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SERI/TR-35-078
Volume III

February 1980

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Conversion System Overview Assessment

Volume III
Solar Thermal/Coal or Biomass Derived Fuels

R. J. Copeland

Solar Energy Research Institute
A Division of Midwest Research Institute

1617 Cole Boulevard
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Operated for the
U.S. Department of Energy
under Contract No. EG-77-C-01-4042

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Printed in the United States of America
Available from:
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price:
Microfiche $3.~~00~~ 50
Printed Copy $~~4.50~~ 6. 00

SERI/TR-35-078
VOLUME III OF III
UC CATEGORY: UC 62e

CONVERSION SYSTEM OVERVIEW ASSESSMENT

VOLUME III SOLAR THERMAL/COAL OR BIOMASS DERIVED FUELS

FEBRUARY 1980

AUTHOR: R.J. COPELAND

PREPARED UNDER TASK NO. 3503

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FOREWORD

This report documents work done on Task 3503, "Conversion System Overview Assessment," contained in SERI's FY78 Annual Operating Plan, on the following technologies:

- solar thermoelectrics,
- solar-wind hybrid systems,
- ocean thermal energy conversion, and
- synthetic fuels derived with solar energy.

SERI Task 3503 is divided into the following subtasks: Wind (3503.01); OTEC (3503.02); Solar-Wind Hybrid (3503.03); Solar Thermoelectrics (3503.04); and Synthetic Fuels (3503.05). This report documents work done on all of these subtasks except 3503.02 on Ocean Thermal Energy Conversion, which will be covered in a separate report.

This report is divided into three parts. Part I deals with solar thermoelectrics and Part II with solar-wind hybrid systems. Part III covers the production of synthetic fuels utilizing solar thermal heat. Two appendices document reports by General Atomics of LaJolla, California, and Syncal Corporation of Sunnyvale, California, on costing of thermoelectric generators. Each candidate technology was surveyed by reviewing the literature, by contacting individuals and companies active in the field, and by attending conferences.

Two of the technologies--solar thermoelectrics and solar-wind hybrid systems--are new. Presented here is a preliminary study to determine the viability of these new technologies and examples of typical applications.

Dean A. Nordman, Manager
Large Systems Group

Approved for:

SOLAR ENERGY RESEARCH INSTITUTE

Neil H. Woodley, Chief
Systems Analysis Branch

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SUMMARY

The three volumes of this report cover three distinct areas of solar energy research: solar thermoelectrics, solar-wind hybrid systems, and synthetic fuels derived with solar thermal energy. Volume I represents the assessment, done at SERI, of thermoelectrics for solar energy conversion. It is concluded that there is significant potential for solar thermoelectrics in solar technologies where collector costs are low; e.g., Ocean Thermal Energy Conversion (OTEC) and solar ponds. It is expected that thermoelectrics also may have potential in other renewable energy source applications such as geothermal energy and waste heat utilization. Reports of two studies by manufacturers assessing the cost of thermoelectric generators in large scale production are included in the appendix, and several new concepts of solar thermoelectric systems are presented. Volume II discusses solar-wind hybrid systems. It is shown that there are large areas in the United States where solar and wind resources are comparable in magnitude, and there are diurnal and seasonal complementarities which offer the potential for cost-effective hybrid systems. There are also distinct engineering features of the two conversion technologies. Electric power generation from wind is straightforward and cost-effective, whereas solar thermal conversion to generate heat is more cost-effective than to generate electricity. Examples of hybrid systems utilizing these features in total energy applications are presented. Volume III deals with the conversion of synthetic fuels with solar thermal heat. The method is a hybrid combination of solar energy with either coal or biomass. A preliminary assessment of this technology is made by calculating the cost of fuel produced as a function of the cost of coal and biomass. It is shown that within the projected ranges of coal, biomass, and solar thermal costs, there are conditions when solar synthetic fuels with solar thermal heat will become cost-competitive.

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SECTION 1.0

INTRODUCTION

A synthetic fuel made by means of solar conversion would clearly be advantageous to the United States. The western part of the country has very large areas that have large amounts of both insolation and available land. A synthetic fuel would provide the means for transporting solar thermal energy to eastern markets.

This document presents the results of a study that evaluated one method of making synthetic fuel. The path chosen was a hybrid: solar thermal heat source combined with either coal or biomass. The process and cost data are presented herein.

1.1 APPROACH

The cost data are given for synthetic methane. One thousand (1,000) Btu/ft^3 of gas are readily transportable over long distances in existing pipelines.

A single gasification process is assumed. The same process was selected to compare both a hybrid system and one using only coal (or biomass). Based upon the assumed process, energy requirements are determined. A common estimate of capital equipment cost to perform methanization is obtained. The costs of synthetic methane as a function of the cost of coal or biomass are then determined.

Cost data for thermal energy are accumulated. Solar thermal data are taken from several sources, notably the DOE goals. The projected costs of coal and biomass are assimilated from several sources and, finally, the costs of synthetic fuels from coal (or biomass) alone are compared with those for a hybrid solar thermal approach.

1.2 THE SOLAR RESOURCE

Figure 1-1 presents direct normal insolation data for the United States. The southwestern states--Arizona, California, Colorado, Nevada, New Mexico, Oklahoma, Texas, and Utah--have an area of 1,031,229 mi^2 and the best isolation. However, due to a number of restrictions (earthquakes, mountains, national parks, cities, military reservations, bad soil strength, etc.), the available siting area is considerably reduced. The available area in all of the southwestern states is between 21,500 mi^2 and 161,000 mi^2* and is shown as the white areas in the map on the following page.

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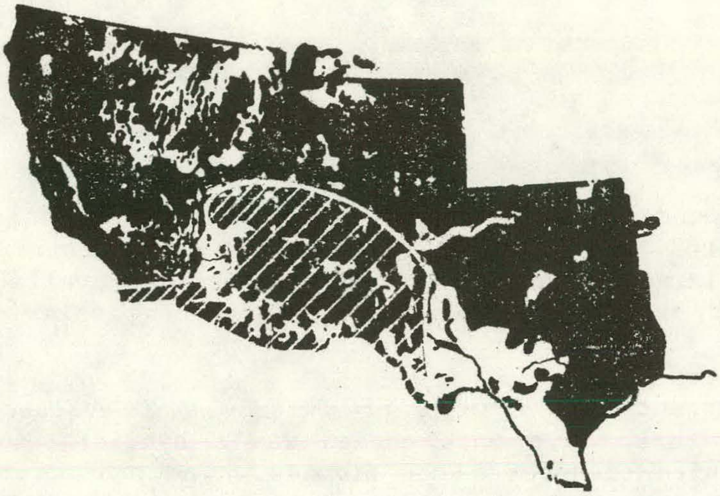
*From "Solar Thermal Mission Analysis Study of the Southwestern United States," Vol. 5, November 15, 1974; Aerospace Report ATR-(74-1716)-2.



As indicated in the marked area of the map, the area of interest for this study comprises only part of the southwestern states, occupying about 250,000 mi^2. If the data (the white areas) can be scaled linearly for the area of interest, 5,200 to 39,000 mi^2 are available, with an insolation of more than 800,000 Btu/ft^2/yr. At a 50% collection efficiency and 20% land utilization factor, the available area represents a resource of $12x10^{15}$ Btu/year to $86x10^{15}$ Btu/yr (12 to 86 quads). The resource can be made even larger by considering good but not best sites.

The insolation in the southwestern United States is approximately twice that in the eastern part. For the area east of the Mississippi River, the direct insolation ranges from 350,000 to 500,000 Btu/ft^2/yr. For the area of interest, the direct insolation is 800,000 to 850,000 Btu/ft^2/yr. Hence the cost of western solar thermal energy is approximately half that in the east. The very low population density and the desert climate (i.e., unsuitable for agriculture) ensure that land is available for solar technology. Additional advantages are the ease of use and storage of fuels and the continued use of existing fossil-fueled equipment without modification.

The solar thermal resource has the potential to supply a large quantity of energy. If an economically attractive system could be developed, the potential could be utilized. However, if a solar thermal system is more expensive than an alternative energy source, then little use of the solar thermal approach can be expected. The remainder of this report discusses the costs of one method of generating synthetic fuels, and a comparison is made between solar thermal and coal (or biomass) fueled systems.

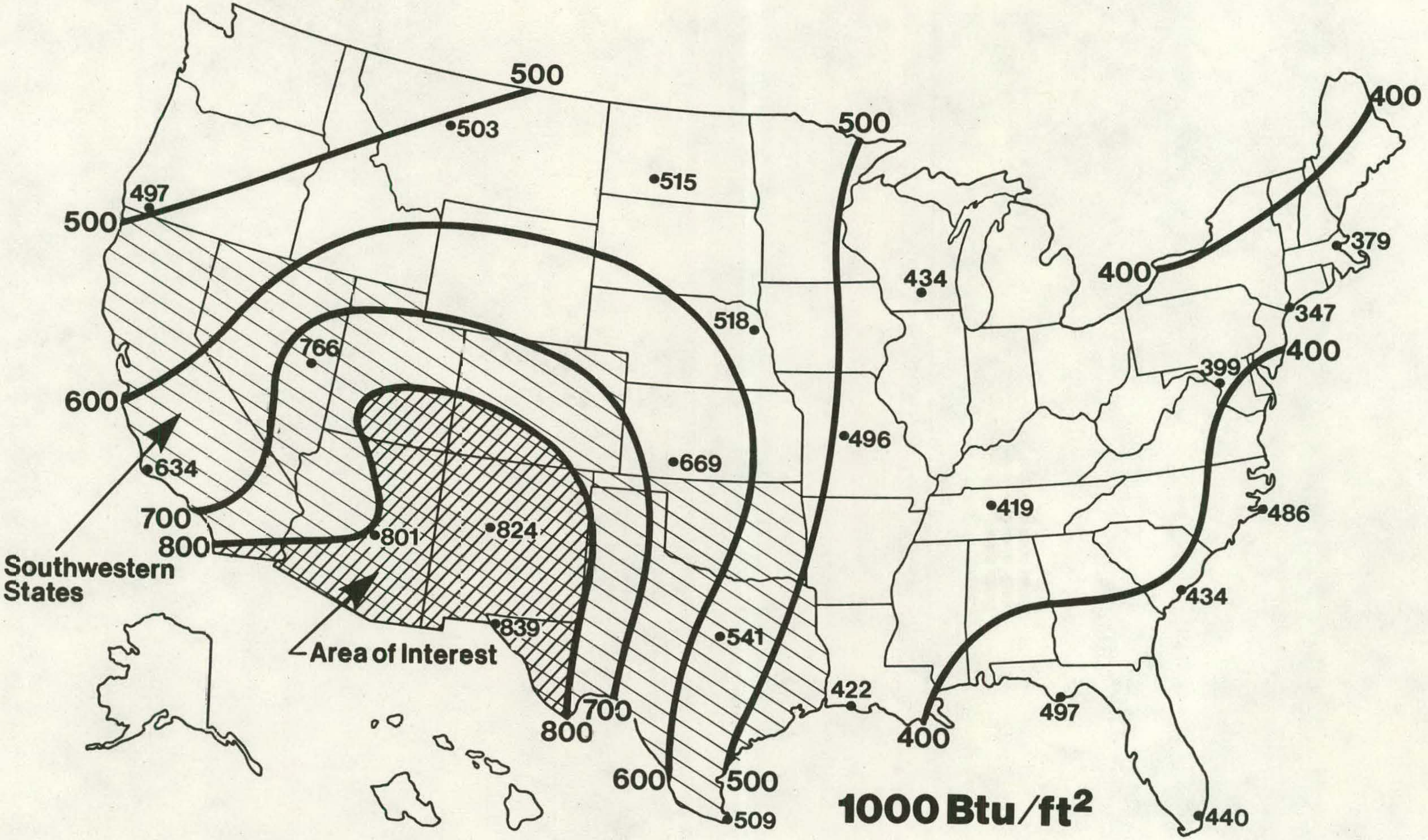


Figure 1-1. AVERAGE ANNUAL DIRECT NORMAL INSOLATION [1]

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SECTION 2.0

SYNTHETIC FUEL PRODUCTION PROCESS

2.1 POTENTIAL PROCESSES

Several processes for generating synthetic fuels with solar thermal energy can be envisioned. By simply modifying processes being developed for nonsolar technologies, solar thermal energy can be configured to be a heat source in the process. Two general approaches can be defined: solar thermal alone and hybrids. The following identifies some (but certainly not all) of the potential processes.

Solar Thermal (STE - Solar Thermal Energy)

Water + STE → H_2

CO_2 + STE → CO

H_2O + CO_2 + STE → Liquid Hydrocarbons

H_2O + CO_2 + STE → CH_4

Hybrids

Hydrocarbons + Water + STE → H_2*

Coal + Water + STE → H_2*

Coal + Water + STE → Liquid Hydrocarbons

Coal + Water + STE → CH_4

Biomass + Water + STE → H_2*

Biomass + Water + STE → Liquid Hydrocarbons

Biomass + Water + STE → CH_4

In the first set of reactions, the only energy input is from a solar thermal energy (STE) source. The STE can be in the form of thermal energy and may include electrical power generated by solar thermal means. Gaseous fuels such

---

*Or mixture of CO and H_2 called Producer Gas.

as hydrogen, carbon monoxide, and methane can be produced by current processes. Liquid fuels such as methanol can also be produced.

The hybrids are a combination of solar thermal energy and another energy resource. Solar thermal energy can be combined with existing fossil fuels (natural gas, liquid hydrocarbons, and coal). The product is higher in energy content than the fossil fuel alone. Biomass is also a renewable solid fuel. When solar thermal energy is added, more synthetic fuel can be produced than from using only biomass.

An evaluation of the economics for each process is desirable but was beyond the scope of this study. To limit the effort, two were chosen. Combinations of solar thermal energy with coal and biomass to produce methane were selected for the following reasons.

- Methane (synthetic natural gas) is readily transportable over long distances and can be used in existing equipment and pipelines.
- The processes required to produce methane from coal and biomass are well known.
- The hybrid processes are expected to be economical at an earlier date than the synthetic fuels produced only with STE.
- A direct comparison of synthetic fuel costs from a solar thermal resource with a coal-only or biomass-only produced fuel is desired.

The same process is employed for both the hybrid and nonsolar thermal resources.

2.2 GASIFICATION PROCESS

The gasification system is illustrated in Figure 2-1. A transport gas (either steam or a mixture of carbon monoxide, hydrogen, and steam) is heated. The hot gas is then passed through a bed of coal or biomass. The steam reacts with the carbonaceous material forming CO and H_2. The resulting mixture can enter the methanation equipment, or part of the steam may be recycled as a source of gas (i.e., it serves as a heat transfer medium). The methanation equipment removes any sulfur compounds and produces CH_4. The waste products are CO_2 and water. The CO_2 is vented and the water may be recycled. The product methane is transported to market via pipeline.

The same processing equipment is used for both hybrid and nonhybrid gasification. Clearly the solar thermal equipment is omitted when calculating the cost of coal- or biomass-only synthetic fuel. However, all elements are needed for the hybrid approach. The intermittence in the solar thermal resource requires a means of storage. For this study the coal- or biomass-fired heat source was assumed to provide that storage mechanism.

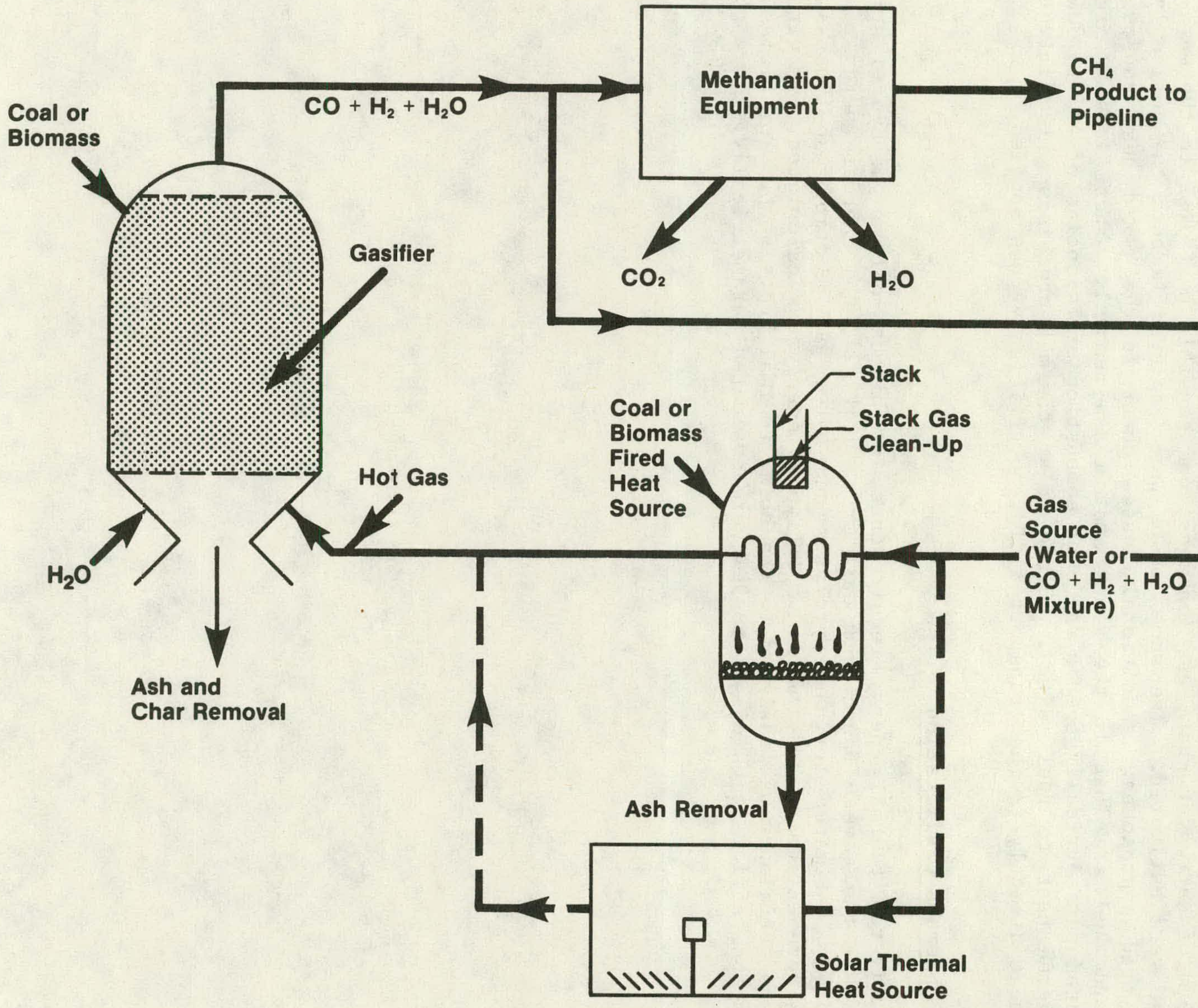


Figure 2-1. ASSUMED GASIFICATION PROCESS

2.2.1 Coal Gasification

The delivered thermal energy requirements for coal-only or for a hybrid approach are the same. The thermal energy input to the process was estimated and included energy requirements for the reaction of water with coal to form the producer gas (i.e., the $CO + H_2$ mixture leaving the gasifier). Losses in the form of carryover char, gas leakages, and sensible heat loss to the environment were estimated. The same losses were employed in both the coal-only and hybrid approaches. Additional losses occur in the fired heat source. Heat and fuel are lost in the stack and in ash removal. These losses were evaluated parametrically over a range of combustion efficiencies of 45% to 90% (delivered heat to fuel value). Since solar thermal processes will deliver this heat directly to the transport fluid, no efficiency* was applied.

2.2.2 Biomass Gasification

The delivered thermal energy requirements for biomass-only or a hybrid approach are the same. Based upon data from Antal [2], the thermal energy required was estimated for the pyrolysis and water gas reactions of biomass. Losses were estimated and the total delivered energy was calculated. As with coal, no efficiency was assigned to the solar thermal heat input. For biomass combustion, efficiencies of 45% to 90% were evaluated parametrically.

---

*The solar thermal receiver does have losses; however, that effect is included in the solar thermal cost calculations.

SECTION 3.0

COST DATA

This section presents cost data for solar thermal/coal or biomass derived fuels. The projected costs for solar thermal heat, coal, and biomass are presented separately. A cost comparison is then made for the hybrid approach versus the conventional approach for gasification.

3.1 PROJECTED COSTS FOR SOLAR THERMAL HEAT

For this study, the solar thermal heat source is the Central Receiver System (CRS) illustrated in Fig. 3-1. The heliostats are mirrors which reflect sunlight to the receiver, where a heat transfer fluid transports the heat to a processing plant at the base of the tower. Each heliostat tracks the sun throughout the day. High concentration ratios and high temperatures are achievable. High heating rates (on the order of 300 MBtu/h sustained) are possible.

The projected costs for solar thermal heat are based upon the DOE goals. Braun stated these goals as follows [3]:

	1975 Dollars		
	1980	1985	After 1985
For Electric Power	\$5,500/kW_e to \$8,800/kW_e	\$2,500/kW_e	\$1,300/kW_e
Heliostats	\$350/m^2	\$150/m^2	\$65/m^2

Table 3-1 presents data employed to calculate the cost for delivered solar thermal heat. Two cases are presented; one is the old DOE goal and the other is a more recent estimate of obtainable costs. The insolation is that for the area of interest. The annual collection efficiency is as estimated from data for electric power plants. The receiver temperatures for gasification are probably much higher than for electric power production and thus the annual collection efficiency might be lower. The electric power data were employed since better information was not available. The heliostat costs were taken from Braun [3] for the old goal and from Eicker for more recent obtainable cost estimates. Both heliostat costs are based on commercial production in very large quantities. The balance of the plant includes the receiver, tower, field mining, controls, land, site preparation, etc. No storage is included. Since the process is to be a hybrid plant, coal or biomass combustion will provide the storage mechanism.

The cost of the balance of plant equipment was estimated from studies on advanced central receiver electric power plants. The cost of the electrical generation equipment was excluded in the balance of plant costs. Nondirect

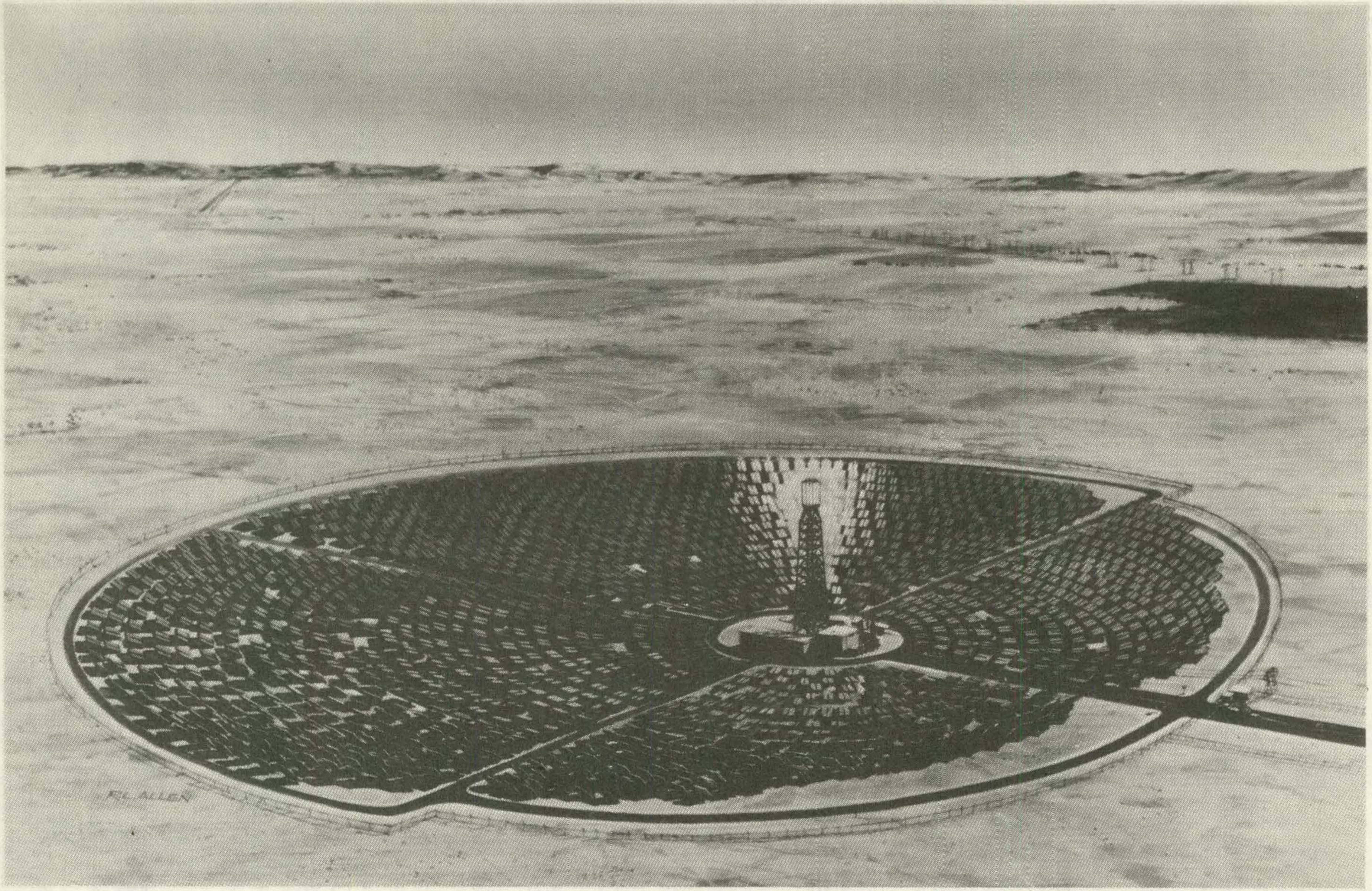


Figure 3-1. SOLAR PLANT

Table 3-1. SOLAR THERMAL COST DATA

Item	Symbol	Units	Old Goal	Obtainable
Insolation	I_s	Btu/ft^2/yr	800,000	800,000
Annual Collection Efficiency	h	%	51-60	51-60
Heliostat Costs[a]	HC		(\$65/m^2, 1975 \$)[b]	(\$72/m^2, 1978 \$)[c]
1975 \$		\$/ft^2	6.04	4.8
1978 \$		\$/ft^2	8.3	6.9
Balance of Plant (Directs, excluding storage)	BOP	% of Total (% of Heliostat)	20 to 35[d] (25 to 54)	33[c] (50)
Nondirects[e]	ND	% of Directs	44	44
Operation and Maintenance	O&M	% per year of Direct Costs	1 to 3	1 to 3
Fixed Charge Rate (30-year Payback Investor Owned)	FCR	\$/\$-year	0.15 to 0.18	0.15 to 0.18
Unit Availability[f] (Annual)	AF	%	90	90

---

[a] At 10% inflation, 1975 to 1976; 12% inflation, 1976 to 1977; and 12% inflation, 1977 to 1978.

[b] Braun, February 1977 [3].

[c] Eicker, April 1979, presentation at "Focus on Goals."

[d] Martin/Rockwell data for molten salt & liquid metal receivers, September 1978.

[e] Includes contingencies and spares, indirect costs, and interest during construction; data from Westinghouse EPRI 648 Study.

[f] Due to scheduled and unscheduled outages for maintenance.

costs are real costs to the user that must be paid to build the plant. Nondirect costs include contingencies and spares, indirect costs, and interest during construction. Contingencies and spares are costs that are due to unexpected events (bad weather, poor soil strength, equipment breakages during shipment, strikes, etc.) and the initial supply of spare parts. Indirect costs are associated with the purchase of the plant (internal manpower to select the contractor, monitor the construction, environmental impact statements and legal questions, etc.). The interest during construction includes the accumulated interest payments for all expenses during the construction period. Fifteen percent of the sum of heliostat and balance of plant costs was employed for contingencies and spares, and 10% of the sum was employed for indirects. Interest during construction was assigned at 15% of the sum of the direct costs plus contingencies and spares plus indirect costs.

The fixed charge rates assigned were for a 30-year payback period and assumed utility-type financing (i.e., cost of money). Industrial financing might require shorter payback and higher return on investment and has a high fixed charge rate. This fixed charge rate estimate was taken from the Electric Power Research Institute Technical Assessment Guide (1978) [4], and is typical of investor-owned utilities. The unit availability is that fraction of the year that the equipment is able to operate due to scheduled and unscheduled maintenance; the availability factor assumes scheduled maintenance is conducted during winter and night when possible.

Table 3-2 presents the cost of delivered thermal energy. The first item is the cost associated with the heliostats. The cost includes the heliostats, nondirects, collection efficiencies, annual availability, and the cost of money. The second item is the cost of all capital equipment, including the balance of plant equipment. The total cost is the cost of all equipment and operations and maintenance. Total cost (Unit Energy Cost, UEC) is calculated as

$$\text{UEC} = \frac{\text{Levelized Annualized Costs}}{\text{Average Annual Energy Delivery}}$$

$$\text{UEC} = \frac{(\text{HC})(1 + \text{BOP})[(1 + \text{ND})(\text{FCR}) + (\text{O\&M})(\text{LF})]}{(I_s)(\eta)(\text{AF})} ,$$

where LF is the levelizing factor for O&M. Operation and maintenance were assumed to increase with inflation and those costs were levelized by the procedure described in the EPRI Technical Assessment Guide [4]. A value of 2.0 was assigned to LF based upon the EPRI data. The data in Table 3-2 were evaluated over the expected range of parameters. The lowest and highest cost extremes are presented. The data were converted to 1976 dollars. For the old goals, the range is \$4.54 to \$8.89/MBtu (1976 \$). The latest obtainable cost estimate is \$4.37 to \$6.95/MBtu (1976 \$). Costs in both cases are on the order of \$5/MBtu (1976 \$). Recognizing the early stage of development, costs for solar thermal heat of \$3, \$5, and \$10/MBtu (1976 \$) were employed in the analysis of synthetic fuel costs.

Table 3-2. COST OF SOLAR THERMAL HEAT

$/MBtu (30-Year Payback)

Cost Base	Old Goal (1975 $)	Obtainable (1978 $)
Heliostats Only	3.02 to 4.26	3.35 to 4.73
Capital Only	3.78 to 6.56	5.03 to 7.09
Total Cost (including O&M)	4.13 to 8.09[a]	5.48 to 8.72[b] (7 to 8)[c]

[a] At 10% inflation, $4.54 to $8.89/MBtu at old goals in 1976 $.

[b] At 12%/year inflation, $4.37 to $6.95/MBtu in 1976 $.

[c] "SLL Assumptions for Process Steam Supply;" from Eicker, April 1979, presentation at "Focus on Goals."

3.2 PROJECTED COSTS FOR COAL

The future costs of coal are highly uncertain. Various assumptions for escalation rates and inflation rates have been made that have significant effects upon the levelized cost of coal. Table 3-3 (on the following page) presents projected fuel costs for coal from Battelle [5]. Figure 3-2 presents coal costs by region from ITC [6]. In the year 2000, the price may be from as low as $0.58/MBtu to as high as $2.50/MBtu (1976 $). Moreover, the cost of coal will continue to rise beyond the year 2000, also at uncertain rates.

Table 3-4 presents the effect of coal price increases over the life of a plant. The costs of coal in the first year of operation of a plant are presented for 1985, 1990, and 2000. The levelized coal cost for plants beginning operation in those years is included. Three projected coal cost scenarios are defined as follows:

Scenario A: uses the lowest projected cost of coal from ITC region VI;

Scenario B: uses an average cost of coal for mountain utilities from the Battelle data;

Scenario C: uses the highest projected cost of coal for U.S. utilities from the Battelle data.

Synthetic fuel plants will probably be located near sources of low cost coal. Scenarios A and B represent the expected range. Levelized costs are in the range of $1.26 to $5.90/MBtu in the year 2000.

Table 3-4. LEVELIZED COST ESTIMATES FOR COAL[5][a]

		Year			
		1985	1990	2000	Scenarios
Cost of coal in the first year of operation in constant 1976 dollars per MBtu		0.29	0.36	0.58	A
		1.00	1.15	1.50	B
		1.75	1.15	2.50	C
Levelized cost[b] of coal in 1976 dollars per MBtu for 30-year plant life	c	0.63	0.79	1.26	A
	d	1.14	1.41	2.28	
	c	2.17	2.50	3.26	B
	d	3.94	4.53	5.90	
	c	3.80	4.35	5.43	C
	d	6.89	7.88	9.84	

[a] Methodology provided by Dean Nordman of SERI.

[b] 6%/yr general inflation and 12% interest.

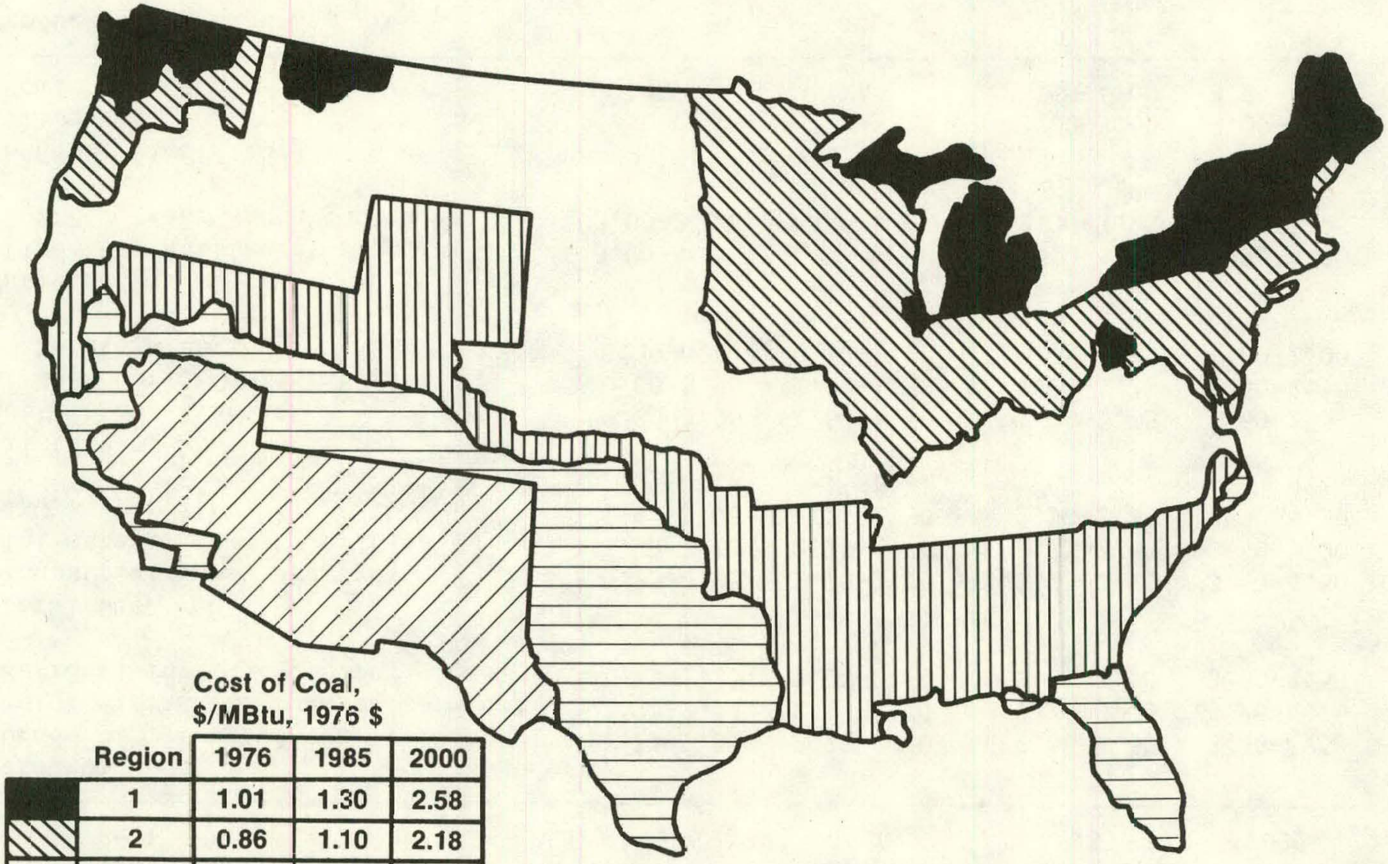
[c] 1.8%/yr escalation plus 6% inflation; total 7.8%/yr price increase.

[d] 6.4% escalation plus 6% inflation; total 12.4%/yr price increase.

Table 3-3. ESTIMATED PRICE RANGES FOR SELECTED FUELS, 1974-2000 [5]

	Price Ranges (Constant 1976 Dollars per Million Btu)			
Fuel	1976	1980	1985	2000
Petroleum				
Crude oil, composite at refinery	1.70-1.80	2.25-2.50	2.50-3.50	3.50-4.50
No. 2 distillate fuel at terminal	2.00-2.30	2.45-2.75	2.70-3.75	3.70-4.75
Residual fuel, low sulfur	1.70-2.20	2.25-2.60	2.50-3.50	3.50-4.50
Natural Gas				
Industrial uses, average	0.85-0.95	1.70-2.25	2.75-3.25	3.50-4.50
Intrastate, new at wellhead	1.90-2.10	2.25-2.75	2.75-3.50	3.50-5.00
LNG at pipeline	1.90-2.00	2.25-2.50	2.50-3.25	3.50-4.50
Coal (Steam)				
Utilities, average	0.80-0.90	1.00-1.50	1.25-1.75	1.50-2.50
East North Central Region	0.80-0.90	1.00-1.50	1.25-1.75	1.50-2.50
Mountain Region	0.30-0.40	0.50-1.00	0.75-1.25	1.00-2.00
Synthetic Gas				
Pipeline, quality at pipeline	3.00-4.00[a]	3.50-4.50[a]	3.50-5.00	3.25-4.50
Low Btu, East North Central	3.00-3.50	3.00-3.25	3.00-3.25	3.00-4.25
Synthetic Liquid Fuel				
Oil shale	NA	NA	3.00-3.50	3.00-4.50
Coal	NA	NA	3.50-4.00	3.25-4.50

[a] Produced from naphtha



Cost of Coal,
$/MBtu, 1976 $

	Region	1976	1985	2000
■	1	1.01	1.30	2.58
▧	2	0.86	1.10	2.18
	3	0.82	1.05	2.08
▥	4	0.83	1.06	2.10
▤	5	0.70	0.90	1.79
▨	6	0.23	0.29	0.58
	Natl Avg	0.84	1.08	2.14

From: InterTechnology Corp., 1977 (6).

Figure 3-2. FUEL COSTS OF COAL AS FUNCTION OF SOLAR REGION AND TIME

3.3 PROJECTED COSTS FOR BIOMASS

Figure 3-3 presents projected costs for two types of biomass: residues and fresh biomass from energy plantations. Something less than five quads of biomass are available as residues (municipal solid wastes, forest and agricultural residues, wastes from lumber mills and paper mills, etc.). The cost rises slowly to about \$2.50/MBtu, at which point the price rises rapidly due to the limited resources. Another 5-10 quads (total of 10-15 quads) could be obtained from energy plantations at a cost of about \$1 to \$2/MBtu (1976 \$). However, when the biomass is dried, the approximate cost will be \$1.25 to \$2.50/MBtu (1976 \$).

The biomass resource in the west is very limited. Irrigation is commonly used in the area to produce significant food crops. The residues (wheat straw, etc.) may be a significant resource, but the quantity of the available biomass has not been addressed in this study.

Inflation will increase the levelized cost of biomass. Assuming 0% escalation, 6% inflation, and 12% interest, the levelized cost of biomass increases by a factor of 1.77. Thus \$2.50/MBtu biomass will have a levelized cost of \$4.42/MBtu (1976 \$). The expected levelized cost range is from \$2 to \$4.50/MBtu (1976 \$), and is relatively insensitive to time frame.

3.4 PROJECTED COSTS FOR HYBRID FUELS

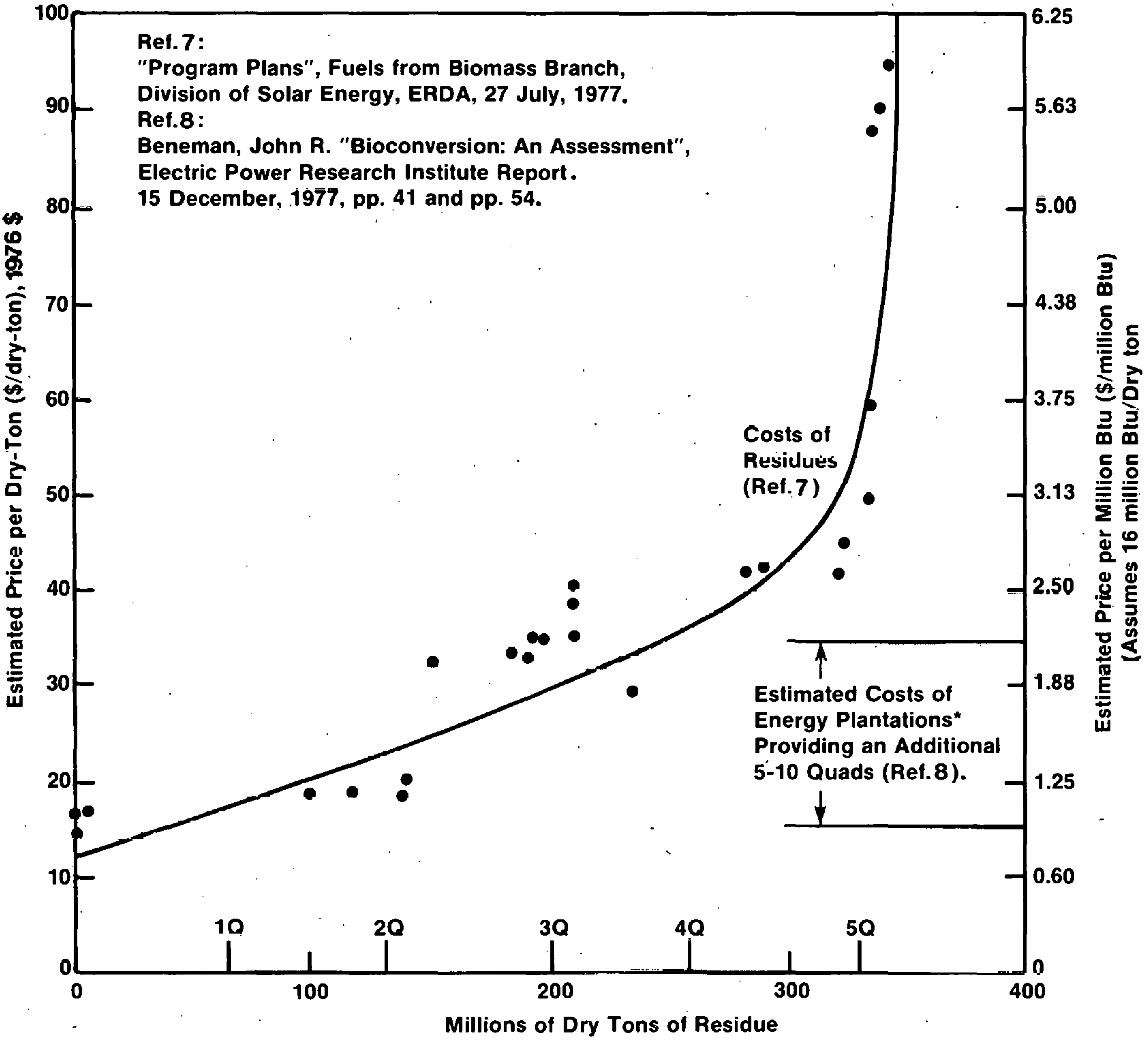
The cost of a synthetic fuel is the sum of the capital, fuel, and thermal energy costs of the plant. These costs were calculated by the following equation:

$$\begin{array}{c}\text{Synthetic}\\ \text{Fuel Cost}\\ (\$/\text{MBtu})\end{array} = \begin{array}{c}\text{Capital}\\ \text{Levelized}\\ \text{Cost}\end{array} + \left[\frac{1}{\varepsilon} \cdot \begin{array}{c}\text{Fuel}\\ \text{Levelized}\\ \text{Cost}\end{array}\right] + \left[\frac{Q}{n} \cdot \begin{array}{c}\text{Thermal}\\ \text{Energy}\\ \text{Cost}\end{array}\right]$$

The estimated capital levelized cost was based on data for a coal plant [9]. The same equipment was assumed for coal, biomass, and hybrid combinations. The levelized fuel cost of the material entering the gasifier was evaluated parametrically and an efficiency factor (ε) was employed to account for losses in the processing. Thermal energy cost is the cost of solar thermal energy, coal, or biomass. Q is the input thermal energy and is the same for the hybrid and nonhybrid. The efficiency of combustion (n) was applied only to the thermal energy input. For solar thermal heat, n was assigned the value of 1.0 (100%).

3.4.1 Solar Thermal/Coal

Figure 3-4 presents approximate costs for synthetic fuel made in part or totally from coal. The costs of synthetic methane from both hybrid and conventional methods are presented as functions of the cost of coal. The dashed lines present three assumed costs for solar heat: \$3, \$5, and \$10/MBtu (1976 \$). The three solid lines present assumptions on the efficiency of coal



*For UNDRIED biomass; for dried biomass, the cost is probably greater than $2/MBtu.
**1 Q = 10^{15} Btu

Figure 3-3. TOTAL RESIDUE AVAILABLE AT VARIOUS PRICES

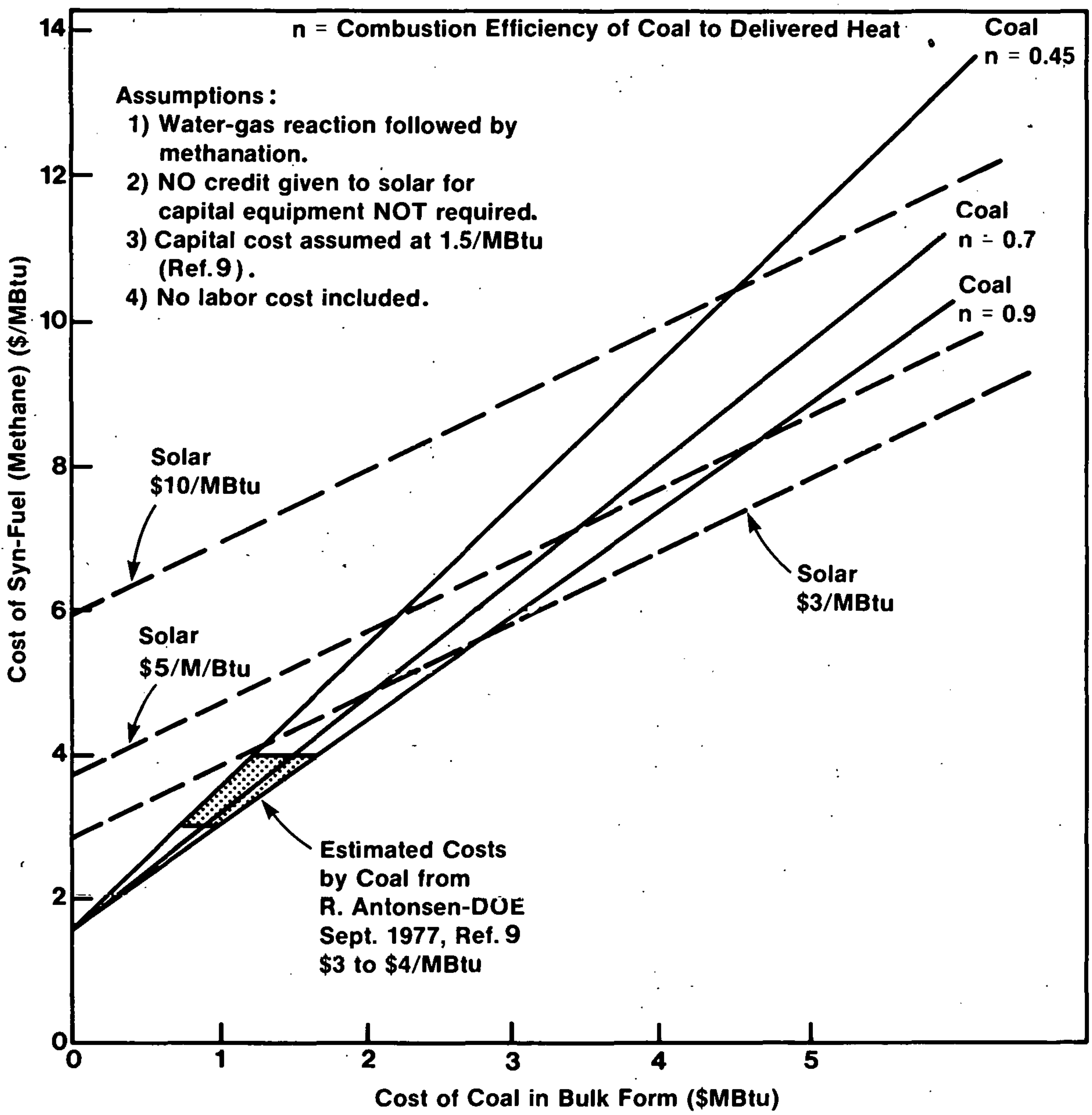


Figure 3-4. APPROXIMATE COSTS OF SYN-GAS FOR COAL OR A COMBINATION OF SOLAR AND COAL

combustion: 45%, 70%, and 90%. Solar thermal hybrid fuel becomes cost-competitive with coal at the intersection of a solid and dashed line as follows:

Solar Thermal Heat Cost	Coal Cost
$3/MBtu	$2.70/MBtu, n = 0.9
	$2.10/MBtu, n = 0.7
	$1.35/MBtu, n = 0.45
$5/MBtu	$4.50/MBtu, n = 0.9
	$3.50/MBtu, n = 0.7
	$2.25/MBtu, n = 0.45
$10/MBtu	$9.00/MBtu, n = 0.9
	$7.00/MBtu, n = 0.7
	$4.50/MBtu, n = 0.45

Generally, a high efficiency for coal combustion is expected for large scale operations. With $5/MBtu solar thermal heat, the levelized coal costs must be in the range of $3.50 to $4.50/MBtu for solar thermal technology to be competitive.

These coal costs are within the possible range of levelized costs for coal before the year 2000. Some of the cost projections for the western coal are lower than $2.50/MBtu. Thus, there are also conditions in which the use of solar thermal technology with coal may not be economic within the foreseeable future.

3.4.2 Solar Thermal/Biomass

Figure 3-5 presents approximate costs for synthetic fuel made from biomass. The costs of synthetic methane from both hybrid and conventional methods are presented as functions of the cost of biomass. The dashed lines present three assumed costs for solar heat: $3, $5, and $10/MBtu (1976 $). The three solid lines present assumptions on the efficiency of biomass combustion: 45%, 70%, and 90%. Solar thermal hybrid fuels become cost-competitive with biomass at the intersection of a solid and dashed line. Because of the simplifying assumptions in the analysis, the intersect points are the same as for coal.* Generally, a high efficiency for biomass combustion is expected. With $5/MBtu solar thermal heat, biomass costs must be in the range of $3.50 to $4.50/MBtu for solar thermal technology to be cost-competitive. The expected range is $2 to $4.50/MBtu (1976 $), and these are conditions under which a solar thermal hybrid approach may be cost competitive. There are also many conditions in which solar thermal is not competitive.

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*Because biomass requires less energy to gasify than coal, the cost for the synthetic methane is less when the cost of biomass and coal are equal.

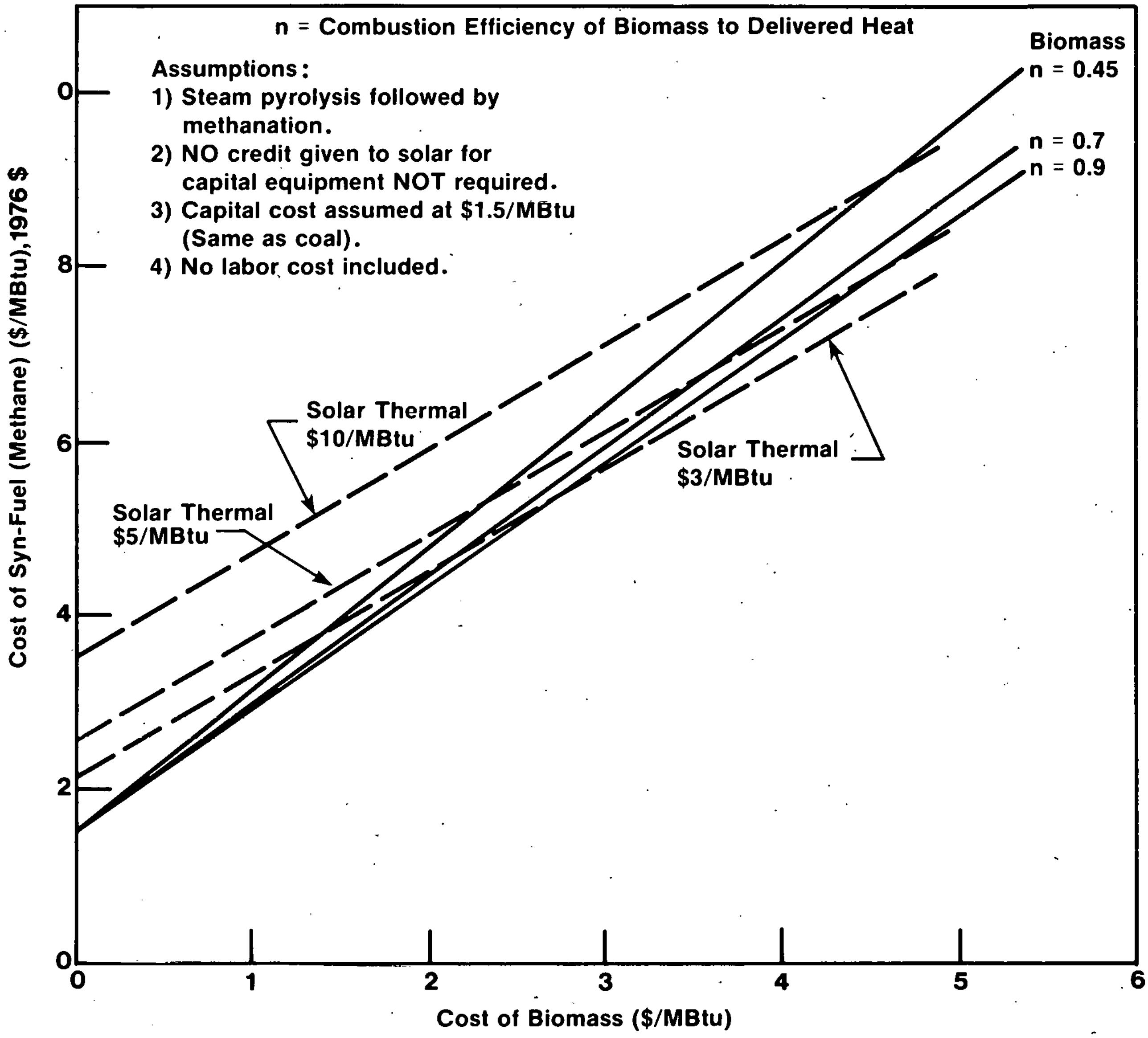

Figure 3-5. APPROXIMATE COSTS OF SYN-GAS FROM BIOMASS OR A COMBINATION OF SOLAR THERMAL AND BIOMASS

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SECTION 4.0

CLOSURE

The costs of a hybrid solar thermal generated synthetic fuel have been calculated parametrically. These rough data for synthetically produced methane have been calculated on a common basis for both conventionally fueled and hybrid solar thermal concepts. The range of uncertainty of future costs is very large, and thus firm conclusions cannot be drawn from these data. Some general observations are possible.

- The solar thermal resource is very large and has the potential to be a large source of energy for the nation.
- Solar thermal hybrid fuels can be cost competitive with the same fuel made by coal or biomass, if either
    - the future costs of coal and biomass are near the high end of the projections, or
    - the cost of solar thermal heat can be reduced below current estimates.
- Solar thermal heat has advantages over coal and biomass that are not directly associated with costs, including:
    - increased quantity of a synthetic fuel made from a limited resource;
    - reduced pollution from the gasification process (NO_x, SO_2, particulates, etc.); and
    - less waste disposal (ash, sulfur, etc.).

These advantages are common to all solar technologies. Although the value of these benefits is real to the general population, the decision maker for a commercial plant would not be expected to consider them. If a tax credit were given for using solar technology, the cost and value of these benefits would be transferred to the general population; but consideration of tax incentives was not part of this study.

This study has addressed only one approach to the production of synthetic fuels with solar thermal energy. Investigation of costs for other synthetic fuels (e.g., H_2, methanol, liquid hydrocarbons) and processes, and research in solar thermal generated fuels are recommended.

SECTION 5.0

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Document Control Page	1. SERI Report No. TR-35-078	2. NTIS Accession No.	3. Recipient's Accession No.

4. Title and Subtitle
Conversion System Overview Assessment
Volume I: Solar Thermoelectrics
Volume II: Solar-Wind Hybrid Systems
Volume III: Solar Thermal/Coal or Biomass Derived Fuels

5. Publication Date
August 1979

6.

7. Author(s) T. S. Jayadev, J. Henderson, J. Finegold, C. Bingham, R.S. Copeland, D. Benson

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Solar Energy Research Institute
1536 Cole Boulevard
Golden, Colorado 80401

10. Project/Task/Work Unit No.
Task # 3503

11. Contract (C) or Grant (G) No.
(C)
(G)

12. Sponsoring Organization Name and Address

13. Type of Report & Period Covered
Technical Report

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This report, in three Volumes, covers three distinct areas of solar energy research: solar thermoelectrics, solar-wind hybrid systems, and synthetic fuels derived with solar thermal energy. Volume I presents the assessment of thermoelectrics for solar energy conversion. There is significant potential for solar thermoelectrics in solar technologies where collector costs are low; e.g., Ocean Thermal Energy Conversion (OTEC) and solar ponds. Thermoelectrics also may have potential in other renewable energy source applications such as geothermal energy and waste heat utilization. Reports of two studies by manufacturers assessing the cost of thermoelectric generators in large scale production are included in the appendix and several new concepts of solar thermoelectric systems are presented. Volume II discusses solar-wind hybrid systems. There are large areas in the United States where solar and wind resources are comparable in magnitude, and there are diurnal and seasonal complementarities which offer the potential for cost-effective hybrid systems. Volume III deals with the conversion of synthetic fuels with solar thermal heat by a combination of solar energy with coal or biomass. A preliminary assessment calculating the cost of fuel produced as a function of the cost of coal and biomass shows that within the projected ranges of coal, biomass, and solar thermal costs, there are conditions when solar synthetic fuels will become cost-competitive.

17. Document Analysis

a. Descriptors Solar Energy ; Hybrid systems ; Wind Power ; Thermoelectric Conversion ; Ocean Thermal Energy Conversion ; Wind Energy Conversion Systems ; Thermoelectric Generators ; Solar Ponds ; Synthetic Fuels ; Refuse Derived Fuels ; Load Management ;

b. Identifiers/Open-Ended Terms Gasification

c. UC Categories
Volume I: 59b, 62, 62e, 64 Volume III: 62e
Volume II: 59b, 60, 62

18. Availability Statement
NTIS, US Dept. of Commerce
5285 Port Royal Rd.
Springfield, VA 22161

19. No. of Pages Vol. I-214
Vol. II-41 Vol. III-35

20. Price Vol. I-$9.25
Vol. II-$4.50 Vol. III-$4.50

Form No. 8200-13 (6-79)

☆ U.S. GOVERNMENT PRINTING OFFICE: 1980—677-175/17

✿ GPO: 1980-677-175-12