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A Study of the Economics of a Thermochemical Energy Pipeline

Conclusion: not much market.
Grid electric seems more attractive.

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A significant unsolved problem in solar energy applications is the cost-effective transport of high temperature energy over long distances. The transport is necessary because the area for the solar collector field is not always available next to the user or because of inadequate solar insolation in the vicinity of the user. There are several ways of transporting high temperature thermal energy for process heat use:

- sensible heat pipelines, using working fluids such as molten salt or hot oil,
- thermochemical energy pipelines, using reaction systems such as steam-methane, and
- electrical networks, i.e., production of electricity from solar energy, with electrical transmission followed by either resistance or inductive conversion to process heat.

This paper presents a discussion of the economics of a thermochemical pipeline. For comparison, a molten salt pipeline is also discussed. The electric transport option is not discussed in this paper.

As a frame of reference, it must be emphasized that this economic analysis represents an attempt to solve tomorrow's problems with today's technology. This must be kept in mind, especially in the interpretation of results. The emphasis should be on relative comparisons, not on the absolute values. This approach will result in definition of problem areas which represent research opportunities. Although absolute numbers are indicative, they are not necessarily accurate since they reflect both the state of the technology and the depth of engineering which went into the analysis. A preliminary economic analysis such as this should not be viewed as a basis for condemning a technology as having insurmountably high costs, mainly because the technology is at an immature stage of development.

Study Approach

Feasibility analysis includes both technical and economic aspects. Technical feasibility is an engineering judgment that a system can be designed, constructed, and operated with a high degree of confidence that actual performance will meet specifications. The data that go into this judgment include physical and chemical properties, heat and mass balances, reaction kinetics, equipment design, materials of construction, and control schemes. If any one of these areas appears to represent an insurmountable problem, then technical feasibility is questionable. Technical feasibility obviously can change with improvement of technical knowledge.

The calculated economics are based on the preliminary equipment specifications. The costs of equipment required to accomplish the job are estimated, and using standard engineering cost estimation techniques, the plant investment is estimated. The investment estimate and the estimate of operating and maintenance costs are input to an economic model in order to calculate an approximate cost of transporting the solar energy via an energy transport pipeline.

SERI used the above approach to assess the potential feasibility of a thermochemical energy pipeline conveying solar energy. SERI used both industrial and academic consultants to achieve a more realistic appraisal. Figure 1 shows the relationship between SERI and the consultant teams. SERI prepared the major inputs such as flowsheets, equipment specifications, etc. The industrial consultants were 3 senior engineers* with extensive experience in the engineering, construction, and operation of chemical plants. They reviewed SERI inputs and did the actual estimating. SERI reviewed the estimates and did the economic modeling. Independent of the industrial consultants, two well-known academic engineers** provided a critique of the entire feasibility study and prepared an independent estimate of investment based on the SERI inputs. The teams held review meetings. Although the estimating techniques used by the academic and industrial consultants differed somewhat, their estimates for the test case differed by less than 20% on investment and by less than 5% on annual operating costs.

As with all early evaluations, the cost estimates are no better than the depth of engineering on which they are based. The estimates described in this paper are rough--error bounds are unknown but are felt to be ±25% to 50%. Most likely, the estimates described in this paper are on the low side, since refined engineering usually results in higher estimates because additional

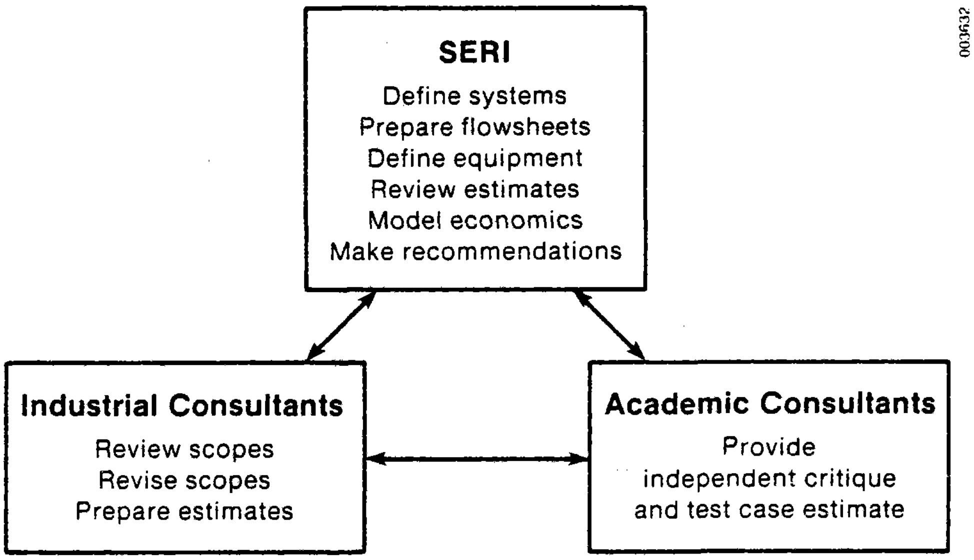

Figure 1. Feasibility Study Organization

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**K. D. Timmerhaus and R. E. West.

equipment and features are included. On the other hand, refined engineering might result in lower cost estimates if there are better ways to do certain steps. The spirit with which the estimates in this paper should be interpreted is that the numbers are indicative and relatively correct--not necessarily absolutely correct.

The System

The system to be investigated transports solar energy from a central receiver to a remote user. The system for thermochemical transport is shown in Fig. 2. For the thermochemical pipeline, we arbitrarily decided to decouple the endothermic reformer from the solar central receiver by using an intermediate working fluid (liquid sodium). To achieve a reasonable capacity factor (utilization) for the system, diurnal storage (~16 h) was assumed, with the sodium stored in tanks on both sides of the receiver. The sodium loop, including the diurnal storage is considered part of the central receiver system, not part of the transport system.

The system steam-reforms methane in the endothermic reformer:

$$\text{heat}_1 + H_2O + CH_4 \rightarrow 3H_2 + CO \, .$$[¶]

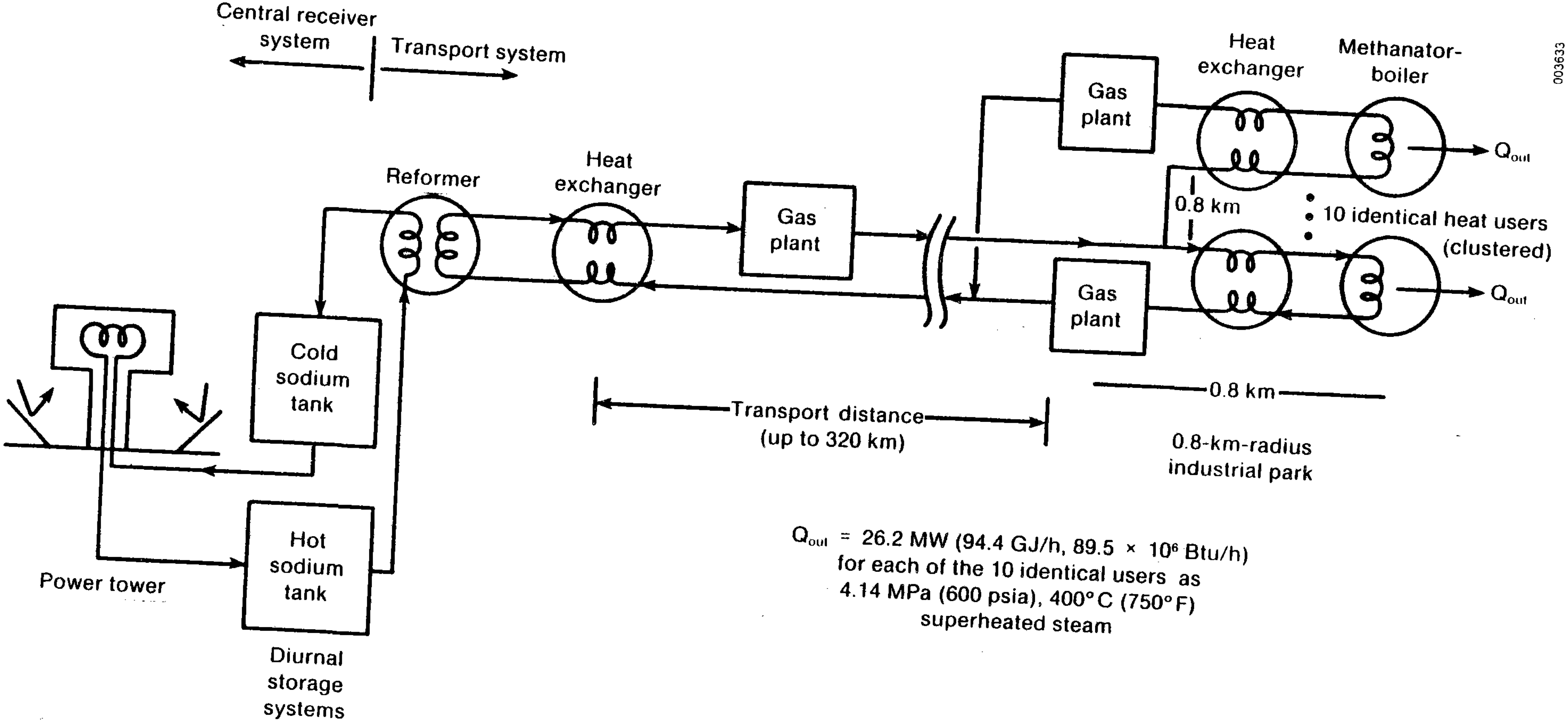
Of course, the chemistry is much more complicated than this. The resulting synthesis gas is cooled by regeneratively preheating the fresh reactor feed; it is then dehydrated and transported by pipeline. At the energy user end, the heat is recovered by methanating the synthesis gas:

$$3H_2 + CO \rightarrow CH_4 + H_2O + \text{heat}_2 \, .$$

The synthesis gas is preheated with the wet methanator product. The resulting methane is dried and returned by pipeline to the heat source. Thus, the gas is strictly an energy carrier and is not consumed to produce energy. Note that water tends to be transported from the reformer end to the methanator end of the pipeline. If the thermochemical energy pipeline is in an arid region, then a return pipeline for water may be required. Transportation system efficiency is defined as $\eta = \frac{\text{heat}_2}{\text{heat}_1 + \text{work}}$, where the term "work" represents the net work input to the entire transportation system.

For this study, the objective was to deliver 262 MW_t (944 GJ/h, 895 × 10^6 Btu/h) of 4.14 MPa (600 psia) steam superheated to 400°C (750°F) to an industrial park located some distance from the solar central receiver system. The steam is assumed to be used in equal amounts by each of 10 users, with each located an average of 0.8 km (0.5 mile) from the center of the industrial park. For the base case, the distance between the solar system and the industrial park was assumed to be 80 km (50 miles). Two methanation scenarios were examined:

[¶] This reaction and the following reaction for the methanation of synthesis gas are the same as that used in the Adam-Eva cycle for high-temperature, gas-cooled reactor applications.



Q_{out} = 26.2 MW (94.4 GJ/h, 89.5 × 10^6 Btu/h) for each of the 10 identical users as 4.14 MPa (600 psia), 400°C (750°F) superheated steam

Figure 2a. Thermochemical Heat Utility with Decentralized Boilers

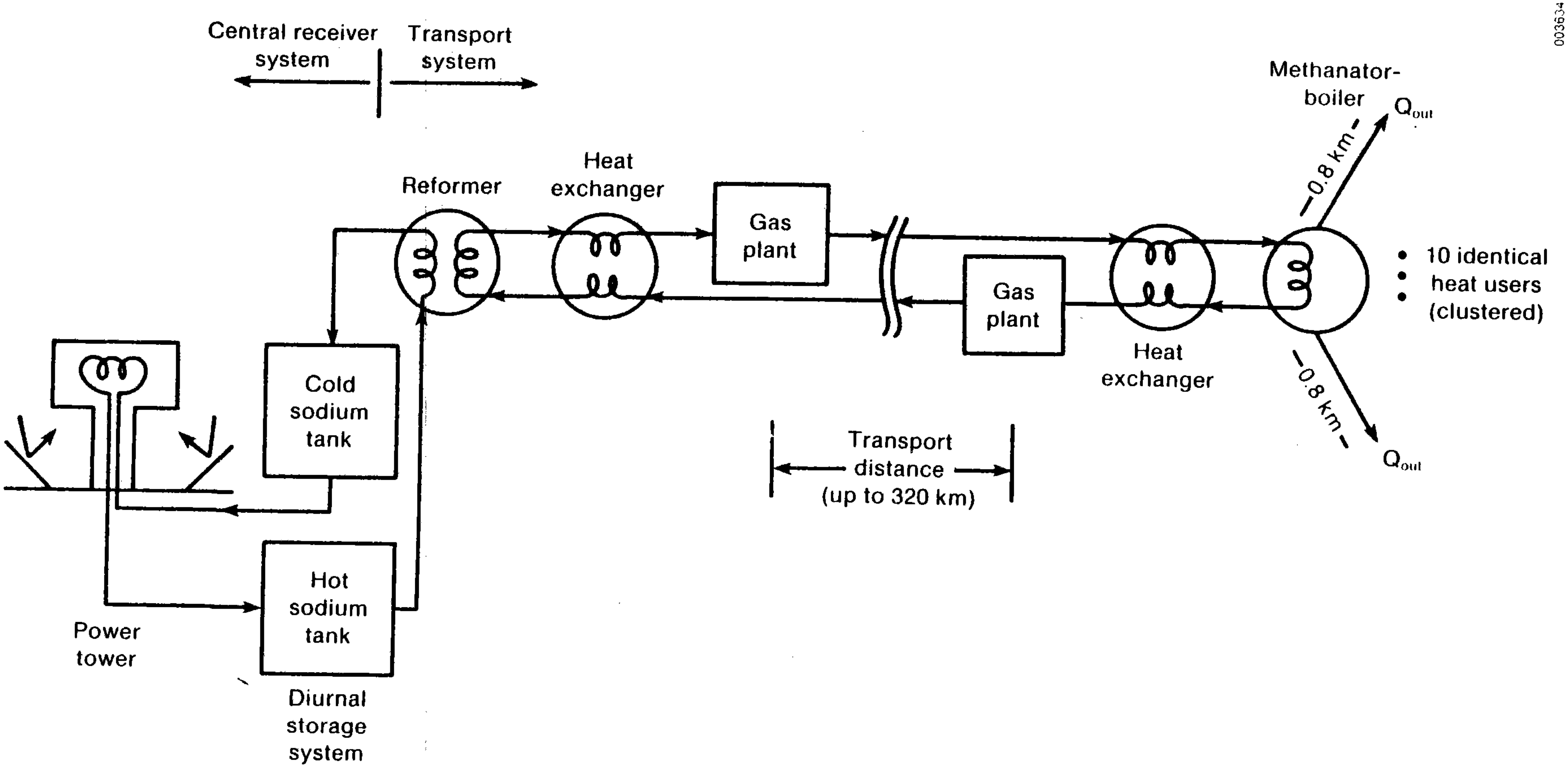


Figure 2b. Thermochemical Heat Utility with Centralized Boilers

1. A single methanation plant located in the center of the industrial park, with pipeline transport of steam to the individual users, and
2. 10 individual methanation plants, with each plant producing steam for an individual user. This case is emphasized in this paper; it results in slightly higher costs than the simple methanation plant.

In either case, the energy transport system is assumed to be owned by a heat utility which sells steam to the individual users. The cost of solar heat from the central receiver is considered a variable, with a reasonable goal established by Battleson (1) at around \$6.65/GJ (\$7/10^6Btu). The sodium loop, including diurnal storage, is assumed to be part of the central receiver system. The energy transportation utility is responsible for investment in the reforming system, the pipeline system, the methanation system, and any steam delivery system.

The analogous energy transport system using a molten salt pipeline and boiler was estimated. The receiver working fluid is molten draw salt (60% w/w $NaNO_3$, 40% KNO_3) and there is no transport system investment at the endothermic end, since the equipment is considered part of the central receiver. The heat utility owns the pipelines, the boiler, and any steam delivery system. Diurnal storage equipment for the molten salt is considered part of the central receiver system, not the transport system.

Figure 3 shows the flowsheet for the thermochemical system, with appropriate mass and energy balances. The calculated system efficiency, ignoring pipeline compressors, is 71.2%. The system is operated at 60 atm (6.0 MPa, 900 psi); if the pipeline is sufficiently short, no intermediate gas compressors are required.

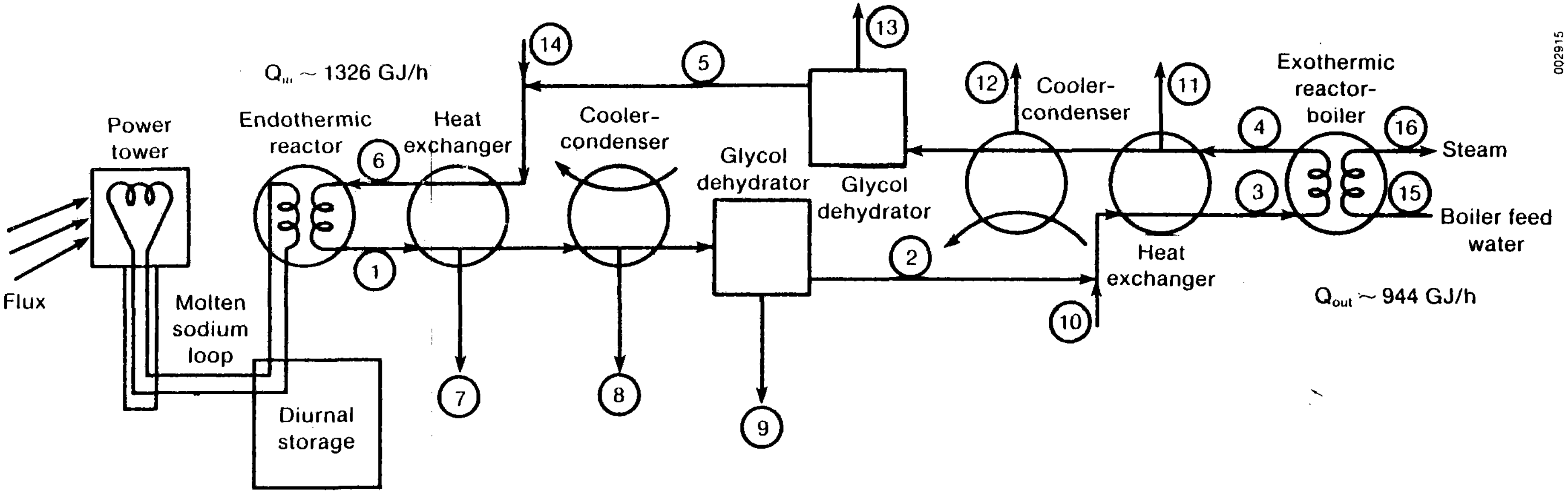
Estimates and the Economic Model

The costs of equipment were estimated by the industrial consultants. The results are included in Appendix A, where various similar pieces of equipment are grouped together. Estimates are in 1981 (Jan. 1) U.S. dollars. In Appendix B are details for an estimate of the annual operating and maintenance costs for the thermochemical system. Table 1 summarizes the cost estimates for both the thermochemical and molten salt energy transport systems.

The economic model is typical of a United States utility, as described in the "Technical Assessment Guide" of the Electric Power Research Institute (2):

$$RR = \frac{(PI \times LAFCR) + (O\&M) \times LF + solar/\eta}{8760 \times LACF \times heat},$$

where RR = levelized revenue requirement (\$/GJ)
PI = plant investment (\$)
O&M = annual operating and maintenance cost (\$)
LAFCR = levelized annual fixed charge rate
LF = levelizing factor
LACF = levelized annual capacity factor
8760 = number of hours/year
heat = total heat produced at capacity (GJ/h)
solar = levelized annual cost of solar energy input to reformer (\$)



Stream	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫
Temperature (°C)	827	25	407	427	25	671	65	38	25	25	125	38
Pressure (MPa)	6.08	6.08	6.08	6.08	6.08	6.08	6.08	6.08	6.08	6.08	6.08	6.08
Total flow (10^3 kg/h)	689.8	303.6	689.8	689.8	174.9	689.8	384.1	1.56	0.55	386.2	506.5	8.11
CO	71.5	71.5	71.5	0.085	0.085	0.085	—	—	—	—	—	—
H_2	37.4	37.4	37.4	3.67	3.67	3.67	—	—	—	—	—	—
CH_4	72.5	72.5	72.5	150.1	150.1	150.1	—	—	—	—	—	—
CO_2	122.2	122.2	122.2	21.1	21.1	21.1	—	—	—	—	—	—
H_2O (*v*)	386.2	—	386	514.9	—	514.9	—	—	—	—	—	—
H_2O (*l*)	—	—	—	—	—	—	384.1	1.56	0.55	386.2	506.5	8.11

Stream	⑬	⑭	⑮	⑯
Temperature (°C)	25	25	25	400
Pressure (MPa)	6.08	6.08	4.24	4.24
Total flow (10^3 kg/h)	0.23	514.9	670	670
H_2O (*v*)	—	—	—	670
H_2O (*l*)	0.23	514.9	670	—

Figure 3. Simplified Steam-Methane Energy Transport Flowsheet

η = efficiency of energy transport by thermochemical energy pipeline.

Table 1. Summary of Estimated Investments

Transport System	Efficiency η	Plant Investment (PI) (10^6\$)	Annual Operating and Maintenance Costs (O&M) (10^6\$)
		Decentralized Boilers	
Thermochemical energy pipeline	0.712	375	21.1
Sensible energy pipeline	0.834	574	17.2
		Centralized Boilers	
Thermochemical energy pipeline	0.712	302	18.6
Sensible energy pipeline	0.834	544	16.5

Basis: 944 GJ/h delivered over 80-km distance with final product as 4.14 MPa, 400°C superheated steam. For decentralized boilers and distances other than 80 km, use the following formulas:

Thermochemical energy: $\mathrm{PI} = [281.64 + 93.37\ (L/80)]10^6\$$

$\mathrm{O\&M} = [13.836 + 7.240\ (L/80)]10^6\$$

Sensible energy: $\mathrm{PI} = [43.33 + 531.3\ (L/80)]10^6\$$

$\mathrm{O\&M} = [2.02 + 15.186\ (L/80)]10^6\$$.

The levelized revenue requirement is the appropriate figure of merit for comparing various cases because it is the average cost of delivered energy that is charged to the customer over the lifetime of the plant. The assumed plant lifetime is 30 years (1990-2020). LACF is 0.65, which is typical for a system with diurnal storage. The assumed LACFR is 0.14, which is on the low side, even for a utility. The assumed LF is a typical 1.886. The discount rate is 10%, and the average inflation rate used is 6%. In general, these values are somewhat optimistic.

The effect of transportation length is taken into account by using the estimated plant investment for an 80-km transport system, modified according to

$$(\mathrm{PI})_{\text{transport system}} = (\mathrm{PI})_0 + (\mathrm{PI})_1(L/80) \ ,$$

where L is the length of the pipeline in km and $(PI)_0$ and $(PI)_1$ are constant factors derived from the investment estimate. Likewise, the effect of pipeline length on the annual operating and maintenance cost is taken into account by

$$(O\&M)_{\text{transport system}} = (O\&M)_0 + (O\&M)_1\ (L/80)\ .$$

Equations for calculating PI and O&M are given in Table 1..

Economic Feasibility

Figure 4 shows how the cost of solar energy at the power tower affects the cost of the energy delivered by pipeline to a user 80 km (50 miles) distant from the power tower. Curves are shown for the CH_4-H_2O thermochemical energy pipeline and the molten draw salt, sensible energy pipeline, and for a single centralized boiler and 10 decentralized boilers at the user end. The intercept at the vertical axis gives the pure transport cost, i.e., if the energy from the power tower were free. The transportation costs are about \$17.2/GJ (\$14.4/GJ, centralized boiler) for the thermochemical energy pipeline and about \$21.0/GJ (\$20.0/GJ, centralized boiler) for the sensible energy pipeline with 10 decentralized boilers at the user-end industrial park. These costs reflect the investment and operating costs of the transport systems. Of course, the energy from the power tower used as input to the energy transport pipeline is not free, so the actual delivered energy prices will be higher, as shown by the curves of Figure 4, dependent upon transport system efficiency.

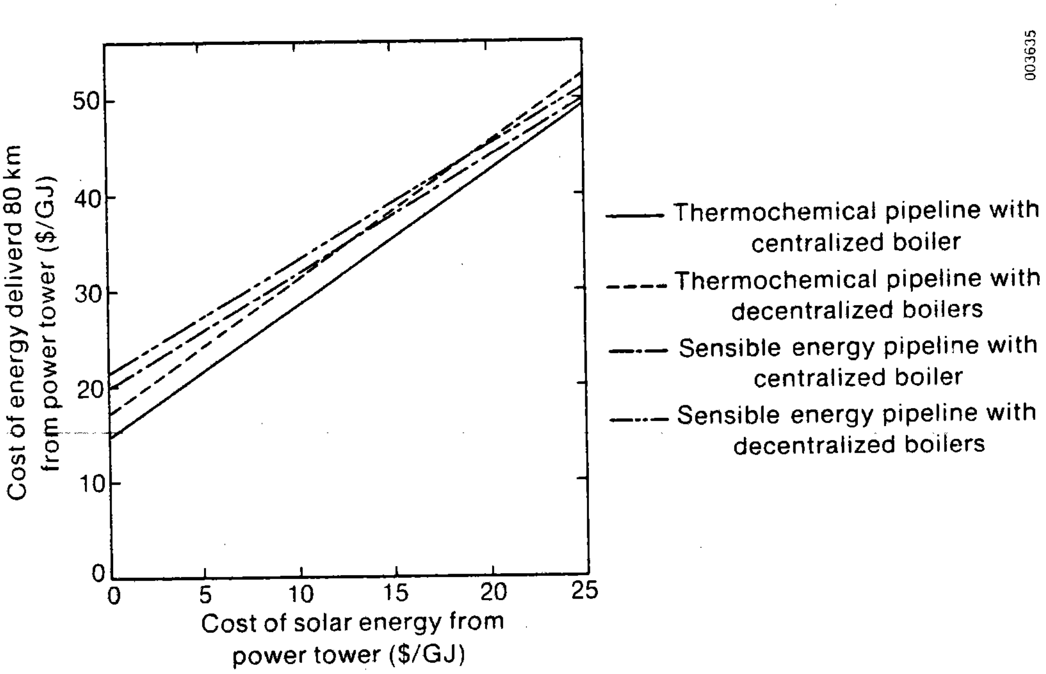


Figure 4. Delivered Energy Cost as a Function of Cost of Solar Energy from the Power Tower (80-km Transport Distance)

Bear in mind that these are levelized costs; i.e., to compare with today's costs, the levelized costs can be divided by a factor of about 2 (1.886, to be exact). Levelizing makes the costs seem high unless this is kept in mind.

These curves indicate that for a thermochemical energy pipeline, the centralized boiler at the user end with steam transport by pipeline to the individual users is advantageous over individual boilers, provided the users are clustered sufficiently close (i.e., radius < 0.8 km). The difference is not as large for the molten salt pipeline. The difference for the thermochemical pipeline is larger because the boilers are methanators, each with its own recuperative heat exchangers and pipeline gas conditioning plants. This equipment tends to be complex and expensive: economy of scale is lost when each user is provided with his own boiler. The balance of the discussion in this paper is in terms of decentralized boilers; note that costs could be reduced ~\$3/GJ and \$1/GJ, respectively, for thermochemical and sensible energy pipelines if centralized boilers were used. However, centralized boilers might result in loss of flexibility.

Figure 5 shows the effect of transport distance on the cost of delivered energy when the cost of energy input to the transport system from the power tower is \$6.65/GJ. The graph indicates that up to a certain distance, the molten salt, sensible energy transport pipeline is economically more attractive than the CH_4-H_2O thermochemical energy pipeline. If the estimates of plant investment, annual operating costs, and transport efficiency are correct, this distance is ~67 km. At greater distances, the thermochemical energy pipeline is more attractive economically. Another conclusion can be made from Figures 4 and 5: for a reasonable cost of solar energy from the power tower (e.g., \$6.65/GJ), the transport system will add costs such that the final delivered energy cost will be several times greater than the power tower energy costs. Under these conditions, if the cost of the solar energy at the power tower is marginally high, then the cost of the solar energy delivered as heat to a remote user will be prohibitively high. A successful solar energy system must minimize the costs associated with the central receiver system and especially with the long-distance energy transport system.

The accuracy of the estimates in this paper is uncertain, but error bounds are probably within the range of ±25 to 50%; they are probably lower than the actual construction and operating costs. For discussion purposes, let us assume error bounds of ±25%. Figure 6 shows the cost-effectiveness of thermochemical energy transport relative to molten salt sensible energy transport if the investment and operating cost estimates are increased or decreased by ±25% with input energy cost of \$6.65/GJ. The transport distance for relative cost-effectiveness then ranges from 35 km to 142 km. Below the break point, a molten salt, sensible energy pipeline is more economically attractive than a thermochemical energy pipeline. Beyond the break point, the CH_4-H_2O thermochemical pipeline is more economically attractive. However, the wide range indicates more refined estimates are needed. Most likely, the estimates are inaccurate in the same direction, so the 65-km break point indicated on Figure 5 is probably close to reality. The obvious conclusion is that sensible energy pipelines should be emphasized for short distances and the thermochemical pipeline should be emphasized for long distances.

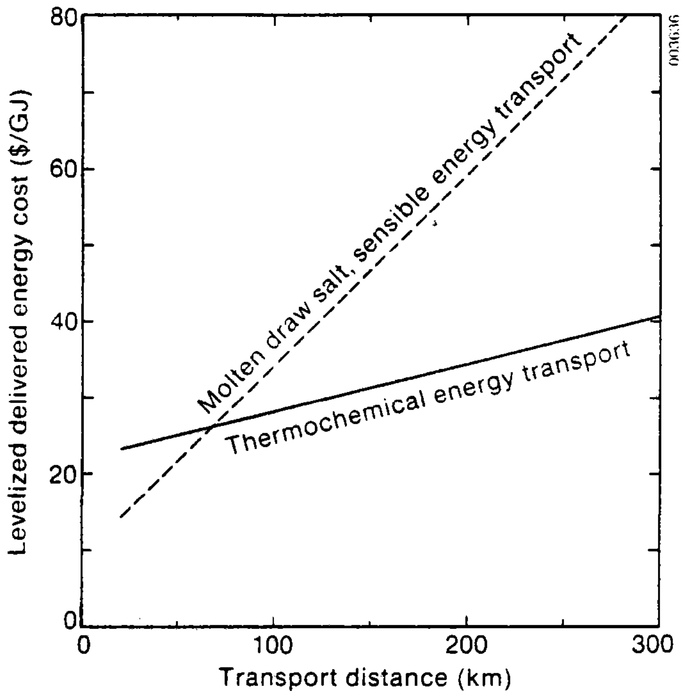


Figure 5. Delivered Energy Cost as a Function of Transport Distance ($6.65/GJ Energy at the Power Tower, Decentralized Boilers)

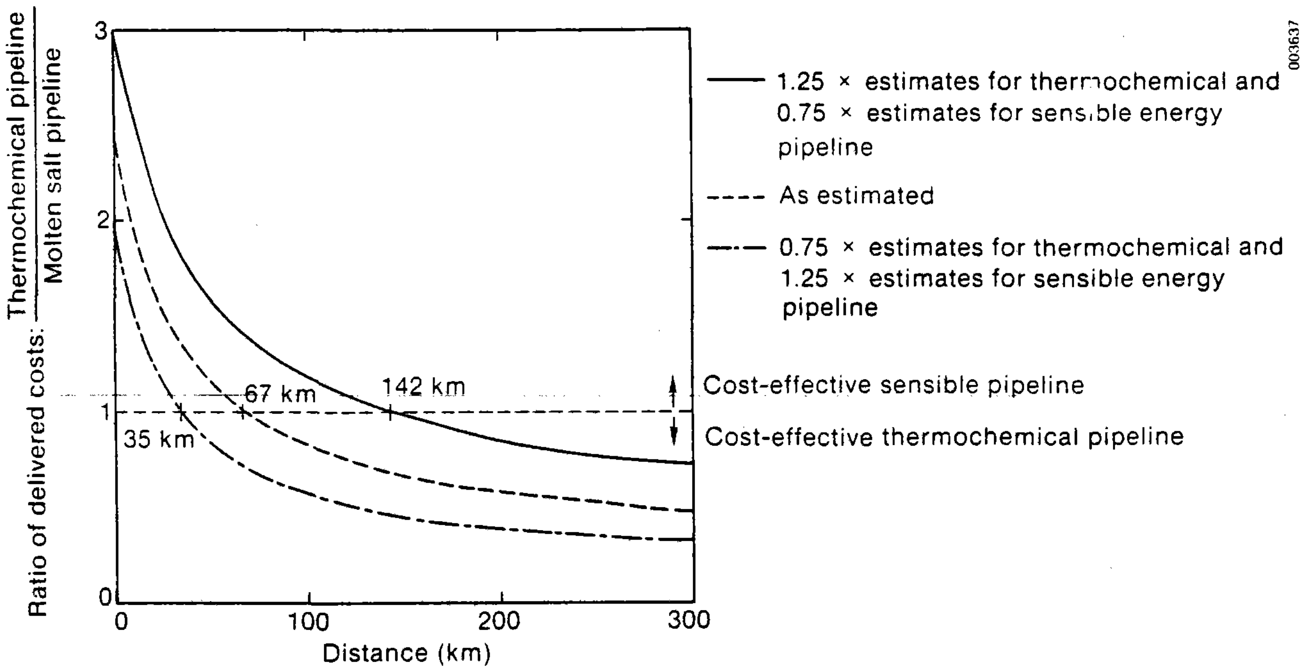


Figure 6. Sensitivity of Cost-Effectiveness to ±25% Investment Accuracy ($6.65/GJ Energy Input from Power Tower, Decentralized Boilers)

Technical Feasibility

The study attempted to stay close to known technology, as is reflected by the choice of a decoupled reactor heated by a working fluid, compared to a direct radiation, coupled reactor located at the top of the power tower, as described in Ref. 3. Some of the potential problems in the system as configured include corrosion of containment vessels by both the process fluids and the working fluid, potential catalyst performance and lifetime problems since the reactors will be cycled more often than they would be with a steady heat source, and potential process control problems. The system appears technically feasible as configured, with no evidently insurmountable problems. However, some development work is required, especially with catalysts. Factors that contribute to system technical feasibility are:

- The chemicals involved are relatively abundant, cheap, and acceptable from an environmental point of view.
- Reforming and methanation are currently practiced.
- Catalysts are typically Ni on Al_2O_3 and are inexpensive.
- The gas mixtures are suitable for pipeline transport with minimal change in current natural gas practices. H_2 embrittlement must be considered.
- Reactors are designed to operate fairly continuously by virtue of the working fluid storage. The operating temperature can be easily and cheaply maintained by appropriate fossil heat during nonoperative periods.

Factors inhibiting system feasibility are:

- Higher temperatures accelerate corrosion rates relative to those of current industrial practice.
- Reactor control will require development work.
- Excessive steam must be used to control carbon deposition, with resultant lower process efficiency.
- Plants are relatively large and complex.

Discussion

From the analyses, it appears that the CH_4-H_2O thermochemical energy pipeline could be built and operated successfully, with some minor development. However, it also appears that the costs of transporting the energy may be several times the cost of the energy at the base of the power tower. Thus, research must be aimed at significantly reducing costs, both initial and annual. The investment items can be grouped into items that can be affected by research breakthroughs and those that are relatively unaffected, e.g., the equipment or conditions dictated by safety or environmental issues. The items that can be significantly affected include the reformer and the methanator. The items potentially affected by research, especially materials research, include the reactors, shell-and-tube heat exchangers, pumps, process compressors, vessels, and tanks. Items which will be little affected by research include the pipelines and pipeline compressors, since standards are dictated by safety and reliability.

The potential effect of research can be visualized by assuming a parametric reduction in investment. If the initial investment in the thermochemical system were reduced by 50%, the delivered energy costs would decrease 18% from \$26.49/GJ to \$21.60/GJ (assuming \$6.65/GJ solar heat cost at the base of the tower and 80-km transport distance). Thus, it appears that in addition to reduced system investment, annual operating costs must also significantly decrease and system efficiency must increase. If operating expenses were reduced by 50%, initial investment were reduced by 50%, and efficiency were increased from 71.2% to 80%, then the delivered energy costs for the above conditions decrease from \$26.49/GJ to \$16.90/GJ delivered, a reduction of 36%.

Several questions relate to this study and are discussed below.

1. Will the solar energy system with a thermochemical energy pipeline and the above hypothesized cost reductions be competitive? In this study, we estimated the delivered energy costs from fossil-fuel-fired boilers as shown in Table 2. It appears that if the thermochemical transport system investments and annual costs were reduced by 50% and if transport efficiency were increased from 71.2% to 80%, then the solar system would be more cost-effective than either natural gas or residual oil-fired boilers; however, the solar system would still be more expensive than coal. Note that these observations are valid only when the above requirements are met. There appears to be reasonable incentive for additional research, with the 50% investment and operating cost reductions and ~10% transportation system efficiency increase as reasonable goals.

Table 2. Potential Impact of Research on Delivered Energy Costs

Delivered solar energy	\$16.9*-\$26.5**/GJ
Natural gas-fired boiler	\$17.9-\$26.2/GJ
Residual oil-fired boiler	\$17.4-\$43.2/GJ
Coal-fired boiler	\$10.8-\$14.2/GJ

Basis: Solar system with \$6.65/GJ energy at base of the power tower, with final delivery 80 km away. The single asterisk designates a solar system with estimated investment and annual operating expense reduced by 50% and transport efficiency increased to 80%, as a result of research breakthroughs. The double asterisk designates the solar system as estimated in this paper. Fossil-fuel-fired boilers are as described in Ref. 4 for production of 4.14 MPa, 400°C superheated steam. The price range for steam from fossil-fuel-fired boilers reflects the projected price range of the fuels in the United States, per Refs. 5 and 6.

2. What are the major research opportunities? They appear to be as follows:

   - Materials research to produce cheaper, but highly corrosion-resistant alloys.
   - Reformer research to produce direct flux coupled reformers for mounting on the tower with the goal of reducing size and cost.
   - Catalyst development to produce highly selective catalysts that are structurally stable and highly active under thermal cycling conditions. The selectivity should improve system efficiency about 10% by reducing the amount of water produced.
   - Process equipment research to minimize the cost and to maximize the efficiency of equipment such as methanators and heat exchangers.
   - A reexamination of pipeline standards, equipment, and techniques to reduce the cost of treating and transporting both methane and synthesis gases. Questions to be considered should include: Are there alternative pipeline materials that are cheaper than X-52? How much dehydration is necessary for a given climate? Are there acceptable ways to minimize pipeline installation costs?

3. What are the possibilities for achieving the projected cost reductions and performance increases? This question is hard, perhaps impossible, to answer at this time. The required cost reductions will be difficult to achieve, even with significant breakthroughs. If fossil fuels are scarce and at high prices, then there is good incentive for performing the research. Additional work and much more sophisticated analyses are required to answer this question; both research and economic analyses must be performed and coordinated to maximize return on the research investment. The experimental program must be structured with appropriate decision points in a rational long-range plan.

4. What about the molten salt, sensible energy pipeline? It should certainly be considered for short transport distances, e.g., less than 50 km. The estimates in this paper are based on a hot salt pipeline of Incoloy 800H and a cold salt pipeline of carbon steel. Research to identify a high temperature salt that is less corrosive than draw salt or to define an inexpensive alloy that is more corrosion resistant than Incoloy 800H would substantially enhance the economic attractiveness of a molten salt pipeline. No molten salt pipeline of any significant length (>1 km) appears to have been built. Rigid design and construction practices would be required to prevent freeze-ups, and special designs such as gut-line heaters or skin heaters would be required to alleviate freeze-ups. However, these technical problems are probably solvable.

Conclusion

The analysis indicates that a thermochemical energy pipeline is a reasonable approach to long-distance transport of solar energy. Preliminary economics indicate that significant research breakthroughs and cost reductions will be required for a thermochemical energy pipeline to be attractive relative to fossil fuel alternatives in the United States in the near term. However, this requirement may be different for other areas of the world. Major research opportunities include direct flux reactors, materials research, and catalyst development. The molten salt, sensible energy transport pipeline should also be considered for short-distance energy transport (≤50 km).

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Appendix B

Thermochemical Energy Pipeline - Estimates Annual Costs

Steam-methane system (60 atm), 944 GJ/h, 80-km transport
4.14 MPa, 400°C superheated steam product, decentralized boilers
(1 Jan. 1981 U.S. Dollars)

	Unit Cost	Reformer		Methanator		Pipeline Compressor		Pipelines	
		Units	$\$10^3$/yr	Units	$\$10^3$/yr	Units	$\$10^3$/yr	Units	$\$10^3$/yr
Natural gas (10^6 Btu/h)	\$5/10^6Btu	16.7	723	10	438	--	--	--	250
Power* (kW)	5¢/kW	711	307	330	9513	4167	--	--	--
Water [10^3 gal (U.S.)/day]	10¢/10^3gal	820	30	2490	91	--	--	--	--
Catalysts	--	--	538	207	--	--	--	--	--
Chemicals	--	--	18	4	--	--	--	--	--
Royalties	--	--	50	50	--	--	--	--	--
Operating labor	\$30,000/yr	26	780	10	300	3	90	--	--
Maintenance labor	\$26,00/yr	15	390	20	520	8	208	5	130
Clerical labor	\$24,000/yr	4	96	2	48	--	--	2	48
Technical labor	\$36,000/yr	5	180	2	72	1	36	1	36
Legal labor	\$60,000/yr	0.5	180	2	72	1	36	1	36
Management**									
Maintenance material#	% of investment	--	1473	1.5	2227	1.5%	236	0.5%	335
Taxes and insurance#	% of investment	--	1719	1.75	2597	1.75%	276	1.75%	1006
Miscellaneous#	% of investment	--	491	--	--	0.5%	335	--	--
Totals			6825		7011		5046		2194

Estimated Annual Operating and Maintenance Expense: \$21,000,000

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*1 BHP = 0.9 kW.

**10% of all other payroll.

#Investment subtotal B in Appendix A as basis.

Appendix A

Thermochemical Energy Pipeline: Estimated Investment

Steam-methane system (60 atm), 944 GJ/h, 80-km transport
4.14 MPa, 400°C superheated steam product, decentralized boilers
(1 Jan. 1981 U. S. dollars)

	Reformer (10^6\$)	Methanator (10^6\$)	Pipeline Compressor (10^6\$)	Pipeline (10^6\$)
Reactors	28.28	9.8	--	--
Shell-and-tube exchangers	35.75	35.76	--	--
Pumps and drives	--	22.71	--	--
Compressors	0.48	--	15.75	--
Vessels and tanks	9.16	16.44	--	--
Heaters	1.00	19.13	--	--
Boilers	1.77	--	--	--
Cooling tower	0.70	5.27	--	--
Package units	4.69	25.78	--	--
Subtotal A	81.83	134.89	15.75	--
Offsites	16.37	13.49	included	--
Subtotal B	98.20	148.38	15.75	67.07
Catalyst and chemicals	1.61	0.62	--	1.00
Spare parts	1.96	3.00	0.16	--
Start-up	0.49	0.75	0.08	--
Subtotal C	102.26	152.75	15.99	68.07
Land	0.10	0.48	0.20	included
Interest during construction	9.82	14.84	1.58	6.81
Working capital	0.69	0.70	0.50	0.22
Subtotal D	112.87	168.77	18.27	75.10

Total Investment (all facilites): $375,000,000