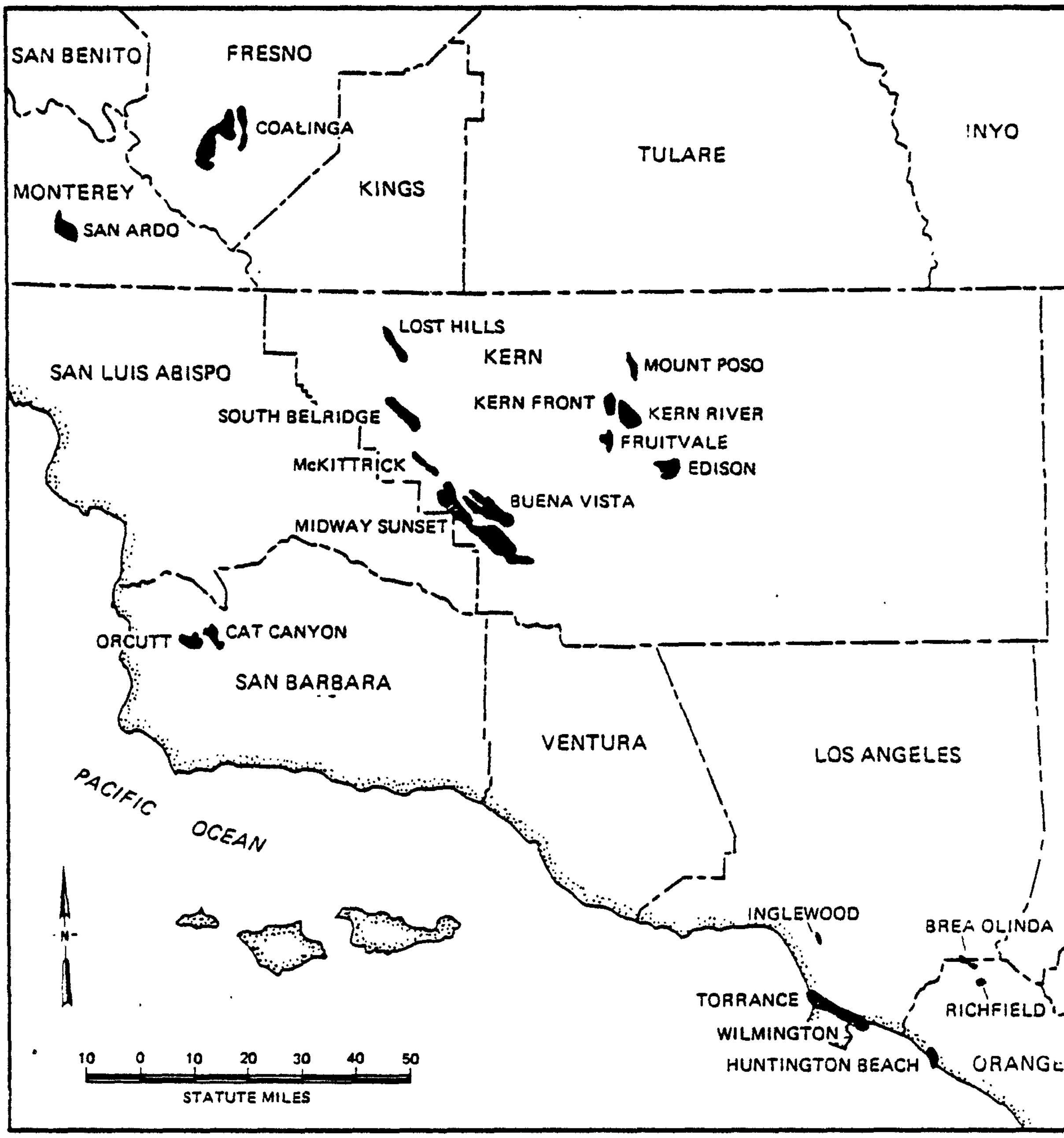
(2) Solar steam generation will not displace installed fossil fuel generators.

(3) Steam will not be transported more than 1.6 Km (one mile).

(4) No collectors located in areas having more than one well per 4,046 M^2 (1.0 acres).

Also considered was the suitability of land for trough collectors. This judgement was made with the help of a representative of Acurex Corporation.

A total of 21 fields representing 92% of California's steam capacity were considered (Figure 1.4). Of these, ten fields were quickly eliminated since the fields were located under water, in a city or were not using steam. This left eleven fields having 91% of California's current steaming capacity for the more detailed analysis.



LOCATION OF CALIFORNIA HEAVY OIL FIELDS USED IN STEOR SCREENING STUDY.

FIGURE 1.4

The results of applying the remaining screening criteria to the 11 fields are summarized in Table 1.6. In only one case (Kern River) was land topography a limit to the amount of solar derived steam that could be generated.

However, the land surface which is technically suitable for installation of solar collectors may not necessarily be available for that purpose. Conventional oil and gas leases do not convey the right to utilize 100 percent of the land surface. Consequently, for land either inside or outside the field, some kind of total surface leasing or land purchase will be required Strong resistance to extensive land saturation by solar collectors is to be expected from other land use groups such as ranchers and farmers. A rapid climb of lease and purchase costs can also be expected.

State or federal regulations on land use may also affect extensive use of solar collectors. Although solar energy is considered to be pollution-free with regard to air and water, the question of "land pollution" has not been addressed. The distribution of solar collectors very severely restricts other uses of the land.

Required pressure was not considered as a screening limitation at this time. However, with the current limit on receiver temperature, 288°C (550°F), the maximum steam pressure is 5960 k Pa absolute (865 psia). Figure 1.5 derived from the field survey data in Table 1.6 shows that current technology trough collectors should be applicable to about 80% of the anticipated expansion in steam capacity.

1.5.3 PROJECTED PERFORMANCE AND PRICE OF TROUGH COLLECTOR SYSTEMS

Significant improvements in performance and cost of trough systems are possible. Both factors will be important if this type of equipment is to capture a significant share of the the future TEOR market. Based on the current and projected DOE supported R&D effort a 50% improvement in collector performance during the next 5 years is anticipated. Collector cost reductions during the same period could be as much as 50% provided sufficient incentive exists to continue the current upward trend in trough purchases. Additional cost savings are projected for the remainder of the system.

Assuming that collector manufacturers are able to justify the investment needed for large scale production, then a possible scenario for future system costs based on the Edison preheat plus storage concept is summarized in Table 1.7. It can be seen that while solar equipment is the major item of investment it is important to make significant reductions in the cost of conventional equipment as well in order to approach parity with an oil fired system. The latter will require innovative approachs to design fabrication and construction not yet practiced by the process industry. One approach, a

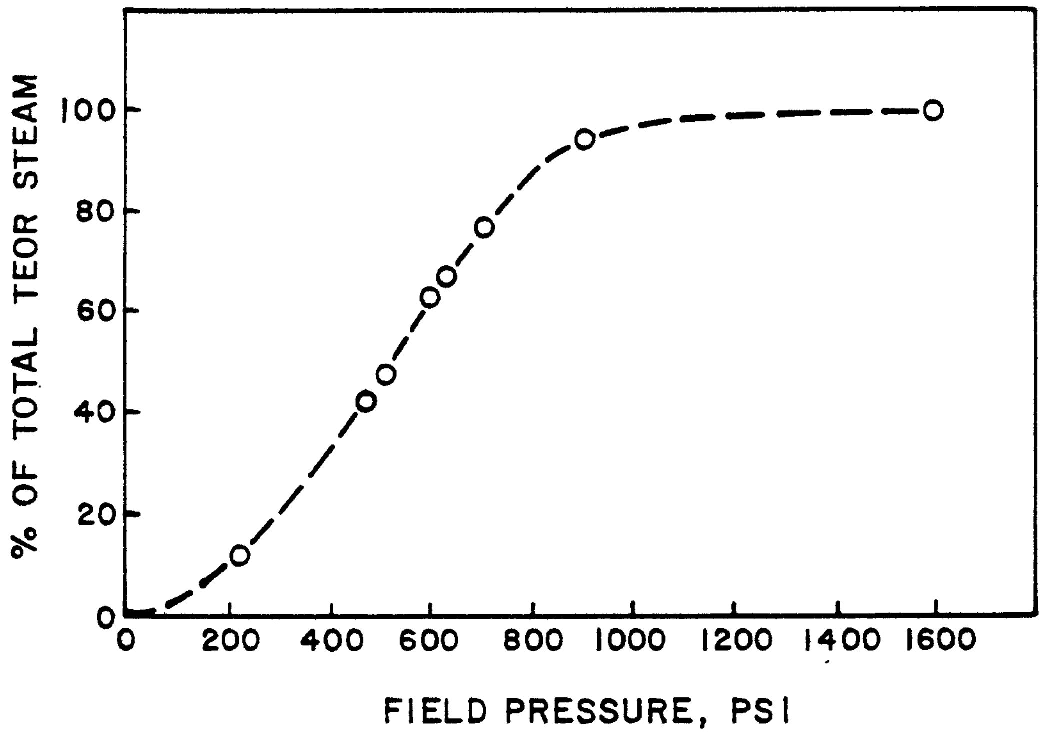
TABLE 1.6

APPLICABILITY OF PARABOLIC TROUGH SOLAR COLLECTORS TO CALIFORNIA HEAVY OIL FIELDS - A TECHNICAL SCREEN

(Fields listed in order of decreasing potential)

Field	Typical Steam Surface Pressure kPa	(psi)	Present Steam Gen. Capacity (bbl/day)	Estimated Max. Steam Gen. Cap. (bbl/day)	Theoretical Wax Solar Potential: Coll Area $10^6 m^2$	(10^6 ft^2)	Steam Cap. (bbl/day)
Midway-Sunset	2,754-3,789	(400-550)	186,000	800,000	8.7	(94)	221,000
South Belridge	6,198	(900)	169,000	500,000	6.6	(71)	167,000
Coalinga-West	3,444-6,198	(500-900)	64,700	250,000	2.9	(31)	73,000
Kern River	689-2,410	(100-350)	856,000	1,070,000	2.5	(27)	63,000
Lost Hills	4,132	(600)	33,000	160,000	2.1	(23)	53,000
Kern Front	4,132	(600)	24,000	210,000	2.1	(23)	53,000
San Ardo	2,927-4,132	(425-600)	130,000	230,000	2.0	(22)	51,000
Cat Canyon-Sisquoc	8,264-13,774	(1200-2000)	38,400	160,000	1.7	(18)	42,000
McKittrick-Main	4,339	(630)	24,500	100,000	1.2	(13)	30,000
Edison-Main	2,754-6,198	(400-900)	2,600	19,000	0.2	(2.6)	6,000
Mount Poso	4,132	(600)	84,000	84,000	0.0	(0.0)	0
			1,612,200	3,583,000	30.2	(325)	759,000

Note: Columns may not add due to rounding. 6.29 barrel = 1 m^3.



STEAM PRESSURE REQUIREMENTS FOR TEOR
FIGURE 1.5

modular system having 4,645m^2 (50,000 ft^2) of trough collectors, is being prototyped by several DOE contractors. Although such technology does not exist today it is possible that it could be developed by 1985. Previous efforts to affect savings of this type have had some success in other industries. A full investigation of oil producer experience and assessment of pre-packaged process systems would be important in a more detailed market analysis.

A significant uncertainty in this analysis is whether or not sufficient incentives will be provided between now and 1985 to encourage manufacturers to invest in production equipment needed to reduce collector costs. A rough estimate indicates that a net total of \$30 to \$36 x 10^6 would be required (as tax incentives to the customers) to cover the period from 1982 through 1985. This amounts to \$8 to \$9 x 10^6 per year, and does not seem unreasonable in terms of current DOE solar expenditures.

1.5.4 COMPETITIVE FACTORS

Developments along several fronts will provide competition for solar derived heat in TEOR. Our evaluation of this aspect of the market analysis was confined primarily to an Edison Field site. In that time scale it is clear that oil fired equipment will remain the primary competition. Gas fired boilers were ruled out because indications are that gas will be more expensive than oil beyond 1985. Coal fired boilers and down hole steaming were judged to be insufficiently demonstrated for the installation. In the longer term, coal utilization for TEOR in California could be blocked by environmental factors.

Manufacturers of oil fired field boilers are actively developing more efficient equipment which can be justified by today's oil prices. The first major improvement is likely to be an add-on low temperature convection section which would reduce exhaust gas temperatures from current levels of 177/204°C (350/400°F) to 65°C (150°F). This modification would improve the boiler efficiency by 5 to 6%. Corrosion due to acidic condensate is the major technical problem to be overcome. It is our understanding that field tests are now in progress to demonstrate a prototype low temperature convection section.

If the low temperature convection section does become available it will be more difficult to interface a solar preheating section with the oil fired boiler. The reason for this is that cold boiler feed water is needed to achieve low flue gas temperatures i.e. preheating the feed water would reduce boiler efficiency by increasing the flue gas temperature. There are several alternatives to this including preheating only a portion of the boiler-feed water or preheating boiler combustion air. However, these would require additional system and control complexity. Longer term we believe the preferred STEOR system will be one in which solar heat is used to generate steam so that the interface with the oil fired boiler is at the steam header.

TABLE 1.7

PROJECTED COST FOR SOLAR PREHEAT PLUS STORAGE SYSTEM

Direct Materials & Labor $/M^2($/ft^2)	Projected 1981		Projected 1985		Projected 1990	
Solar Collector Subsystem (1)						
- Collectors F.O.B. Site (2)	233.5	(21.7)	151.7	(14.1)	117.3	(10.9)
- Foundations (3)	46.3	(4.3)	36.6	(3.4)	29.1	(2.7)
- Installation	45.2	(4.2)	37.7	(3.5)	32.3	(3.0)
Storage Tanks	28.0	(2.6)	28.0	(2.6)	28.0	(2.6)
Piping & Pumps (4)	122.7	(11.4)	109.8	(10.2)	96.8	(9.0)
Electrical (5)	103.3	(9.6)	92.5	(8.6)	92.5	(8.6)
Instruments & Controls (6)	51.6	(4.8)	38.7	(3.6)	25.8	(2.4)
Structure & Fencing & Other	32.3	(3.0)	32.3	(3.0)	32.3	(3.0)
Spares	5.4	(0.5)	3.2	(0.3)	2.2	(0.2)
Engineering Charges						
- Owners Engineering (7) & Project Management	47.3	(4.4)	31.2	(2.9)	31.2	(2.9)
- Design & Procurement (8)	63.5	(5.9)	48.4	(4.5)	32.3	(3.0)
- Field Supervision (9)	21.5	(2.0)	19.4	(1.8)	17.2	(1.6)
Project Contingency (10)	124.8	(11.6)	63.5	(5.9)	53.8	(5.0)
Project Contingency % (10)		(15.7%)		(10%)		(10%)
Total	925.4	(86.0)	692.9	(64.4)	590.7	(54.9)
Annual Performance kwh/m^2-yr. (KBTU/ft^2-yr)	1060	(336)	1432	(454)	1432	(454)
Levelized Solar Energy Cost (11) $/kwh, ($/MBTU)	1.4×10^{-2}	(4.1)	4.1×10^{-2}	(12.1)	3.7×10^{-2}	(10.9)
Competing Fossil Energy Cost $/kwh, ($/MBTU)	2.3×10^{-2}	(6.6)	2.7×10^{-2}	(7.8)	3.3×10^{-2}	(9.8)
Additional Investment Tax Credits Required For Solar Parity, %		0		19		6

Note: Columns may not add due to rounding

Notes to Table 1.7

(1) Area = 103,640 ft^2. Capital costs in 1980 Year-end dollars.

(2) Collector Costs track 85% learning curve per Section 8.2 using '80...'82 Trendline (not DOE goals for implied volume).

(3) Foundations and installation costs reduced per Section 8.2, Table 8.8, percentages to account for longer module lengths and improved designs, e.g. number of footings reduced by 1/2.

(4) Piping and insulation costs and performance are improved by 20%. As in section 8.2, we treat this as purely a cost reduction. Costs reflect 750 m (2,460 ft.) of lines to and from boiler pad.

(5) Electrical costs reduced to account for larger modules and drive strings. Current costs reflect 750 m (2,460 ft.) high voltage above ground feeder and transformer from boiler pad to solar field.

(6) Reductions in special solar data instruments ($100k) and maturing designs with larger collector rows ($150k) are projected. Estimated amounts are uncertain.

(7) Owners engineering charges reflect reduced design costs and increased familiarity with solar by project manager in future jobs.

(8) Design costs in 1985 are assumed to be 75% of 1980 total and in 1990 are 50% of 1980 due to modularity. Procurement costs do not change.

(9) Field supervision is based on a constant fixed percent of non-collector direct costs.

(10) Contingency is reduced to 10% based on assumed experience in early DOE reported efforts.

(11) Approximate solar levelized costs are for a 20 year life and a 15% discount rate. Windfall Profits Tax (Tier 2 = 60%) is applied to years before 1991. Tertiary Incentive applies to left column only. Incentives in 1985 and 1990 are 30.4% tax credits. All projections have direct capital costs stated in 1980 dollars and operating cash flows stated in comparable current 1982 to 2001 year dollars as follows: all first year cash flows are in 1982 dollars, all second year cash flows are in 1983 dollars, etc. Real price growth in fuel and electric costs are included.

1.5.5 ENVIRONMENTAL CONSIDERATIONS

The major environmental factors related to STEOR are emissions and ambient air quality. The reduction in emissions from a given source (oil field) will be in proportion to the degree to which heat is supplied from solar. Thus if a 30% solar contribution is used there will be a corresponding reduction in emissions. Air quality improvements due to STEOR are more difficult to assess due to the uncertainties in the TEOR contribution to air quality.

1.6 Conclusions And Recommendations

This feasibility study has provided the background for an improved understanding of the application of trough collectors to STEOR. It has clarified the issues which still need to be resolved and from this recommendations for the future program have been developed.

1.6.1 TECHNICAL READINESS OF TROUGH COLLECTORS

The technical feasibility of trough collectors has been adequately demonstrated in current DOE programs. Based on results from these programs we have been able to project the performance of a STEOR system to our satisfaction. If steam conditions like those at Edison are present, an initial demonstration using a preheat only design would avoid potential problems of exceeding temperature limits on the collector receiver and on flexible hose connections. These limitations will be less of a problem in other oil fields having lower steam pressure requirements. Furthermore, considering the development effort by DOE on trough collectors it is likely that these limitations will be removed within the time frame of the major STEOR installations. In addition, major improvements in performance can be anticipated which will reduce the collector area needed.

1.6.2 ECONOMIC READINESS OF TROUGH COLLECTOR SYSTEMS

Current system costs are high due in part to the high manufacturing costs of trough collectors. Therefore, incentives will be required to initiate the STEOR market. These incentives can be greatly reduced but not eliminated by 1990 when the majority of the STEOR installations should be completed. The major uncertainty in the economics for trough systems is the degree of cost reduction which can be achieved in the non-collector portions of the system (67% of installed system costs). As a result of current DOE programs on modularization and mass production this uncertainty should be better defined in the near future. However, unless this program is successful the continuing need for incentives is indicated at least for trough type systems.

1.6.3 PRELIMINARY ASSESSMENT OF STEOR MARKET POTENTIAL

A large market could exist in STEOR applications provided technical and economic feasibility can be demonstrated and land availability does not become a constraint. The upper limit of this market (30 x 10^6 m^2 (325 x 10^6 ft^2) of collectors) is based on the assumption that solar would contribute only about 30% of the total steaming capacity added. An important finding was that most of the domestic steam capacity additions will be made by 1990 and therefore it is important for solar technology to be ready to take advantage of this opportunity.

If market penetration is considered, the outlook for STEOR appears to be mixed. In the near term the possibility exists that several pilot systems will be installed using TIR. Not all of these will use line focus collectors, but line focus technology could be present. The near term impact would be a short spurt to the collector manufacturers and should provide synergistic benefits with other DOE projects in process heat and modularity of trough systems.

Once the TIR program terminates, a large economic gap will again exist. Given current oil prices, the Windfall Profits Tax, and solar prices, the economics of STEOR will be unfavorable. The modest reduction in solar hardware costs resulting from a few early STEOR pilot plants cannot be expected to improve system cost effectiveness enough to overcome the burden of current industry design and construction practices which were developed for process plant applications. An opportunity (with large business risk) could exist for an inventive approach to use multiple unit production methods to cut recurring system design and procurement costs (e.g. "Liberty Ship" approach).

The alternatives to line focus technology-based STEOR should also be considered. Point focus technology (e.g. heliostat central receivers) may be inherently more attractive, depending on the actual experience of forthcoming operational demonstrations. The DOE may find it desirable for its objectives to provide assistance either directly or indirectly to induce the owners of any pioneering STEOR projects to try again on a larger scale. The objective of such follow on efforts should be to provide a fair test of STEOR and to provide private decision makers with additional operational and economic information upon which they can prudently evaluate both risks and benefits of STEOR investments as either manufacturers or users.