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ROUGH COST ESTIMATES OF SOLAR THERMAL/COAL OR BIOMASS-DERIVED FUELS

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ABSTRACT

The production of a synthetic fuel from a solar thermal resource could provide a means of replacing critical liquid and gaseous fossil fuels. The solar thermal resource is large and economics favors a southwestern site. A synthetic fuel would provide a desirable product and a means of transporting solar thermal energy to large load centers outside the southwest. This paper presents cost data for one method of producing synthetic methane. A hybrid approach was chosen, a combination of solar thermal and either coal or biomass. The magnitude of the solar thermal resource is estimated as well as projected cost. Cost projections for coal and biomass are accumulated. The cost of synthetic gas from a hybrid and a conventional fuel source are compared.

INTRODUCTION

The development of alternative energy sources is needed to provide the United States with a stable supply of energy. The Department of Energy is vigorously developing new technologies in fossil, nuclear, geothermal, and solar energy. These new technologies are needed relatively soon and must be economic when compared to alternatives. Synthetic fuels are one attractive method of supplying new energy sources to users. Synthetic fuels are, in general, functionally the same as petroleum or natural gas. The new fuels can be used in currently installed equipment and have the potential of being low cost.

Synthetic fuels can be produced from coal, shale oil, nuclear energy, biomass, and solar energy. The technologies which are developed will be those which have a significant resource and which are economically attractive. The solar energy resource is known to be large but the cost of synthetic fuels from solar energy is not well known.

One potential method of producing synthetic fuels is with solar thermal energy. The resource is large and economics favor deployment in southwestern sites. The production of a synthetic fuel could provide both a desirable product and the means of transporting solar thermal energy to large load centers outside the southwest.

This paper presents the results of a study evaluating the costs of a synthetic fuel produced with solar-thermal heat. The objective is to calculate approximate costs and to assess the economical potential of this technology. One method of providing fuels is selected to obtain a first order of magnitude estimate of costs. The technology selected is a hybrid: a solar-thermal heat source combined with either coal or biomass. This approach allows a direct comparison with conventionally produced synthetic fuel on a common basis. A single conversion process is selected to generate rough cost data. Other hybrids and nonhybrids could be considered but are beyond the scope of this initial study.

The cost data are given for synthetic methane. One thousand (1,000) Btu/ft^3 gas is readily transportable over long distances in existing pipelines. A single gasification process is assumed. The same process is employed to determine energy requirements for both a hybrid system or one using only coal (or biomass). Based upon these energy requirements, the costs of solar thermal energy, coal and biomass, and capital costs for methanation equipment, rough costs of synthetic methane are calculated.

The following sections present data on the magnitude of the solar thermal resource, and projected costs for solar thermal heat, coal, and biomass. The gasification process is described. Finally cost data for both hybrid solar thermal and conventionally generated synthetic methane are presented.

THE SOLAR RESOURCE

Figure 1 presents direct normal insolation data for the United States. The southwestern states have the best insolation. The area of interest is the marked area of Figure 1 and occupies about 650,000 km^2 (250,000 mi^2). However, due to a number of restrictions (earthquake, mountains, national parks, cities, military reservations, inadequate soil strength, etc.), the area available for synthetic fuel production is about 13,500 km^2 to 100,000 km^2 (5,200 mi^2 to 39,000 mi^2).* The insolation in this area is greater than 6.9 kWh/m^2-day (800,000 Btu/ft^2-year). At a 50% collection efficiency and 20% land utili-

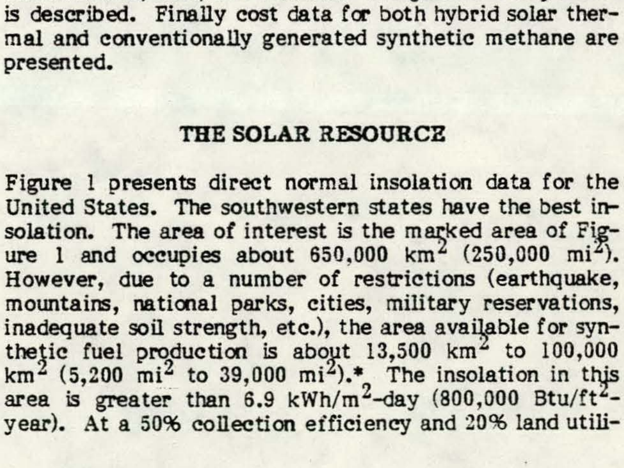


Figure 1. Average Annual Direct Normal Insolation (1000 Btu/ft^2) (9)

*Based upon data from Aerospace Corporation [1].

zation, 3.4×10^{12} kWh to 2.5×10^{13} kWh (12 to 86 quads) of solar thermal energy could be supplied from this area. 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 3.0 to 4.3 kWh/m^2-day (350,000 to 500,000 Btu/ft^2-year). For the area of interest, the direct insolation is 6.9 to 7.3 kWh/m^2-day (800,000 to 850,000 Btu/ft^2-year). 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 with synthetic fuels are the ease of storage, ease of use, 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 paper discusses the costs of one method of generating synthetic fuels, and a comparison is made between solar thermal and coal (or biomass) fueled systems.

SYNTHETIC FUEL PRODUCTION PROCESS

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 (1)
- CO_2 + STE ⟶ CO (2)
- $H_2O + CO_2$ + STE ⟶ Liquid Hydrocarbons (3)
- $H_2O + CO_2$ + STE ⟶ CH_4 (4)

Hybrids

- Hydrocarbons + Water + STE ⟶ H_2* (5)
- Coal + Water + STE ⟶ H_2* (6)
- Coal + Water + STE ⟶ Liquid Hydrocarbons (7)
- Coal + Water + STE ⟶ CH_4 (8)
- Biomass + Water + STE ⟶ H_2* (9)
- Biomass + Water + STE ⟶ Liquid Hydrocarbons (10)
- Biomass + Water + STE ⟶ CH_4 (11)

*Or mixture of CO and H_2 called Producer Gas.

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 as hydrogen, carbon monoxide, and methane can be produced by current known 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:

(1) Methane (synthetic natural gas) is readily transportable over long distances and can be used in existing equipment and pipelines.

(2) The processes required to produce methane from coal and biomass are well known.

(3) The hybrid processes are expected to be economical at an earlier date than the synthetic fuels produced only with STE.

(4) A direct comparison of synthetic fuel costs from a solar thermal resource and a coal-only or biomass-only produced fuel is desired.

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

GASIFICATION PROCESS

The gasification system is illustrated in Figure 2. 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 stream 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.

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. The estimate included energy requirements for reacting water with

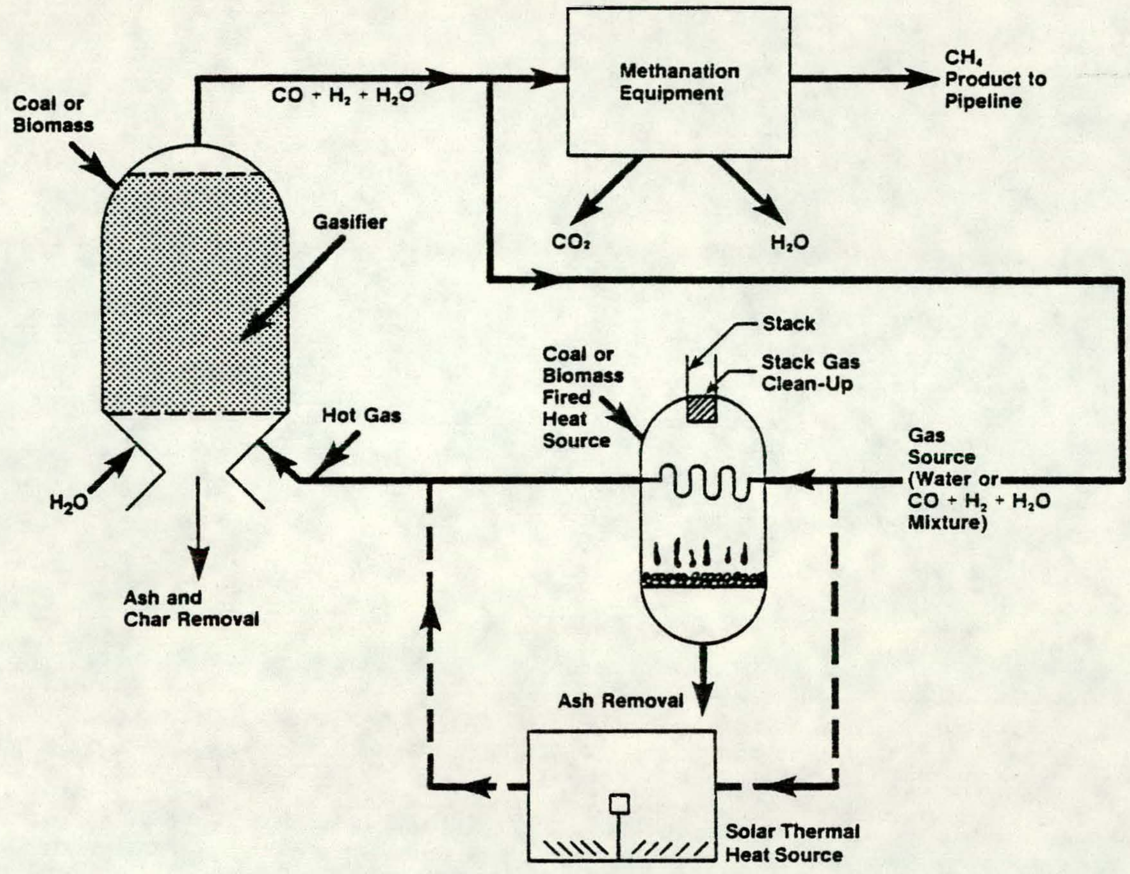


Figure 2. Assumed Gasification Process

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 lost to the environment were estimated. The same losses (ϵ) 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% ($\bar{n}$, delivered heat to fuel value). Since solar thermal processes will deliver this heat directly to the transport fluid, no efficiency* was applied.

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 for 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.

COST DATA

PROJECTED COSTS FOR SOLAR THERMAL HEAT

For this study, the solar thermal heat source is the Central Receiver System (CRS) illustrated in Figure 3. The heliostats are mirrors that reflect sunlight to the receiver, and 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.

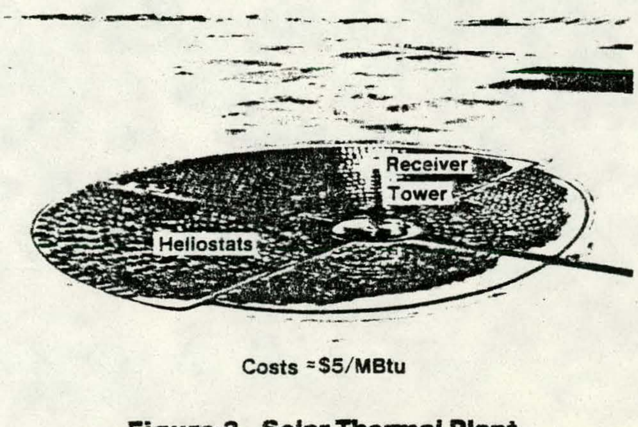


Figure 3. Solar Thermal Plant

The projected costs for solar-thermal heat are based upon the DOE goals. Braun [3] stated the heliostat goal as $65/m^2 in 1975 dollars in the post 1985 period. Including the balance of plant, costs* on the order of $5.00/MBtu are projected for a southwestern location. Recognizing the early stage of development, costs of solar-thermal heat over a range of $3/MBtu to $10/MBtu are investigated.

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 on the levilized cost of coal. Table 1 presents projected fuel costs for coal from two sources; in the year 2000 costs may be as low as $0.58/MBtu to as high as $2.50/MBtu (in 1976 dollars). Moreover, the cost of coal will continue to rise beyond 2000.

Table 1. Estimated Price Ranges for Coal

	Price Ranges (Constant 1976 Dollars per Million Btu)		
	year		
Region of USA	1976	1985	2000
Mountain Region [4]	0.30-0.40	0.75-1.25	1.00-2.00
Southwestern [5]	0.23	0.29	0.58

Table 2 presents the effect of coal price increases over the life of a plant. The costs of coal at the first year of operation of a plant are presented for 1985, 1990, and 2000. The levelized coal costs for plants beginning operation in those years are included. Two projected coal cost scenarios are defined as follows:

Scenario A: The low projected cost of coal from ITC [5] with low escalation.

Scenario B: An average cost of coal from the Battelle data [4] with high escalation.

The levelized cost of coal may be as low as $1.26/MBtu to a maximum of $5.90/MBtu. The expected levelized cost is from $(1.26 - 3.26)/MBtu for plant startup in 2000.

PROJECTED COSTS FOR BIOMASS

Figure 4 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 it rises rapidly due to the limited resource. Another 5-10 quads (total of 10-15 quads) could be obtained from energy plantations at a cost of about $(1 - 2)/MBtu. However, when dried, biomass will cost approximately $(1.2 - 2.5)/MBtu.

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.

*Assuming 30 year financing for the plant.

Table 2. Levelized Cost Estimates for Coal[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
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	A
	c 2.17	2.50	3.26	B
	d 3.94	4.53	5.90	B

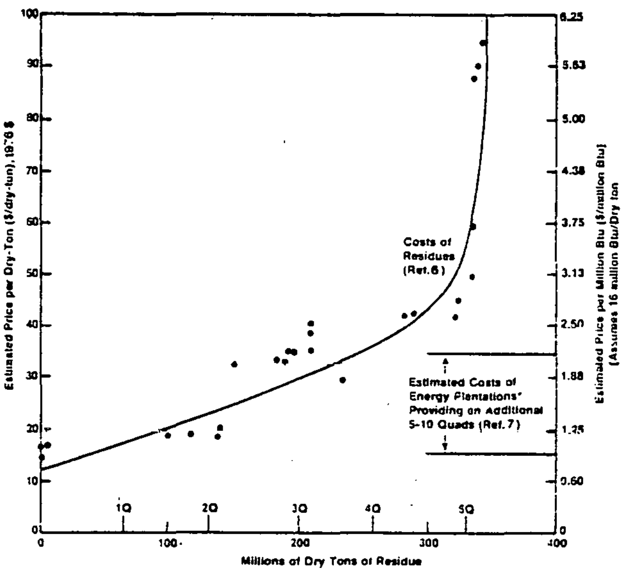
[a]Methodology provided by Dean Nordman of SERI
[b]6% year general inflation and 12% interest
[c]1.8% year escalation plus 6% inflation or total 7.8%/year increase
[d]6.4% escalation plus 6% inflation or total 12.4% year increase

Thus $2.50/MBtu biomass will have a levelized cost of $4.42/MBtu (1976 dollars). The expected levelized cost is from $(2 - 4)/MBtu for a plant startup in 2000.

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 thefollowing equation:

$$\text{Synthetic Fuel Cost (\$/MBtu)} = \text{Capital Levelized Cost} + \frac{1}{\epsilon} \cdot \text{Fuel Levelized Cost} + \frac{Q}{n} \cdot \text{Thermal Energy Cost}$$



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

Levelized Cost ≈ $(2-4)/MBtu

Figure 4. Costs of Biomass

The capital levelized cost was estimated based on data for a coal plant [8]. The same equipment is assumed for both coal and 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 either the cost of solar thermal energy or the 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%).

Solar Thermal/Coal

Figure 5 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 thermal heat: \$3, \$5, and \$10/MBtu (in 1976 dollars). The three solid lines present cost data for three assumptions on the efficiency of coal utilization: 45%, 70%, and 90%. Solar thermal hybrid fuel becomes cost-competitive with coal at the intersection of a solid and dashed line.

The coal costs at the break-even point are within the possible range of levelized costs for coal before the year 2000 but only with high escalation rates. Most of the cost projections for coal indicate that the coal-only route is least costly. Thus, there are conditions in which the use of hybrid solar-thermal/coal technology may not be economic within the foreseeable future.

Solar Thermal/Biomass

Figure 6 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 (in 1976 dollars). The three solid lines present cost data for three 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.

The levelized costs of biomass are expected to be approximately \$(2 - 4)/MBtu. At the higher price of biomass, a synthetic fuel can be produced by either biomass alone or by a hybrid employing solar thermal energy at approximately equal costs.

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 in 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 cost 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.).

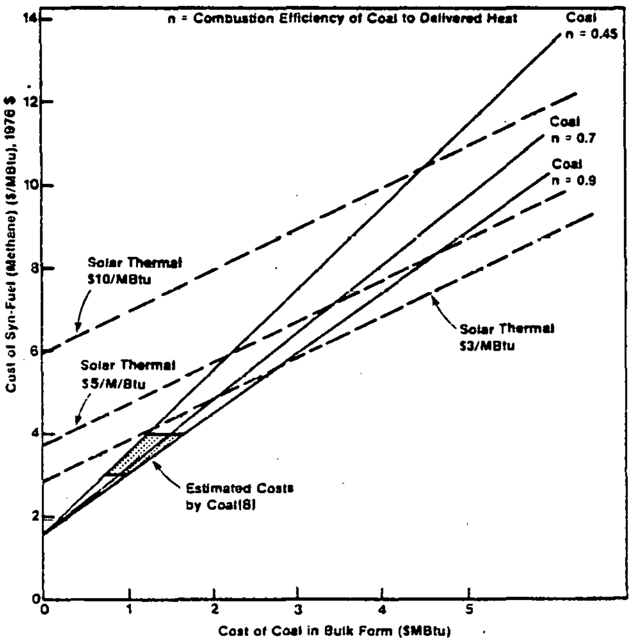


Figure 5. Approximate Costs of Syn-Gas (Methane) from Coal or a Combination of Solar Thermal and Coal

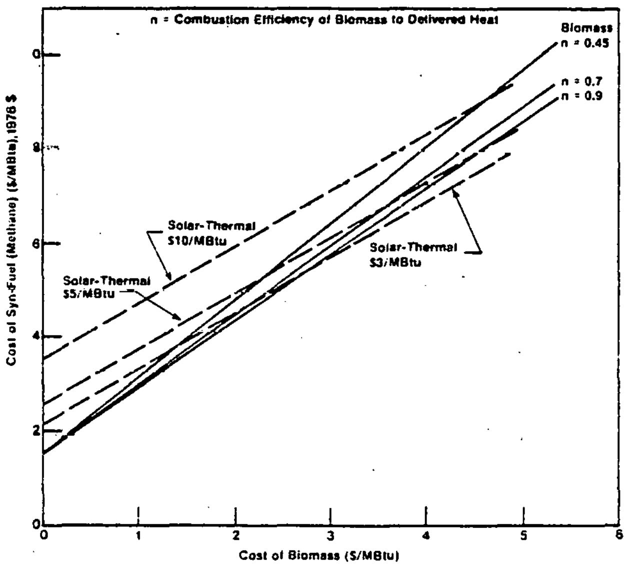


Figure 6. Approximate Costs of Syn-Gas (Methane) from Biomass or a Combination of Solar Thermal and Biomass

These advantages are common to all solar technologies. Although the value of these benefits is real to the general population, the decisionmaker 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 other processes and research in solar thermal generated fuels are recommended.

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