CHAPTER IV

NET ENERGETICS ANALYSIS

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I. INTRODUCTION TO NET ENERGETICS METHODS

Economic analysis, next to technical analysis, has traditionally constituted the major decision-making tool of the capitalist economic system. As long as capitalism survives, this will remain to be the case. However, during the current period of increasing scarcity and cost of energy--a period accompanied by higher than normal inflation rates--a proposed project may appear attractive and economic when, in fact, its demands on energy resources are extraordinarily high. Such a conclusion could well be the case when the major energy expenditure in construction or operation is directed toward a fuel, the price of which is held unusually low by legal regulation. Net energetics analysis, as applied to energy generation facilities, is a method for determining the total amount of energy, IE, required to construct, operate, and maintain the energy generation facility compared to the total energy, TE, generated (or converted) throughout the facility's lifetime. Fuel consumed by the facility as direct input to the conversion or utilization process is not considered a debit while energy generated is not considered a credit in the calculation of the construction, operation, and maintenance energy account, IE. Energy required to run equipment auxiliary to the conversion process is, on the other hand, considered a debit to IE. The latter considerations apply to the production, processing, and transport of fuel but not to the energy content of the fuel itself.

A useful format for presenting net energetics results is in terms of the ratio,

$$R = \frac{\text{total energy required to construct, operate, and maintain}}{\text{total energy generated or utilized}} = \frac{IE}{TE}$$

The numerator of the ratio, R, is determined by multiplying individual capital, installation, operation, and maintenance estimated or actual costs by the per dollar energy equivalent (or energy content), e, for the particular capital item or activity. The per dollar energy equivalents, or "energy factors", are expressed as energy units per money unit, typically British Thermal Units per dollar or kilowatt-hours per dollar.

Successful net energetics analysis, then, depends entirely on the accurate determination of the various money costs for a facility and of the energy factors. For the former, actual known or estimated equipment, construction, and maintenance costs are used. Occasionally, an operation cost--as in-plant service electricity for pumps, etc,--needs to be included. With respect to the latter, energy factors prove to be difficult to obtain and are usually calculated from input-output models for cash flow and energy flow in a national economy as that of the United States.

The input-output models will consist of (1) investment, operating costs, profits, and contributions to gross product by the various industries in various sectors of the economy, and (2) energy consumed and/or produced by the various industries in various sectors of the economy. Typically the model data is organized according to Standard Industrial Classifications (SIC) as established by the U. S. Department of Commerce. Recent fairly complete input-output statistical data has been officially published for the years 1963, 1967, and 1971. Factors which introduce uncertainty into the analysis are general inflation and, recently, rapidly escalating energy costs, attempts by manufacturers to reduce energy costs by reducing energy consumption per unit productivity, and rapid, shortage-influenced escalation of the prices of particular products. The last factor is particularly important in geothermal net energetics analysis as costs for piping, drill stem and tubular goods, and certain types surface equipment have increased by factors of two and three in a period of two to three years.

The energy factors, e, are obtained from detailed economic and energy input-output analysis of the national economy. These two analyses allow one to relate the total energy matrix, E, to the consumer demands (sales) matrix, $\underset{\sim}{Y}$, using the total energy equivalent matrix, $\underset{\sim}{e}$:

$$\underset{\sim}{E} = \underset{\sim}{e}\,\underset{\sim}{Y}.$$

The methodology used to obtain the above relationship is discussed in what follows.

Review of Economic Input-Output Analyses:

The basic data for economic input-output analysis are the dollar sales per year measured in terms of the producers' prices. Let X_i be the total dollar sales of industrial sector i. These total sales will include both final consumer demand (total dollar value paid by consumers for sector i goods), Y_i, and interindustry sales from sector i to a number, n, of sectors j, X_j; that is,

$$X_i = \sum_{j=1}^{n} X_{ij} + Y_i \tag{1}$$

(The value added by sector i, V_i, will be

$$V_i = X_i - \sum_{j=1}^{n} X_{ji}). \tag{2}$$

A common assumption in input-output analysis is that the interindustry sales inputs, X_{ij}, for sector i to sector j are linearly related to the total dollar sales of sector j:

$$X_{ij} = A_{ij} X_j \tag{3}$$

Thus,

$$X_i = \sum_{j=1}^{n} A_{ij} X_j + Y_i \tag{4}$$

In matrix form this becomes

$$\underset{\sim}{X} = \underset{\sim}{A}\,\underset{\sim}{X} + \underset{\sim}{Y}$$

$\underset{\sim}{X}$ can be determined as

$$\underset{\sim}{X} = (\underset{\sim}{I} - \underset{\sim}{A})^{-1} \underset{\sim}{Y} \tag{5}$$

Clearly, A_{ij} is the dollar transaction from sector i to sector j required to produce one dollar worth of final consumer demand (sales) from sector j. The term $(\underset{\sim}{I} - \underset{\sim}{A}) \underset{\sim}{X}$ will not be the value added by the various sectors

$$[\ X_i - \sum_j^n A_{ji} X_i = (1 - \sum_{j=1}^n A_{ji}) X_i$$

is the value added by sector i] .

The total dollar sales from sector i, X_i, are related to the consumer demand sales of sector j, Y_j, as

$$X_i = \sum_{j=1}^n [(\underset{\sim}{I} - \underset{\sim}{A})^{-1}]_{ij} Y_j$$

and can be written as

$$X_i = \sum_{j=1}^n X_i^{(j)} \ ; \ X_i^{(j)} = \left\{\begin{array}{l}\text{total dollar sales of sector i} \\ \text{which relates to final demand} \\ \text{sales in sector j}\end{array}\right\}$$

where

$$X_i^{(j)} = [(\underset{\sim}{I} - \underset{\sim}{A})^{-1}]_{ij} Y_j$$

Thus,

$$[(\underset{\sim}{I} - \underset{\sim}{A})^{-1}]_{ij} = X_i^{(j)} / Y_j = \left\{\begin{array}{l}\text{total dollar sales of sector i} \\ \text{per dollar of final demand} \\ \text{sales in sector j}\end{array}\right\}$$

That is, $[(\underset{\sim}{I} - \underset{\sim}{A})^{-1}]_{ij}$ is the total dollar output of sector i required to produce one dollar's worth of consumer demand sales in sector j. Consequently $(\underset{\sim}{I} - \underset{\sim}{A})^{-1}$ contains the type of information necessary for calculating the contributions of energy used in sector i toward producing a dollar's worth of consumer demand sales in sector j.
Thus, it is now possible to focus attention on energy Input-Output analysis.

Review of Energy Input-Output Analysis:

Let E_i be the total energy output of energy-producing sector i. The total energy output, E_i, will be equal to the energy supplied directly to consumer demand sales, ε_i, from sector i, plus the sum over all energy inputs, E_{ik}, from energy sectors k to energy sector i:

$$E_i = \sum_{k=1}^{n} E_{ik} + \varepsilon_i \qquad (6)$$

Note that the number of energy supply sectors is taken equal to the number of industrial sectors and each energy supply sector corresponds to an industrial sector. Some E_{ik}, will thus be zero. If Z_i is taken as the final consumer demand sales of energy sector i, the energy equivalent, ε_i, can be computed as

$$\varepsilon_i = Z_i/P_i \; ;$$

$$P_i = \left\{ \begin{array}{l} \text{Price of energy i sold} \\ \text{to final demand, \$/Btu} \end{array} \right\}$$

Hence,

$$E_i = \sum_{k=1}^{n} E_{ik} + Z_i/P_i \qquad (7)$$

Now assume that the interindustry energy transfers, E_{ik}, are <u>linearly</u> related to the total dollar sales output of energy sector k as

$$E_{ik} \, P_{ik} = B_{ik} \, X_k$$

where P_{ik} is the "Price" of Energy (\$/Btu) sold from energy sector k to energy sector i. Consequently

$$E_i = \sum_{k=1}^{n} (B_{ik}/P_{ik}) \, X_k + Z_i/P_i \, . \qquad (8)$$

In general, Herendeen (1973) used basic energy data to calculate the E_{ik} and basic cash flow data to calculate X_{ik}. The P_{ik} are then obtained as

$$P_{ik} = X_{ik}/E_{ik} \tag{9}$$

It is important to note that the $\underset{\sim}{Z}$ matrix entries are actually identical to some or all of the entries in the $\underset{\sim}{Y}$ matrix.

In order that the $\underset{\sim}{Y}$ matrix may be substituted for the $\underset{\sim}{Z}$ matrix, one must fix the value of $1/P_i = 0$ for industry sectors i which do not sell energy directly to consumer demand. In order to simplify notation, define $S_{ii} = 1/P_i$ where $S_{ik} = 0$ for sectors k not selling energy directly to consumer demand.

Obviously, if sector i is an energy-producing industrial sector, then $B_{ik} = A_{ik}$; otherwise $B_{ik} = 0$. Let us define a matrix R whose entries are $R_{ik} = B_{ik}/P_{ik}$.

Then,

$$E_i = \sum_{j=1}^{n} R_{ik} X_k + Y_i/P_i \tag{10}$$

<u>Energy Factors</u>:

The energy equivalence factors, e_j, are defined as the total energy (Btu) required to produce a dollar's worth of product to final consumer demand in industry sector j. To obtain these energy factors requires only that E_i be related to Y_i. This is done by using the fact that

$$X_k = \sum_{j=1}^{n} \left[(\underset{\sim}{I} - \underset{\sim}{A})^{-1} \right]_{kj} Y_j$$

from Eqn (5), so that Eqn (8) becomes

$$E_i = \sum_{k=1}^{n} \sum_{j=1}^{n} R_{ik} \left[(\underset{\sim}{I} - \underset{\sim}{A})^{-1} \right]_{kj} Y_j + Y_i/P_i \tag{11}$$

or

$$\underset{\sim}{E} = \underset{\sim}{e}\,\underset{\sim}{Y}$$

$$\underset{\sim}{e} = [\underset{\sim}{R}\,(\underset{\sim}{I} - \underset{\sim}{A})^{-1} + \underset{\sim}{S}] \qquad (12)$$

The entries, e_{ij}, of the total energy equivalent matrix, $\underset{\sim}{e}$, are the necessary total energy outputs from sectors i in order that industrial sector j can sell a dollar's worth of sector j product to final demand. Summing over the energy sectors i, we obtain the total energy supplied to industrial sector j in order that sector j can sell a dollar's worth of product to final demand,

$$e_j = \sum_i e_{ij} \qquad (13)$$

The quantities e_j are the energy equivalents of a dollar's worth of final demand sales in sector j and as such are the energy factors used in net energetics analysis.

Herendeen (1973) has performed the matrix inversions for the 1963 input-output statistical data and presented the results as energy factors for the SIC categories. Similar work for later (1967, 1971) input-output statistical tabulations seem not to have been performed. Thus, the net energetics analysis had to be performed by one of three procedures:

1. Correcting individual SIC category costs back to 1963 using wholesale price indices and then calculating energy equivalents from the 1963 Herendeen energy factors.
2. Correcting the 1963 Herendeen factors by multiplying by the ratio of "1975 value of units energy consumed per unit of gross product" to "1963 value of units energy consumed per unit of gross product" and applying the corrected factors.

3. Calculating the 1975 value of "units of energy consumed per unit of Gross product" and applying the obtained economy-wide energy factor to the overall cost of equipment, construction, maintenance, and operations (excluding fuels) to calculate the desired energy equivalents.

Each method will introduce uncertainties in calculating the net energetics ratio, although the first method should result in the best evaluation. For method 1, the wholesale price indices were obtained from the 1963 and November 1975 tabulations of wholesale price indices for commodity groups and subgroups (Dept. of Labor, 1963, 1975).

A convenient way to present power generation unit net energetics data is in terms of the number of baseload production years of generated electric power required for equipment fabrication, plant construction, and plant operation. Rombough and Koen (1975) have obtained a value of approximately 2.0 years for a coal-fired plant fueled with mine-mouth strip-mine coal and a value of approximately 2.0 years for a light water reactor. Both calculations assume a 30-year economic life. Oil and gas-fired power plants and hydroelectric plants will have net energetics values less than the two referenced above.

II. CURRENT NET ENERGETICS WORK

Four net energetics analyses have been performed in order to place geopressured geothermal power generation plants in perspective with respect to other geothermal generation plants and fossil-fueled plant. The first plant analyzed consists in a geothermal plant planned for a low-salinity (<20,000 ppm), moderate temperature (~380^{o}F), hydrothermal (hot water) resource in California's Imperial Valley. Two geopressured geothermal plants were analyzed--A flash-steam plant and a secondary working fluid plant--on the same basis as the Imperial Valley Plant, but using a different resource model. Finally, a coal-fired plant currently under construction in Central Texas was evaluated to provide a fossil-fueled benchmark with which to check the analysis of Rombough and Koen (1975) and to compare with the current geothermal plant analysis.

The benchmark analysis of the coal-fired plant is important for two reasons:

1. Inflation since the original coal-fired plant analysis has been considerable and many construction costs have risen very rapidly.
2. Temporary market shortages for certain durable goods have led to extraordinary price escalations relatively unrelated to concurrent inflation rates.

It is thus important to achieve reasonable agreement of the two coal plant analyses in order to measure whether the above two factors have been appropriately removed from the geothermal plant analyses.

A. LOW-SALINITY, MODERATE TEMPERATURE HYDROTHERMAL PLANT

Bechtel Corporation of San Francisco, California, has proposed a 10 MW(e) secondary working fluid generation plant (Bechtel, 1975) for the Heber, Imperial Valley, California resource. The conceptual design was performed under a "Phase 0" contract for the National Science Foundation's RANN Program and for the Energy Research and Development Administration's Division of Geothermal Energy.

The Heber resource is a low-salinity (~15,000 ppm), moderate temperature (~380^{o}F) hot water resource in which the wells are pumped to prevent in-well flashing of brine water to steam. Bechtel Corporation proposed a socondary working fluid cycle using isobutane as the secondary fluid. The secondary working fluid cycle was designed as a super critical cycle to prevent isobutane boiling in the brine/isobutane heat exchangers, to minimize heat transfer surface area, and to maximize power output from the cycle. Heat rejection is via tube and shell condensers to a conventional wet cooling tower.

The Bechtel estimates are for the power plant alone. Well costs and operation and maintenance costs were estimated by the University of Texas. Bechtel determined that 2.0×10^6 lbm/hr of brine were required for the 10MW(e) net power plant. Assuming that each well produced 4.5×10^5 lbm/hr of brine, about 4.5 production wells are required. Six, initial production wells 6,000 feet deep costing $\$5.0 \times 10^5$ each were assumed (including one spare), and six additional production wells (representing redevelopment of well field to compensate for declining production) costing $\$5.0 \times 10^5$ each were assumed. Four wells drilled for production were assumed to have poor production potential and not to be completed at a cost of $\$3.5 \times 10^5$ each.

Injection wells peripheral to the well field were assumed, with each production well requiring an injection well. Assuming that injection is into the production horizon, the injection wells are taken as 6,000 feet deep and costing $\$5.0 \times 10^5$ apiece. Six initial injection wells, six injection field redevelopment wells, and four wells inappropriate for reinjection were assumed. Each well was assumed to cost $\$5.0 \times 10^5$. This information is summarized in Table IV-1.

Table IV-2 presents the various capital, construction, and services expenditures for the 10MW(e) plant. These expenditures are identified by specific architect/engineer items, each of which is identified with a Standard Industrial Classification (SIC) category, an energy factor, an uncorrected total energy equivalent, an inflation correction factor, and an inflation-corrected total energy for the item.

Bechtel's cost figures were not broken down into subitems sufficiently well to enable direct net energetics analysis so that certain assumptions were necessary. These were:

1. Bechtel item pumps and drives was assumed to consist of 50% pumps and 50% drives; maximum error possible is <0.6%.

2. Bechtel item auxiliary systems was assumed to consist of 10% fabricated plate work (receivers, heat exchangers, etc.), 15% refrigeration machinery, 15% pumps and compressors, and 45% pipes, valves, fittings, and duct work. These assumptions could introduce no more than approximately 0.8% error to the final result

TABLE IV-1

ASSUMED WELL FIELD COSTS; LOW-SALINITY, MODERATE TEMPERATURE HYDROTHERMAL PLANT

Capital Item:	Number	Unit Cost ($x10^{-6})	Item Cost ($x10^{-6})	Item Totals ($x10^{-6})
1. Initial Production Wells	6	0.50	3.00	
2. Redevelop Production Wells	6	0.50	3.00	
3. Production Wells Not Completed	4	0.35	1.60	
4. Initial Reinjection Wells	6	0.50	3.00	
5. Redevelop Reinjection Wells	6	0.50	3.00	
6. Reinjection Wells Not Useful	4	0.50	2.00	15.60
7. Production Well Downhole Pumps	12	0.05	0.60	
8. Reinjection Well Surface Pumps	12	0.05	0.60	1.20
9. Gathering/ Dispersal System				
Pipeline:				
i. 6-inch	48,000(LF)	$30/LF*	1.440	
ii. 8-inch	12,600(LF)	$36/LF*	0.454	
iii. 10-inch	23,800(LF)	$48/LF*	1.142	
iv. 12-inch	13,200(LF)	$60/LF*	0.792	3.83
10. Wellhead Equipment	12	0.10		1.20
11. TOTAL				21.83

*Includes installation, insulation, etc.

TABLE IV-2

NET ENERGETICS OF 10 MW(e) LOW-SALINITY, MODERATE TEMPERATURE SECONDARY WORKING FLUID PILOT PLANT

Architect/Engineer Item	SIC Category	Installed Cost (10^3\$)	Energy Factor (Btu/\$)[1963] ($x10^{-4}$)	Total Energy (Btu) ($x10^{-7}$)	Price Index Correction Factor (1963/1976)	Corrected Total Energy (Btu) ($x10^{-7}$)
I. Engineering Fees	Miscellaneous Professional Services	2040	2.655	5417	0.5291	2866
II. Construction Costs		11475	-----	-----	-----	-----
A. Plant Equipment		6140				
1. Heat Exchangers, Condensers	Fabricated Plate Work	3100	11.56	35840	0.4883	17500
2. Turbine, Generator, Main Feed-Pump Turbine	Steam Engines and Turbines	1275	8.423	10740	0.5577	5990
3. Cooling Tower	Fabricated Wood Products	540	12.41	6700	0.5291	3545
4. Pumps and Drives	a. Pumps and Compressors (50%)	162.5	5.825	947	0.5577	528
	b. Motors and Generators (50%)	162.5	6.182	1062	0.5577	592
5. Auxiliary Systems	a. Fabricated Plate Work (10%)	22	11.56	254	0.4883	124
	b. Non-Electric Heating Equipment (15%)	33	7.351	243	0.5577	136
	c. Refrigeration Machinery (15%)	33	6.402	211	0.5577	118
	d. Pumps and Compressors (15%)	33	5.825	192	0.5577	107
	e. Pipes, Valves, and Fittings (45%)	99	7.374	730	0.4883	356
6. Electrical Equipment	a. Communications Apparatus	27	4.282	114	0.5291	60
	b. Switchgear, Switchboard Apparatus	106	4.878	517	0.5291	274
	c. Transformers	132	8.105	1074	0.5291	568
	d. Electrical Equipment	132	6.173	818	0.5291	433
	e. Industrial Controls	133	3.866	512	0.5291	271
B. Plant Bulk Materials		3930	-----	-----	-----	-----
1. Concrete and Earthwork	New Construction (All Other)	720	7.126	5131	0.5291	2715
2. Electrical		400	-----	-----	-----	-----
a. Electric Lamps (15%)	Electric Lamps	60	4.466	268	0.5291	142
b. Lighting Fixtures (15%)	Electric Lighting Fixtures	60	7.664	460	0.5291	243
c. Wiring Devices (35%)	Wiring Devices	140	7.428	1040	0.5291	550
d. Elec. Ind. App. (35%)	Electrical Industrial Apparatus	140	7.050	987	0.5291	522
3. Pipes, Valves, Insulation	a. Pipes, Valves, Fittings (80%)	1856	7.374	13690	0.4883	6685
	b. Gaskets and Insulation (20%)	464	7.930	3680	0.5464	2011
4. Instrumentation	a. Electrical Measuring (40%)	108	3.829	414	0.5291	219
	b. Industrial Controls (60%)	162	3.866	626	0.5291	331
5. Site Improvement	a. Water and Sanitary Services (10%)	22	11.67	257	0.5291	136
	b. Electric Utility (20%)	44	9.695	427	0.3747	160
	c. Fabricated Wire Products (35%)	77	14.46	1113	0.4883	543
	d. Roadway Construction (35%)	77	9.851	759	0.5291	412
C. Control and Turbine Building						
1. New Construction	Non-Residential Buildings (40%)	322	6.637	2137	0.5291	1131
2. Structural (Heavy)	Fabricated Structural Steel (60%)	483	12.34	5960	0.4883	2910
D. Engineering and Construction Support	Miscellaneous Professional Services	550	2.655	1460	0.5291	772
TOTAL CONSTRUCTION		13515	-----	103800	-----	52950
III. Fuel Plant ++						
A. Engineering Fees	Miscellaneous Professional Services	2600	2.6552	6900	0.5291	3650
B. Production, Reinjection Wells						
1. Wells	a. 50% Pipes, etc.	7800	7.3742	57520	0.4883	28090
	b. 50% Well Drilling Services	7800	8.0000 +	62400	0.5291	33020
2. Wellhead Equipment	Pipes, Valves, Fittings	1000	7.3742	7370	0.4883	3599
3. Down-Hole Pumps	Pumps and Compressors	1200	5.8254	6990	0.5577	3898
C. Gathering/Dispersal System						
1. Pipes, Valves	Pipes, Valves, Fittings	2515	7.3742	18550	0.4883	9058
2. Insulation	Gaskets and Insulation	1250	7.9301	9910	0.5464	5415
3. Installation	New Construction, Industrial	1245	6.6371	8260	0.5291	4370
IV. Operations and Maintenance ++						
A. Power Plant						
1. Operators	Miscellaneous Professional Services	5700	2.6552	1513	0.5291	8005
2. Maintenance	Maintenance and Repair Construction	15900	7.5000 **	119250	0.5291	63100
3. Insurance	Insurance Carriers	1620	2.5000 *	4050	0.5500	2228
4. Regulation	Government Industry	315	3.5000 *	1103	0.5000	552
B. Fuel Plant						
1. Operators	Miscellaneous Professional Services	2160	2.6552	5730	0.5291	3031
2. Maintenance	Maintenance and Repair Construction	3600	7.5000 *	27000	0.5291	14290
3. Pumping Power	Direct Equivalent in Btu	-----	-----	1380	-----	1380
4. Insurance	Insurance Carriers	1700	2.5000 *	4250	0.5500	2338
TOTAL FUEL PLANT, OPERATIONS AND MAINTENANCE		60310		355790		186000
TOTAL ESTIMATED ENERGY REQUIRED (30 YEARS)		73825		459590		238900
TOTAL ESTIMATED ENERGY PRODUCED (30 YEARS)			ELECTRICITY = 8.06×10^{12}		TOTAL = 8.06×10^{12}	
NET ENERGY RATIO					R = 0.296	

NOTE:
* Estimated from consideration with respect to professional services.
** Estimated by comparison with new construction (all other) and non-residential.
\+ Estimated with respect to industrial construction.
\++ Estimated by University of Texas, not Bechtel Corporation.

3. Bechtel item electrical equipment (Plant Equipment) was subdivided into 5% communications apparatus, 20% switch gear apparatus, 25% transformers, 25% electrical equipment and electronics, and 25% industrial controls. Maximum error contribution is approximately 0.9% in final result.

4. Bechtel item electrical equipment (Plant Bulk Items) was assumed to be 15% electric lamps, 15% lighting fixtures, 35% wiring and wiring devices, and 35% industrial electrical apparatus; this breakdown could introduce a maximum possible error of 0.3% in the final result.

5. Bechtel item site improvements was estimated as 10% water and sanitary services, 20% electric utility, 35% fencing products, and 35% roadway construction. Basis of estimates were comparative breakdowns in other similar jobs. Maximum possible error introduced is about 0.6% of final result.

The net energetics analysis is detailed in Table IV-2; total energy required to construct, maintain, and operate the low-salinity hydrothermal plant is 2.38×10^{12} Btu. For a load factor of 90% the total energy generated in a thirty year period is 8.06×10^{12} Btu. Thus the energy ratio is 0.296 and approximately 8.9 years are required to recover the construction, operation, and maintenance costs.

This plant is only a 10MW(e) [net] facility. Thus, the plant costs, estimated at $1620/kW-installed, do not properly reflect either the capital or energetics costs of a commercial-sized unit. The cost of a commercial-sized unit would probably be of the order of $750/kW - installed, cutting the energy cost of the generation plant to about 2.80×10^{11} Btu per 10MW(e) [net]. (It is assumed that operation costs were cut in proportion to construction costs.)

No credit has been allowed for experience gained in sequential drilling operations. This experience will tend to reduce drilling time and, hence, drilling cost. Assuming that this were so, a 30% decrease in drilling costs might be appropriate. This adjusted energy cost of the production field would be approximately 1.30×10^{12} Btu. Overall adjusted energy cost under these assumptions is

1.58×10^{12} Btu; the corresponding energy ratio, R, is 0.19. The adjusted energy recovery period is 5.7 years.

The above adjusted value is high compared to estimates of approximately 2.8 years computed by Gilliland (1975), for a 100 MW(e) [net] generating plant. The difference probably originates from the scaling of the Bechtel 10MW(e) [net] pilot plant to a 50→100 MW(e) [net] commercial plant and from the gross estimates applied to the wellfield/fuel plant costs. For instance, the Gilliland paper assumes 78 production wells 4700 feet deep and 39 reinjection wells 1500 feet deep. This compares with the equivalent assumption of this work of 100 production wells 6000 feet deep and 100 reinjection wells 6000 feet deep over the 30 year power plant life. As the fuel plant represents about 37% of the total energy expenditure for construction, operations, and maintenance, Gilliland's lower well field estimates (only 35% of those made in this work) result in about a 30% difference in the net energy ratio.

The estimates made here for operations and maintenance costs are much higher than these estimated by Gilliland. Gilliland's estimates are less than 40% of those estimated in this work, both for power plant and fuel plant. As total construction costs for neither the fuel plant nor power plant can be determined from Gilliland's work, standard utility or petroleum industry estimates based on percentage of capital invested connot be used as a comparison.

Gilliland does not identify the reservoir and wellhead characteristics (Pressure, temperature, flow quality) assumed for the resource. Either the wellhead conditions are more favorable or the flow rates are higher (of order of 575,000 lbm/hr per well). Lack of a common resource base and plant size make meaningful comparison difficult. However, factoring in the observed differences results in a somewhat comparable result of 3.3→ 3.9 year energy recovery period.

B. 25 MW(e) TWO-STAGE FLASH STEAM GEOPRESSURED GEOTHERMAL PLANT

Dow Chemical Company USA of Freeport, Texas has proposed a 25 MW(e) flash-steam generation plant with geohydraulic generation as detailed in Appendix B. Table IV-3 presents the fuel plant, site development, power plant, and operations and maintenance estimated installed or operations costs. All costs except for operations and maintenance are those estimated by Dow. Operations and maintenance costs are University of Texas estimates obtained from analysis of the Seventeenth and Nineteenth Steam Station Surveys (Electrical World 1973, 1975) modified to adjust fossil fuel data to geothermal conditions. Well field costs shown are based upon Dow cost estimates modified by the University of Texas to allow for sustained production over the thirty year life of the fuel processing and power plants.

The Dow estimating method does not result in sufficient breakdown of costs to allow direct net energetics analysis so that certain assumptions were necessary. These were:

1. Dow item geohydraulic turbine/generator set was assumed to consist of generator ($168K), instruments ($145K), cable ($14K), turbine ($380K), controls equipment ($180K), lube oil system ($90K), and foundations ($630K), all installed costs.

2. Dow item cooling tower miscellaneous equipment was assumed to be pipes, valves, and fittings ($11.8K, 55.1K) and pumps ($14.7K, 68.4K) where the figures in each parenthesis are for makeup and blowdown systems, respectively.

3. Dow item switch gear was assumed to include analog control equipment ($60K) and switch gear itself ($600 K).

4. Dow item motor control center was assumed to consist of industrial control ($370K), electronic measurement equipment and instruments ($141K), electrical equipment ($30K), and electrical cable ($30K).

5. Dow item steam turbine/generator set was assumed to include generator ($1068K), foundations ($1080K), instruments ($280K) [electrical measuring equipment ($205K) and industrial control ($75K)], cable ($59K) [electrical equipment ($29.5K) and cable ($29.5K)], steam turbine ($2,976K).

TABLE IV-3

NET ENERGETICS OF GEOPRESSURED GEOTHERMAL
25 MW(e) FLASH-STEAM PLANT

Architect/Engineer Item	SIC Category	Installed Cost (10^3\$)	Energy Factor (Btu/\$)[1963] ($x10^{-4}$)	Total Energy (Btu) ($x10^{-7}$)	Price Index Correction Factor (1963/1976)	Corrected Total Energy (Btu) ($x10^{-7}$)
I. Site Development (Fuel Plant)						
A. Site Preparation						
1. Surveying	Miscellaneous Professional Services	9.2	2.6554	24.43	0.5291	10
2. Grading and Drainage	Earth Works	13.8	9.8507	135.93	0.5291	70
B. Fencing	Miscellaneous Fabricated Wire Products	22.5	14.465	325.46	0.4883	160
C. Roads	Highway Construction	227.5	9.8507	2241.0	0.5291	1190
D. Water and Sanitary Service	Water and Sanitary Services	7	11.666	81.66	0.5291	40
E. Electric Power, Outside Lighting						
1. Electric Power Services	Electric Power	10	9.6952	96.95	0.3747	40
2. Flood Lighting, etc.	General Lighting	5	7.6642	38.32	0.5291	20
F. Warehouse, Shops, Offices	New Construction, Non-Residential	75	6.6371	497.98	0.5291	260
G. Contingency	None (Averaged Over Site Development)	55	9.3016	511.58	0.5200**	270
II. Fuel Plant 10 Well Fields						
A. Source Wells +	50% Pipe, etc; 50% Drilling Services	30000	7.6871	230610	0.4500*	103770
B. Reinjection Wells						
1. Converted Dry Source +	50% Pipe, etc; 50% Drilling Services	11100	7.6871	85330	0.4500*	38400
2. New Reinjection +	50% Pipe, etc; 50% Drilling Services	8100	7.6871	62270	0.4500*	28020
C. Gathering/Disposal System						
1. Piping	Pipe, Valves, etc.	1909	7.3742	14080	0.4883	6880
2. Reinjection Well Pumps	Pumps and Compressors	452	5.8254	2630	0.5577	1470
3. Air Coolers	Refrigeration Equipment	40	6.4015	260	0.5577	150
4. Compressors (Methane)	Pumps and Compressors	990	5.8254	5770	0.5577	3220
5. Water Separators	Fabricated Steel Plate Work	65	11.5620	750	0.4883	770
6. Particulates Filter	General Industrial Equipment	4	6.2497	30	0.5577	20
7. Glycol Dehydrator System	Refrigeration Equipment	109	6.4015	700	0.5577	390
8. High Pressure Methane Separator	Fabricated Steel Plate Work	4708	11.562	54400	0.4883	26560
TOTAL FUEL PLANT		57902	-----	460780	-----	211710
III. Power Plant						
A. Power Cycle						
1. Inter. Press. Methane Separator	Fabricated Steel Plate Work	390	11.562	4510	0.4883	2200
2. Low Press. Methane Separator	Fabricated Steel Plate Work	270	11.562	3120	0.4883	1520
3. Flash Chamber #1	Fabricated Steel Plate Work	228	11.562	2640	0.4883	1290
4. Flash Chamber #2	Fabricated Steel Plate Work	473	11.562	4780	0.4883	2330
5. Hydraulic Turbine	Pumps and Compressors	1315	5.9806	7864	0.5577	4386
6. Generator for Item A.5	Motors and Generators	227	6.0872	1382	0.5577	770
7. Steam Turbine/Generator						
a. Generator	Motors and Generators	1068	6.5378	6980	0.5577	3890
b. Turbine	Steam Turbines	2976	8.4232	25070	0.5577	13980
c. Foundations (Pedestals)	New Construction (All Other)	1083	7.1266	7720	0.5291	4310
d. Instruments	Elec. Instruments, Indus. Control	282	3.8392	1080	0.5577	600
e. Cable, etc.	Wiring Devices/Switchboard App.	59	7.9034	470	0.5291	250
8. Surface Condenser	Fabricated Steel Plate Work	2150	11.562	1730	0.4883	840
9. Dryer	Refrigeration Equipment	35	6.4015	220	0.5577	120
10. Chilled Water System	Refrigeration Equipment	135	6.4015	860	0.5577	480
11. Vacuum Pumps	Pumps and Compressors	598	5.8254	3480	0.5577	1940
12. Condensate Pumps	Pumps and Compressors	48	5.8254	280	0.5577	160
B. Heat Rejection System						
1. Cooling Tower						
a. Tower	Fabricated Ind. Wood Products	1699	5.2875	8980	0.5000	4490
b. Piping and Valves	Piping, Valves, etc.	750	7.3742	5530	0.4883	2700
c. Miscellaneous						
(1) Blowdown Pumps	Pumps and Compressors	26.5	6.5164	170	0.5577	90
(2) Makeup Pumps	Pumps and Compressors	123.5	6.5164	800	0.5577	450
2. Cooling Tower Recirc. Pumps	Pumps and Compressors	923	5.8254	5780	0.5577	3220
C. Electric Services (Plant)						
1. Switchgear	Switchgear/Control Equipment	660	4.6817	3090	0.5291	1630
2. Motor Control Center	Range of Electrical Equipment	571	4.2809	2440	0.5577	1360
3. Step-up Transform Sta.	Transformers	200	8.1050	1620	0.5291	860
D. Structural (Foundations)	Industrial Construction (All Other)	290	7.1266	2070	0.5291	1100
E. Site Development						
1. Site Preparation						
a. Surveying	Miscellaneous Professional Services	9.2	2.6554	25	0.5291	10
b. Grading and Drainage	New Construction, Highways	13.8	9.8507	135	0.5291	70
2. Fencing	Fabricated Wire Products	22.5	14.465	325	0.4883	160
3. Roads	Highway Construction	227.5	9.8507	2240	0.5291	1190
4. Water and Sanitary Services	Water and Sanitary Services	7	11.666	80	0.5291	40
5. Electric Power Services						
a. Power Services	Electric Utilities	10	9.6952	100	0.3747	40
b. Lighting	Lighting Fixtures	5	7.6642	40	0.5291	20
6. Warehouse, Shops, Offices	New Construction, Non-Residence	75	6.6371	500	0.5291	260
F. Contingency	Average Over Site Development	55	9.3015**	510	0.5200*	270
TOTAL POWER PLANT		16945	-----	106515	-----	57015
IV. Operations and Maintenance						
A. Power Plant						
1. Operators	Miscellaneous Professional Services	8550	2.6552	22700	0.5291	12010
2. Maintenance	Maintenance and Repair Construction	18390	7.5000	137950	0.5291	72990
3. Insurance	Insurance Carriers	2030	2.5000	5080	0.5500*	2790
4. Regulation	Government Industry	790	3.5000	2760	0.5000*	1380
B. Fuel Plant						
1. Operators	Miscellaneous Professional Services	3240	2.6552	8600	0.5291	4550
2. Maintenance	Maintenance and Repair Construction	16500	7.5000	12380	0.5291	6550
3. Insurance	Insurance Carriers	6960	2.5000	17400	0.5500	9570
4. Compression Power (Methane)	Direct Power Equivalent (Btu)			19780	0.5000	9890
TOTAL OPERATION AND MAINTENANCE		56460		226650		119730
TOTAL ESTIMATED ENERGY REQUIRED (30 YEARS)		131307		793950		388455
TOTAL ESTIMATED ENERGY PRODUCED (30 YEARS)	METHANE = 4.86×10^{13}		ELECTRICITY = 1.95×10^{13}		TOTAL = 6.85×10^{13}	
NET ENERGY RATIO					R = 0.0567	

+Over the 30 year Life of Power Plant.
*Estimated by University of Texas.
**Averaged over Site Development.

The details of the net energetics analysis are displayed in Table IV-3. The total energy required to construct, operate, and maintain the Dow two-stage flash steam plant is 3.88×10^{12} Btu while the energy produced from methane and electricity totals 6.85×10^{13} Btu. The net energy ratio, R, is 0.0567 with an energy recovery period of 1.7 years. If a methane energy credit is not included, the revised net energy ratio would be R'=0.199 with a revised energy recovery period of 5.97 years.

C. 33 MW(e) SECONDARY WORKING FLUID GEOPRESSURED GEOTHERMAL PLANT

Brown and Root, Inc., of Houston, Texas has proposed a 25 MW(e) secondary working fluid generation plant utilizing propane as the secondary fluid (see Appendix A). Table IV-4 presents the fuel plant, site development, power plant, and operations and maintenance costs for a 33 MW(e) generation plant which produces 25 MW(e) from a propane secondary working fluid cycle and 8 MW(e) from a geohydraulic turbine. The propane SWF cycle is that proposed by Brown and Root, Inc. while the geohydraulic unit has been scaled up for the appropriate fluid flow rates from the geohydraulic unit design proposed by Dow Chemical USA. The scale-up was performed by University of Texas, Department of Mechanical Engineering personnel.

The following assumptions were made with respect to scaling up the Dow-estimated 8.9 well fuel plant in order to provide 13.4 wells of production for the Brown and Root, Inc. SWF plant:

(1) Wells-costs increase linearly as a function of number of wells required (10 wells → 15 wells)

(2) Gathering/Disposal System--linear extrapolation with added costs to cover longer transmission pipeline distances

(3) Fuel Processing (Methane Separation) plant--used 0.6 power rule; for 2000 PSIA methane separator, scale 8.9 wells down to 7.0 wells and install two each to service up to 14 wells.

(4) Site Development--use almost as is basis except increase flood-lighting, roads, fencing, surveying lineary with wellfield

TABLE IV-4

NET ENERGETICS OF GEOPRESSURED GEOTHERMAL
33 MW(e) SECONDARY WORKING FLUID PLANT

Architect/Engineer Item	SIC Category	Installed Cost (10^3\$)	Energy Factor (Btu/\$)[1963] ($x10^{-4}$)	Total Energy (Btu) ($x10^{-7}$)	Price Index Correction Factor (1963/1976)	Corrected Total Energy (Btu) ($x10^{-7}$)
I. Site Development						
A. Site Preparation						
1. Surveying	Miscellaneous Professional Services	15.0	2.6554	39.89	0.5291	21.10
2. Grading and Drainage	Highway Construction	21.0	9.8507	206.9	0.5291	109.5
B. Fencing	Misc. Fabricated Wire Products	35.0	14.465	506.3	0.5291	267.9
C. Roads	Highway Construction	354.0	9.8507	3471.0	0.5291	1836.0
D. Water & Sanitary Service	Water & Sanitary Services	7.0	11.666	81.6	0.5291	43.2
E. Electric Power, Outside Lighting						
1. Electric Power Services	Electric Power	10.0	9.6952	96.9	0.5291	51.3
2. Flood Lighting, etc.	General Lighting	10.0	7.6642	76.6	0.5291	40.5
F. Warehouse, Shops, Offices	New Construction, Non-Residence	75.0	6.6371	497.8	0.5291	263.4
G. Contingency	None (Average Over Site Develop)	86.0	9.302	800.0	0.5291	423.3
II. Fuel Plant/Well Field						
A. Source Wells	50% Pipe; 50% Drilling Services	46665.0	7.6871	358720.0	0.4500	161400.0
B. Reinjection Wells						
1. Converted Dry Source	50% Pipe; 50% Drilling Services	17266.0	7.6871	132700.0	0.4500	59720.0
2. New Reinjection	50% Pipe; 50% Drilling Services	12600.0	7.6871	96860.0	0.4500	43590.0
C. Gathering System						
1. Piping	Pipes, Valves, etc.	3300.0	7.3742	24330.0	0.4883	11880.0
2. Reinjection Well Pumps	Pumps & Compressors	703.0	5.8254	4095.0	0.5577	2284.0
3. Air Coolers	Refrigeration Equipment	62.2	6.4015	398.0	0.5577	222.0
4. Compressors (Methane)	Pumps & Compressors	1540.0	5.8254	8971.0	0.5577	5000.0
5. Water Separators	Fabricated Steel Plate Work	101.1	11.562	11690.0	0.4883	5708.0
6. Particulates Filter	General Industrial Equipment	6.2	6.2497	38.7	0.5577	2123.0
7. Glycol Dehydrator System	Refrigeration Equipment	169.5	6.4015	1085.0	0.5577	605.1
8. High Pressure Methane Separ.	Fabricated Steel Plate Work	8098.0	11.562	93630.0	0.4883	45720.0
TOTAL FUEL PLANT		91124.0	-----	738219.0	-----	341308.0
III. Power Plant						
A. Propane/Brine System						
1. Vaporizers	Fabricated Steel Plate Work	4700.0	11.562	54340.0	0.4883	26535.0
2. Condensers	Fabricated Steel Plate Work	2000.0	11.562	23120.0	0.4883	11291.0
3. Receiver	Fabricated Steel Plate Work	108.5	11.562	1254.0	0.4883	612.0
4. Liquid Knock-Out Drum	Fabricated Steel Plate Work	8.9	11.562	102.9	0.4883	50.0
5. Booster Feed Pumps and Drives	50% Pumps; 50% Motors & Generators	140.0	6.1816	865.4	0.5577	483.0
6. Feed Pumps and Drives	50% Pumps; 50% Motors & Generators	687.0	6.1816	4246.0	0.5577	2368.0
7. Piping, Valves	Pipe, Valves, Pipe Fittings	1412.	7.3742	10412.	0.4783	4980.
8. Insulation	Gaskets and Insulation	200.	7.9301	1586.	0.4783	759.
9. Misc. Eqpt. (Unloading, Makeup)	(See Section C)	623.0	7.8987	4920.0	0.5152	2535.0
B. Turbine/Generator Set						
1. Turbine	Steam Turbines	875.0	8.4232	7370.0	0.5577	4110.0
2. 45 MW(e) Generator	Motors & Generators	1125.0	8.4232	9476.0	0.5577	5283.0
3. Misc. Eqpt. (Cooling, Lube Oil)	(See Section C)	200.0	6.6273	1325.0	0.5369	712.0
C. Cooling Water System						
1. Cooling Tower	Fabricated Wood Products	1050.0	5.2875	5552.0	0.5291	2937.0
2. Cooling Water Pumps, Drives	50% Pumps, 50% Motors	360.0	6.1816	2225.0	0.5577	1241.0
3. Miscellaneous Equipment (Blowdown, Makeup, etc.)	{45% Pipe, Valves, Insulation; 55% Pumps and Drives}	80.0	6.7135	537.0	0.5267	283.0
4. Piping and Valves	Pipes, Valves, Pipe Fittings	290.0	7.3742	2139.0	0.4783	1044.0
D. Instrument & Control System						
1. Local Mounted Instruments	Electrical Measure Instr.	166.8	3.8293	638.9	0.5291	338.0
2. Control Panel Mounted Instrus.	Electrical Measure Instr.	96.7	3.8293	371.0	0.5291	196.3
3. Analog Control System (Misc. Instr. & Controls)	Computing & Related Eqpt.	57.5	2.7460	157.9	0.5291	86.5
4. Analysis, Fire Protect., etc.	{33% Elec. Meas. Intr., 33% Indus. Cont.; 34% Pipes, Valves}	56.0	6.023	281.3	0.5155	145.0
E. Electrical						
1. Substation & Switchgear	50% Transformer, 50% Switch	609.3	6.4917	3957.0	0.5291	2094.0
2. Load & Motor Control Center	Industrial Controls	54.5	3.8656	210.6	0.5291	111.5
3. Lighting & Grounding	50% Light Fixtures, 50% Wiring Devices	28.6	7.5462	215.8	0.5291	114.2
4. Cables & Misc. Elec. Eqpt.	{50% Nonferrous Wire & Insulation; 50% Electrical Equipment}	72.0	7.9034	569.0	0.5378	306.0
F. General Facilities						
1. Fire Protection	{80% Pipes, Valves, Fittings; 20% Industrial Controls}	213.0	6.6724	1421.0	0.4965	705.6
2. Buildings & Foundations						
a. Office Bldg., Control Rm.	New Construction, Non-Residence	200.0	6.6371	1327.0	0.5291	702.3
b. Foundations	New Construction, (All Other)	600.0	7.1266	4276.0	0.5291	2262.0
c. Roads	New Construction, Highways	33.0	9.8507	325.0	0.5291	172.0
d. Sumps	New Construction, Highways	90.0	7.1266	641.0	0.5291	339.3
3. Taxes	No Category, No Contribution	807.0	-----	-----	-----	-----
4. Direct Field Labor, Eqpt.	New Construction, Non-Resident	1819.0	6.6371	12070.0	0.5291	6388.0
5. Burden	No Category, No Contribution	318.0	-----	-----	-----	-----
6. Overhead	Misc. Prof. Services	369.0	2.6554	974.0	0.5000	487.0
7. Contractors, Engineering Fees	Misc. Prof. Services	2541.0	2.6554	6748.0	0.4500	3037.0
8. Contingency	Average Over Power Plant	2199.0	7.8765	17320.0	0.5075	8790.0
G. Hydraulic Turbine/Generator						
1. Hydraulic Turbine	Pumps & Compressors	1714.0	5.8254	9985.0	0.5577	5567.0
2. Generator	Motors & Generators	296.0	6.5378	1935.0	0.5577	1079.0
H. Methane Separation						
1. Methane Separator #1	Fabricated Steel Plate Work	508.0	11.562	5873.0	0.4883	2868.0
2. Methane Separator #2	Fabricated Steel Plate Work	352.0	11.562	4070.0	0.4883	1987.0
TOTAL POWER PLANT		27065.0	-----	202838.	-----	102998.
IV. Operations and Maintenance						
A. Power Plant						
1. Operators	Miscellaneous Prof. Services	9900.0	2.6552	26290.0	0.5291	13910.0
2. Maintenance	Maintenance & Repair Constr.	30600.0	7.5000	229500.0	0.5291	121400.0
3. Insurance	Insurance Carriers	3054.0	2.5000	7635.0	0.5500*	4200.0
4. Regulation	Government Industry	1103.0	3.0000	3300.0	0.5000*	1650.0
B. Fuel Plant						
1. Operators	Miscellaneous Prof. Services	5040.0	2.6552	13380.0	0.5291	7080.0
2. Maintenance	Maintenance & Repair Constr.	25670.0	7.5000	192500.0	0.5291	101800.0
3. Insurance	Insurance Carriers	10830.0	2.5000	27080.0	0.5500*	14890.0
4. Compression Power (Methane)	Direct Power Equivalent (Btu)	-----	-----	30770.0	-----	30770.0
TOTAL OPERATIONS & MAINTENANCE		86197.0		530500.0		295700.0
TOTAL ESTIMATED ENERGY REQUIRED				1472000.0		740000.0
TOTAL ESTIMATED ENERGY PRODUCED	METHANE = 7.57×10^{13}		ELECTRICITY = 2.72×10^{13}		TOTAL = 1.03×10^{14}	
NET ENERGY RATIO					R = 0.0712	

*Estimated +Total Costs over 30-year life.

area. Warehouse, water, and sanitary services remain unchanged.

The relevant Dow power plant components were scaled as follows:

(1) Hydraulic T/G Set -- use 0.6 power law to scale up size by fluid flow ratios

(2) Methane separators (300 psia and 150 psia) in power plant -- scale up using 0.6 power scale law.

Certain Brown and Root, Inc. items required subdividing into categories suitable for net energetics analysis; these were:

(1) Brown and Root items booster and main feed pumps and drives were assumed to consist of 50% pumps and 50% motors

(2) Brown and Root item miscellaneous equipment for unloading and makeup was assumed as: fabricated plate work ($185K), pipes, valves, and fittings ($160K), pumps and drives ($92K), processing machinery ($95K), industrial controls ($65K), and assorted industrial machinery ($26K).

(3) Brown and Root item miscellaneous equipment (cooling, lube oil on T/G set) was assumed to include: pipes, valves, and pipe fittings ($60K), pumps and drives ($60K), and refrigeration equipment ($80K).

(4) Brown and Root item miscellaneous equipment for blowdown and makeup was assumed to comprise pipes, valves, and insulation ($35K) and pumps and drives ($45K).

(5) Brown and Root item analysis and fire control systems are assumed to consist of electrical measuring instruments ($181K), industrial control ($18K), and pipes and valves ($20K).

(6) Brown and Root item substation and switchgear was assumed to include transformers ($305K) and switch gear ($305K)

The total energy required for construction, operations, and maintenance over a 30 - year plant life is 7.40×10^{12} Btu while the energy produced from methane (7.57×10^{13} Btu) and from electricity (2.72×10^{13} Btu) over a 30 - year life at 90% utilization factor totals

1.03×10^{14} Btu. The net energy ratio, R, is 0.0712, resulting in an energy payback period of 2.1 years.

A second net energy analysis was derived from this particular plant study. A fourteen well fuel plant was considered on its own, separating methane at 100% utilization factor. The energy required to construct, operate, and maintain such a plant for 30 years is estimated at 4.99×10^{12} Btu while the methane produced during the 30 years contains 8.41×10^{13} Btu on an electric equivalent basis. The net energy ratio, R, is 0.0593 with an energy recovery period of 1.8 years.

D. 600 MW(e) CENTRAL TEXAS COAL PLANT (Western Coal)

Currently several utilities are engaged in constructing or planning coal-fired generation facilities to be located in Central Texas. Fuel for these units will be obtained from eastern Colorado, Wyoming, or Montana and shipped in by rail using unit trains. Although lignite resources have long been known in the Central Texas area, the only planning for use of lignite to fire these units is to allow for boiler modifications at some later date. Lignite is currently in use in North Central Texas at Rockdale, Big Brown, and a third station and is planned for at least two other stations. The switch from "imported" coal to lignite is possible; however, the net energetics analysis will consider "imported" coal as the fuel.

The coal-fired unit considered is one unit of a two-unit station which shares some common facilities -- cooling reservoir, river water pumping station for makeup to cooling reservoir, railroad spur and coal and ash handling facilities, transmission lines, and substations. The architect/engineer major items are not subdivided themselves but are subdivided by SIC categories instead so that like items of more than one architect/engineer major item subcategory are lumped together in the SIC category to which they belong.

All estimates of costs are taken from architect/engineer estimates based on completed work, contracts let and in progress (with estimated escalation), and current estimates for remainder of items. Fuel acquisition, transportation, and transport equipment costs are based on either contracts or letters of agreement. Transportation costs are taken as 1976 costs and net energetics calculated for the 30 - year plant life on that basis (escalator clauses may affect transport costs but not transport energy). Operations and maintenance costs were estimated by the University of Texas using cost factors reported in the Nineteenth Steam Station Survey (Electrical World, 1975) for coal-fired plants of like size.

Table IV-5 presents the net energetics analysis results. Total energy required to construct, maintain, and operate the plant for 30 years aggregates to 3.65×10^{13} Btu while the electricity produced during 30 years operation at 80% utilization equals 4.30×10^{14} Btu. The net energy ratio, R, is 0.097, yielding an energy payback period of 2.9 years. The net energy ratio obtained is 45% higher than that estimated by Rombough and Koen (1975). However, the transport costs for the coal for this plant are approximately 400% higher than those for the plant discussed by Rombough and Koen; these increased costs dictate the increased net energy ratio and energy payback period. The net energy ratio for just the power plant construction is 0.016; this value compares well with Rombough and Koen's (1975) value of 0.015.

III. SUMMARY AND CONCLUSIONS

The net energetics analysis method has been reviewed and applied to four power plants - three geothermal power plants and one coal-fired power plant. In addition, a geopressured geothermal methane production plant and a pressurized water nuclear power plant are presented for comparison. Table IV-6 presents the results in summary form.

The primary conclusion to be drawn is:

> If the costing factors as estimated for the model resource are correct and if well field conditions no worse than those of the model resource obtain, then utilization of the geopressured geothermal

TABLE IV-5

NET ENERGETICS FOR 600 MW(e) CENTRAL TEXAS COAL PLANT (WESTERN COAL)

Architect/Engineer Item	SIC Category	Installed Cost (10^3\$)	Energy Factor (Btu/\$) [1963] ($x10^{-4}$)	Total Energy (Btu) ($x10^{-7}$)	Price Index Correction Factor (1963/1976)	Corrected Total Energy (Btu) ($x10^{-7}$)
I. Site Selection and Land Acquisition	Miscellaneous Professional Services	427	2.6552	1133	0.5291	600
	Land Costs	5280	------	----	------	---
II. Cooling Reservoir Dam and Spillway Engineering, Inspection, and Testing	Misc. Professional Services	731	2.6552	1940	0.5291	1030
	New Construction, Highway	7651	9.8507	75370	0.5291	39880
	New Construction, Utility	409	7.5334	3080	0.5291	1630
	Engineering & Scientific Instruments	27	4.1106	110	0.5577	60
	Fabricated Structural Steel	6	12.3390	70	0.4883	30
	Wood Products	19	5.2875	100	0.5000*	50
	Misc. Fabricated Wire Products	80	14.4650	1160	0.4883	570
	Gravel Pit Lease	100	------	----	------	---
III. River Pump Station & Pipeline	Misc. Professional Services	71	2.6552	190	0.5291	100
	New Construction, Non-residential	936	6.6371	6210	0.5291	3290
	New Construction, Utilities				0.5291	
	Misc. Fabricated Wire Products	4	14.4650	60	0.4883	30
	Fabricated Plate Work	438	11.5620	5060	0.4883	2470
	Pumps and Compressors	144	5.8254	840	0.5577	470
	Motors and Generators	145	6.5378	950	0.5577	530
	Transformers	250	8.1050	2030	0.5291	1070
	Switchgears & Switchboard App.	53	4.8784	260	0.5291	140
IV. Railroad, Coal Handling, and Ash Facilities	Misc. Professional Services	1894	2.8552	5030	0.5291	2660
	New Construction, Highway	543	9.8507	5350	0.5291	2830
	Fabricated Plate Work	441	11.5670	5100	0.4883	2490
	Conveyors and Conveying Eqpt.	3668	6.4384	23620	0.5577	13170
V. Common Plant Equipment	Misc. Professional Services	357	2.6552	950	0.5291	500
	New Construction, Non-Residential	1148	6.6371	7620	0.5291	4030
	Steam Engines and Turbines	6	8.4232	50	0.5577	30
	Pumps and Compressors	276	5.8254	1610	0.5577	900
	Motors and Generators	363	6.5378	2370	0.5577	1320
	Fabricated Plate Work	201	11.5620	2320	0.4883	1130
	Fabricated Structural Steel	150	12.3390	1850	0.4883	900
	Pipe, Valves, Pipe Fittings	446	7.3742	3290	0.4883	1610
	Switchgear, Switchboard App.	416	4.8784	2030	0.5291	1070
	Industrial Controls	237	3.8656	920	0.5577	510
	Transformers	221	8.1050	1790	0.5291	950
	Computing and Related Machines	502	2.7460	1380	0.5577	770
	Conveyors and Conveying Eqpt.	112	6.4384	720	0.5577	400
	Nonferrous Wire Drawing & Insulation	202	9.6340	1950	0.4883	950
	Hoists, Cranes & Monorails	132	7.5412	1000	0.5577	560
VI. Fuel System, Acquisition, and Transport Eqpt	Misc. Professional Services	723	2.6552	1920	0.5291	1020
	Railroad Cars	13701	11.0610	151500	0.5577	80160
VII. Transmission Lines and Substations	Misc. Professional Services	7	2.6552	20	0.5291	10
	New Construction, Non-Residential	13	6.6371	90	0.5291	50
	Transformers	4	8.1050	30	0.5291	20
	Switchgear & Switchboard App.	4	4.8784	20	0.5291	10
VIII. Plant Communications Facilities	Radio & T.V. Communications Eqpt.	2	3.3167	10	0.5291	5
IX. Turbine-Generator Unit #1	Misc. Prof. Services	9400	2.6552	25000	0.5291	13230
	New Construction, Non-residential	76110	6.6371	505100	0.5291	267300
	Pumps and Compressors	1826	5.8254	10640	0.5577	5930
	Fabricated Plate Work	11934	11.5620	137980	0.4883	67380
	Motors and Generators	1497	6.5378	9790	0.5577	5460
	Fabricated Structural Steel	7492	12.3400	92450	0.4883	45140
	Misc. Fabricated Wire Products	187	14.4600	2700	0.4883	1320
	Pipe, Valves, & Pipe Fitting	3392	7.3742	25010	0.4883	12210
	Screws, Bolts, Nuts, Rivets, & Washers	55	8.7163	480	0.4883	230
	Industrial Controls	2087	3.8656	8070	0.5577	4500
	Switchgear & Switchboard App.	1114	4.8784	5430	0.5291	2870
	Transformers	1809	8.1050	14660	0.5291	7760
	Electrical Industrial Apparatus	9485	7.0500	66870	0.5291	35380
	Storage Batteries	175	7.5884	1330	0.5291	700
	Concrete Products	3535	9.4303	33340	0.5464	18220
	Conveyors & Conveying Eqpt	274	6.4384	1760	0.5577	980
	Elevators & Moving Stairways	150	5.9308	900	0.5577	500
	Motor Freight Trans. & Warehousing	40	8.4037	340	0.4000	140
	Blowers & Fans	1265	6.3324	8010	0.5577	4470
	Steam Engines and Turbines	15573	8.4232	131200	0.5577	73170
	Brick Products, Refractory	9571	11.7260	112200	0.5464	61310
	Cables (Electrical Indus. Apparatus)	993	7.0497	7000	0.4883	3420
	Construction Power	9	------	100	------	100
	Isolated Phase Bus (Elec. Indus. App.)	255	7.0497	1800	0.4883	880
X. Operations & Maintenance						
A. Fuel Transportation (30-yr life)	Railroad Transport	750000	7.9524	5964000	0.4000	2385600
B. Salaries (30-years)	Misc. Prof. Services	34400	2.6552	86030	0.5291	45520
C. Railcar Maintenance	Maintenance & Repair Constr., All other	15000	6.7117	100700	0.5291	52560
D. Maintenance	Maintenance & Repair Constr.	85200	7.5000	639000	0.5291	338090
E. Insurance	Insurance Carriers	23510	2.5000	58780	0.5500	32330
XI. Fuel Extraction and Processing	Calculated Using Train (1973)	-----	------	560000	------	560000
TOTAL POWER PLANT		180298				700275
TOTAL FUEL PLANT		20970				102330
TOTAL FUEL PLANT, POWER PLANT		201268				802605
TOTAL OPERATIONS & MAINTENANCE (30YR)		908110				2854100
TOTAL FUEL EXTRACTION						560000
TOTAL ESTIMATED ENERGY REQUIRED (30YR)		1109378				4156705
TOTAL ESTIMATED ENERGY PRODUCED (30YR)			Electricity = 4.30×10^{14}		Total = 4.30×10^{14}	
NET ENERGY RATIO					R = 0.097	

*Estimated

TABLE IV-6

SUMMARY OF NET ENERGETICS ANALYSIS RESULTS

ENERGY EXTRACTION CONVERSION PROCESS	ENERGY (METHANE)* EXTRACTION (Btu)	ENERGY GENERATION (Btu)	TOTAL ENERGY PRODUCTION (Btu)	CONSTRUCTION OPERATION ENERGY (Btu)	NET ENERGY RATIO	RECOVERY** PERIOD
1. Hydrothermal 10MW(e) Secondary Working Fluid	-----------	8.06×10^{12}	8.06×10^{12}	2.39×10^{12}	0.296	8.9 +
2. Flash-steam 25 MW(e) Includes Geohydraulic	4.86×10^{13}	1.95×10^{13}	6.85×10^{13}	3.88×10^{12}	0.0567	1.7
3. Secondary Working Fluid 33 MW(e) Includes Geohydraulic	7.57×10^{13}	2.72×10^{13}	1.03×10^{14}	7.34×10^{12}	0.0712	2.1
4. Methane Separation	8.41×10^{13}	-----------	8.41×10^{13}	4.99×10^{12}	0.0593	1.8
5. Central Texas Coal Plant 600 MW(e)	-----------	4.30×10^{14}	4.30×10^{14}	3.65×10^{13}	0.0970	2.9
6. Pressurized Water Nuclear Power Plant 1000 MW(e)++	-----------	7.2×10^{14}	7.2×10^{14}	4.9×10^{13}	0.0680	2.1

* Corrected to electricity basis by accounting for generation efficiency; division factor was 2.8.

** 30-year project life.

\+ An appropriate estimate for a commercial-sized unit is $750/kW installed instead of the $1620/kW for the 10 MW(e) unit. If a credit for learning during drilling is taken (say 30% overall cost reduction), construction energy is estimated at 1.58×10^{12} Btu while generation remains at 8.06×10^{12} Btu to give R = 0.19 and recovery time of 5.7 years (on a per 10 MW[e] basis).

++ Koen and Rombough (1975).

> resource competes favorably, on an energetic basis, with Western coal-fired and nuclear power stations sited in central Texas.

A second conclusion can be drawn:

> Hot water resources located in sedimentary deposits at 5,000 → 9,000 foot depths and not possessing reasonably high temperatures (>400°F) wellhead (flashing suppressed by pumping) will not compete, on an energetics basis, with western coal-fired or nuclear power stations in the same locality if methane is not present.

This second conclusion might be debated vigorously. However, as the power plant construction energetics are only about 25 → 30% of the total input energy, a significant advance in power plant technology will not bring the hydrothermal resource into competition on an energetics basis. To make deep hydrothermal resources competitive energetically will require: high wellhead enthalpies, better power plant energetics, and much better well field development energetics than those estimated here.

Several variations of the geopressured geothermal results are immediately available from the preceding work: power generation without methane, power generation without methane and geohydraulic, and power generation without geohydraulic. These are presented in Table IV-7. The results of these variations illustrate that the geohydraulic electricity generation has little impact on the net energy ratio and the energy recovery period. As expected, the project's energetics are dominated by methane recovery; should methane not be present in the geopressured geothermal waters, long energy recovery periods result. These are approximately 7 to 10 years and will undoubtedly result in highly noncompetively-priced electric power.

TABLE IV-7

NET ENERGETICS OF POSSIBLE VARIATIONS OF GEOPRESSURED GEOTHERMAL ENERGY PRODUCTION FACILITIES

ENERGY EXTRACTION, CONVERSION PROCESS	ENERGY (METHANE) EXTRACTION (Btu)	ENERGY GENERATION (Btu)	TOTAL ENERGY PRODUCTION (Btu)	CONSTRUCTION, OPERATION ENERGY (Btu)	NET ENERGY RATIO	RECOVERY PERIOD (YRS)
1. Flash Steam 19 MW(e) Without Geohydraulic	4.86×10^{13}	1.50×10^{13}	6.36×10^{13}	3.83×10^{12}	0.060	1.8
2. Flash Steam 25 MW(e) Without Methane	0.0	1.95×10^{13}	1.95×10^{13}	3.50×10^{12}	0.180	5.4
3. Flash Steam 19 MW(e) Without Geohydraulic Or Methane	0.0	1.50×10^{13}	1.50×10^{13}	3.47×10^{12}	0.231	6.9
4. Secondary Working Fluid 25 MW(e) Without Geohydraulic	7.57×10^{13}	2.06×10^{13}	9.63×10^{13}	7.26×10^{12}	0.075	2.3
5. Secondary Working Fluid 33 MW(e) Without Methane	0.0	2.72×10^{13}	2.72×10^{13}	6.70×10^{12}	0.246	7.4
6. Secondary Working Fluid 25 MW(e) Without Geohydraulic or Methane	0.0	2.06×10^{13}	2.06×10^{13}	6.62×10^{12}	0.321	9.6

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