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COMPARISON OF GEOTHERMAL ENERGY
WITH COAL, OIL, AND NATURAL GAS FOR SELECTED USES

By

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1979

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Final Report

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Abstract

Environmental effects and energy efficiencies for Geothermal energy, Western strip mined coal, and Eastern underground mined coal applied to space heating, process heat, and electric drive have been compared. The measure of an environmental effect is the amount of residual material released to the environment, and the measure of energy efficiency is the "second law efficiency" of the process involved. The results indicate that geothermal energy efficiencies (second law) are higher than those for coal for all three end uses. The environmental effects for geothermal supply systems are smaller than those for coal in the cases of space heat and process heat and are comparable in the case of electric drive. The optimum allocation of a finite geothermal resource and a finite coal resource between space heat and electric drive has been evaluated from the viewpoint of maximum end use service. The results indicate that, to the extent that locational factors permit, geothermal energy should be used for space heat and coal for electric drive.

COMPARISON OF GEOTHERMAL ENERGY AND COAL FOR SELECTED USES

Summary

Environmental effects and energy efficiencies of geothermal energy (hydrothermal), western coal, and eastern coal supply systems are compared for three end uses, namely space heating, process heat, and electric drive (motor). Environmental effects are compared per unit of end use supplied, for example grams of H_2S released per million BTU delivered. The energy efficiencies are second law efficiencies that compare amounts of end use actually delivered to the amounts that could be delivered if the energy resources were utilized in theoretically optimum ways. The comparisons show that the environmental effects of using geothermal sources are smaller than those arising from the use of coal when the geothermal fluids and dissolved gases are reinjected. However, if the dissolved gases are released during geothermal application, the environmental effects produced at some geothermal reservoirs can be similar to those for coal. The second law energy efficiencies are higher for geothermal sources than for coal supply systems in the case of all three end use applications. The reason for the superiority of geothermal energy from a second law perspective is that this supply system does not have any components that involve large entropy increases. On the other hand, in the case of coal, the combustion process itself and the transfer of heat from the high temperature combustion gases to water or steam are both highly irreversible and produce large entropy increases with consequent loss of second law efficiency.

A comparison of geothermal energy and coal from the viewpoint of maximum resource utilization suggests that geothermal energy used should

be used for low temperature heating while electric drive should be supplied by coal. Of course the usually remote location of geothermal sources severely restricts the practical application of this principle.

Description of the Systems Considered

The comparison between coal and geothermal energy is made for several energy end uses, namely space heat, process heat, process steam, and electric drive. Comparisons are made per unit of end use delivered.

The designs for the systems which deliver the end uses have, in most cases, been developed in other studies. The adoption of existing designs avoids the requirement to carry out engineering studies for this project and yet provides a set of realistic supply systems. The principal engineered systems that have been used are described briefly below and in more detail in Appendix A.

(a) The MIUS (Modular Integrated Utility System) designs developed at Oak Ridge National Laboratory⁽¹⁾. These are 900-unit apartment complexes heated in a variety of ways. MIUS designs A, D, and F were used. MIUS A, with hot water geothermal source is shown in Figure 1. MIUS F and MIUS D, which utilize electric resistance heating and heat pump operation respectively, are used in the coal space-heating option.

(b) Designs for a potato processing plant⁽²⁾ supplied on the one hand by a geothermal reservoir and on the other by a coal fired boiler. The geothermal version of the design is shown in Figure 2.

The other system components that were used in the study are standard units such as a coal fired power plant and an electric motor. They are not described here except for the parameters used in the energy and environmental analyses. In all, ten systems were analyzed and these ten are shown in Table 1.

Environmental Impacts

Both geothermal and coal based supply systems produce a variety of adverse environmental effects which, although somewhat different in nature for the two sources, have enough similarity to permit a comparison of the two. The principal effects considered for geothermal and coal systems are

<u>Coal</u>	<u>Geothermal</u>
Air Emissions: Particulates Sulfur oxides Nitrogen oxides Carbon dioxide	Air Emissions: Particulates Hydrogen sulfide Ammonia Carbon dioxide
Water residuals: total dissolved salts	Water residuals: total dissolved salts
Noise	Noise
Land disturbance	Land disturbance
Visual impacts	Visual impacts
Trace toxic residuals	Trace toxic residuals

It is difficult to quantify some of these impacts especially for geothermal energy. Special problems are the enormous ranges in composition of geothermal reservoirs, the great differences between controlled and uncontrolled releases, and the difficulties in specifying impacts dominated by accident conditions. Any conclusions that are drawn about impacts must be tempered by these uncertainties.

For those geothermal supply systems that utilize steam produced directly from geothermal fluids, air emissions are determined by conditions during normal operation. The reason is that the pressure reductions accompanying steam generation release the noncondensable gases from the geothermal fluid, and these gases must be continually removed from the system during normal operation in order to avoid their accumulation in the system. In contrast

to the case of steam, the air emissions from hot water geothermal systems with brine reinjection are primarily associated with drilling, testing, and cleaning operations. The average air emissions for both situations are shown in Table 2. More detail is given in Appendix B. The choice of air residuals included was made on the basis of the expected impacts. Particulates, sulfur compounds, and nitrogen compounds are generally considered to be important pollutants. The CO_2 was included because of recent questions about its effect on climate.

The measure of waterborne residuals used is total salt released. All of the systems studied assume that the geothermal fluids are reinjected so that the releases to the environment occur only during spills. The spill rate used, from Geysers data⁽³⁾, is one spill every five years per well with an average of 375 metric tons of fluid released per spill. Fluids at some fields are extremely salty, ranging up to 25% salt by weight at Niland California⁽⁴⁾. Using this extreme case for the upper limit of salt content and the spill rate above, the average salt release per year has been calculated and is shown in Table 2.

Air and waterborne residuals are released to the environment at several points in the coal supply system but most are produced at the power plant. The air emissions come almost entirely from the plant stacks, while the waterborne salt loads are generated in several plant operations including demineralizer regeneration, ash sluicing, boiler blowdown, and coal pile runoff. These residuals are summarized in Table 3. A discussion of relevant factors is given in Appendix C.

Noise is produced in both geothermal and coal supply systems. In the geothermal case the major noise producers are operations at the geothermal

wells especially drilling, well cleanout, and well testing. Sound levels can reach 90-100 decibels near the wells⁽⁵⁾, about the sound level of a passing freight train. The comparison is appropriate because in the coal option the coal transportation by rail from the mine to the power plant is the principal source of noise. However, there are some differences between the two noise sources. In the geothermal case the high level noise from a well may last for several days but noise episodes will occur very infrequently. On the other hand, the noise from a coal train will last only a few minutes but trains supplying a given plant will pass daily or even more frequently. Quantitative measures of total sound energy emitted by sources, i.e. the source strengths of sound sources, do not appear to be available so that it has not been possible to consider noise pollution in this report in a way comparable to air and waterborne residuals. Qualitatively it seems clear that comparable noise levels are reached in the two energy supply systems, at least for geothermal sources that involve steam. These levels, 90-100 decibels, are above the level of 70 decibels which the Environmental Protection Agency has been using recently as a threshold of concern for hearing loss⁽⁶⁾. Additional data are provided about noise impacts in Appendices B and C.

Land disturbances, visuals impacts, and trace toxic materials are likewise not considered quantitatively in the main body of the report although land disturbance data are included in Appendices B and C. These impacts were considered important but less so than the others.

Energy Efficiencies

The supply systems that are being compared in this report are very different from one another. The geothermal system supplies energy from a heat reservoir, while the coal system releases energy during chemical changes accompanying combustion. Under these circumstances it is especially important to express energy stocks and flows in terms that focus on "useful energy" that is available for end uses. The quantity that serves this purpose is called available work⁽⁷⁾, availability, and it is related to the usual thermodynamic functions by

$$\phi = U + P_0 V - T_0 S - \sum_i \mu_{i0} N_i$$

where ϕ is the availability for a system

U is its internal energy

V is its volume

S is its entropy

N_i is the amount of component i in the system

P_0 is atmospheric pressure

T_0 is atmospheric temperature

and μ_{i0} is the chemical potential of the i th component in equilibrium with the atmosphere.

A system undergoing change can transfer availability to an end use such as electric drive or space heat, but some availability is lost in the process. Availability is not a conserved quantity but gradually diminishes.

Quantitatively

$$W + \left(1 - \frac{T_0}{T_r}\right) Q = -\Delta\phi - T_0 \Delta S_T$$

where W is work carried out as an end use,

Q is heat transferred to end use,

T_r is the Temperature of the space receiving Q ,

and ΔS_T is the loss term arising from overall entropy increases of the system and its surroundings.

The availability delivered to the end uses is less than that supplied from the source by the amount $T_0 \Delta S_T$. The efficiency of the process, defined as availability delivered divided by availability supplied and called the

second law efficiency, is

$$\epsilon = \frac{-\Delta\Phi - T_0 \Delta S_T}{-\Delta\Phi} = \frac{W + (1 - \frac{T_0}{T_r})Q}{-\Delta\Phi}$$

A somewhat more general formulation is

$$\Delta\Phi \text{ end use} = -\Delta\Phi \text{ energy source} - T_0 \Delta S_T - \Delta\Phi \text{ not used}$$

where $\Delta\Phi$ end use is the availability delivered to the end use

$$\text{and } \epsilon_2 = \frac{\Delta\Phi \text{ end use}}{-\Delta\Phi \text{ energy source}}$$

In all of the numerical evaluations in this report some simplifications and approximations are used. In particular the systems are all considered to be closed so that gaseous components among the reactants and the products are considered to be parts of the systems. Under these circumstances the term $\sum_i \mu_{i0} N_i$ does not change during a process. Furthermore, some contributions to changes in availability, such as entropies of mixing and effects of non-condensable gases, are neglected. Finally the change in availability during a chemical reaction is approximated by ΔH , the change in enthalpy during the reaction, usually called the heat of reaction.

Each of the ten systems considered has been analyzed for second law efficiency and the results are tabulated in Table 4. Details of some analyses are given in Appendix A. Table 4 shows that the second law efficiencies of geothermal supply systems are higher than those of coal systems supplying the same end uses. The basic reason for the higher efficiencies of geothermal supply systems is that they do not have any highly irreversible components similar to the combustion process and subsequent heat transfer in steam generators in coal supply systems.

Systems Comparisons

The ten different supply systems are compared for the same end uses in Figures 3-14. The comparisons include (1) air emissions and salt (brine) per unit of availability delivered and (2) energy efficiencies. It should be noted that the columns labeled "sulfur" and "nitrogen" identify hydrogen sulfide and ammonia in the geothermal systems but sulfur dioxide and nitrogen oxides (calculated as NO_2) in the coal systems. The releases of residuals in the geothermal case are based on upper limits among reservoir concentrations. More typical values would be lower by a factor of 10, and for some reservoirs by a factor of 100 to 1000. Moreover the releases are especially uncertain in those cases where they occur during drilling, cleaning, and testing phases of operation or during accidents. Data from the Geysers operation were used to establish the magnitudes used here.

Several conclusions about relative merits of geothermal energy versus coal can be drawn. One is that geothermal energy appears to be superior to coal for space heat and process heat in terms of both energy efficiency and environmental effects. Basically the reason for the lower releases is that the residuals are reinjected into the reservoir during normal operation; only the initial phases of well operation, and accidents, contribute to the releases shown. A second conclusion is that a geothermal source and coal used for electric drive are more nearly comparable in energy efficiency and environmental effects than is the case for space heat and process heat. The hydrogen sulfide and ammonia emissions are much larger in this application because these non-condensable gases are continually removed from the system and released to the atmosphere. A third conclusion is that the use of Western coal is somewhat more efficient and less environmentally damaging than the use of Eastern coal.

A factor not considered in this study, but one that affects the relative position of geothermal and coal, is long distance transportation of energy resources. It is not economical to ship hot water or steam long distances and therefore, although economic analysis is not part of this work, it is taken for granted that direct use of geothermal energy is restricted to users located near the reservoir.

Optimum Resource Allocation

From a long range standpoint an important objective of national energy policy is to satisfy demand as long as possible with the resources that are at hand. This subject was addressed briefly in this study. The following problem was solved:

Given two energy resources, #1 a geothermal reservoir containing A_1 units of availability, and #2 a coal deposit containing A_2 units of availability, and given two end uses, (1) space heating and (2) electric drive. If ϵ_1 and ϵ_2 are the second law efficiencies for supplying end uses (1) and (2) from resource #1 and ϵ_3 and ϵ_4 the efficiencies for supplying end uses (1) and (2) from resource #2, the amounts of space heating and electric drive supplied can be written

$$E_1 = \text{amount of space heating} = \epsilon_1 \alpha A_1 + \epsilon_3 \beta A_2$$

$$E_2 = \text{amount of electric drive} = \epsilon_2 (1-\alpha) A_1 + \epsilon_4 (1-\beta) A_2$$

where α is the fraction of A_1 used to supply space heating and β is the fraction of A_2 used to supply electric drive

Assume that the amounts of end use must be supplied in definite relative amounts, i.e. $E_2 = k E_1$.

The problem is to find the values of α and β that maximize $E_1 + E_2$. The solution is worked out in Appendix D. The results are covered by these four cases:

(A) If $\frac{\epsilon_1}{\epsilon_2} > \frac{\epsilon_3}{\epsilon_4}$ and $\frac{k \epsilon_1 A_1}{\epsilon_4 A_2} < 1$, the optimum solution is $\alpha = 1$

$$\beta = \frac{1 - \frac{k \epsilon_1 A_1}{\epsilon_4 A_2}}{1 + \frac{k \epsilon_3}{\epsilon_4}}$$

$$(B) \quad \frac{\epsilon_1}{\epsilon_2} > \frac{\epsilon_3}{\epsilon_4} \text{ and } \frac{k\epsilon_1 A_1}{\epsilon_4 A_2} > 1, \text{ the optimum solution is } \alpha = \frac{1 + \frac{\epsilon_4 A_2}{\epsilon_2 A_1}}{1 + \frac{k\epsilon_1}{\epsilon_2}}$$

$$\beta = 0$$

$$(C) \quad \frac{\epsilon_1}{\epsilon_2} < \frac{\epsilon_3}{\epsilon_4} \text{ and } \frac{k\epsilon_3 A_2}{\epsilon_2 A_1} > 1, \text{ the optimum solution is } \alpha = 0$$

$$\beta = \frac{1 + \frac{\epsilon_2 A_1}{\epsilon_4 A_2}}{1 + \frac{k\epsilon_3}{\epsilon_4}}$$

$$(D) \quad \frac{\epsilon_1}{\epsilon_2} < \frac{\epsilon_3}{\epsilon_4} \text{ and } \frac{k\epsilon_3 A_2}{\epsilon_2 A_1} > 1, \text{ the optimum solution is } \alpha = \frac{1 - \frac{k\epsilon_3 A_2}{\epsilon_2 A_1}}{1 + \frac{k\epsilon_1}{\epsilon_2}}$$

$$\beta = 1$$

Cases (A) and (B) cover the situation where the geothermal reservoir is better suited to space heat relative to electric drive than is coal ($\frac{\epsilon_1}{\epsilon_2} > \frac{\epsilon_3}{\epsilon_4}$). This is the actual situation for the systems described in this report. Under these circumstances when the coal resource is much larger than the geothermal reservoir, the optimum solution is to allocate all of the geothermal resource to space heat and make up the remaining demands with coal. When the coal is less plentiful, it should all be used to supply electric drive with remaining demands to be supplied by the geothermal resource.

Cases (C) and (D) cover the situation where the coal resource is better suited to space heat relative to electric drive than is geothermal ($\frac{\epsilon_3}{\epsilon_4} > \frac{\epsilon_1}{\epsilon_2}$). These cases do not correspond to the actual situation, but under these circumstances the optimum allocation would stress coal for space heat and geothermal energy for electric drive.

Allocation problems of this kind involving several energy resources and end uses could be worked out, but this was the only case considered in this project. Qualitatively the conclusion can be drawn that geothermal energy should be used for direct space and process heating to the extent that locational factors permit.

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TABLE 1. GEOTHERMAL AND COAL SUPPLY SYSTEMS

Source	Conversion	Transportation	Conversion	Distribution	End Use	Waste Disposal
1. Hydrothermal	----	Pipeline	----	----	Space Heat	Reinjection
2. Western Coal-Surface	----	Rail	Electricity	Trans. Lines	Baseboard Heat	----
3. Eastern Coal-Under-ground	----	Rail	Electricity	Trans. Lines	Baseboard Heat	----
4. Western Coal-Surface	----	Rail	Electricity	Trans. Lines	Heat Pump	----
5. Hydrothermal	----	Pipeline	----	----	Process Heat	Reinjection
6. Western Coal-Surface	----	Rail	Boiler	----	Process Steam and Heat	With Process Wastes
7. Eastern Coal-Under-ground	----	Rail	Boiler	----	Process Steam and Heat	With Process Wastes
8. Hydrothermal	Electricity	----	----	Trans. Lines	Electric Motor	Reinject Liq. Release Gases
9. Western Coal-Surface	----	Rail	Electricity	Trans. Lines	Electric Motor	----
10. Eastern Coal-Under-ground	----	Rail	Electricity	Trans. Lines	Electric Motor	----

TABLE 2. GEOTHERMAL RESIDUALS

RESIDUALS	END USE		
	Space Heat	Process Heat	Electric Drive
PARTICULATES			
G/KG of Geothermal Fluid	.003	.003	.003
G/MMBTU of Heat Delivered	.07	.025	
G/MMBTU of Availability Delivered	1	.25	12
H ₂ S			
G/KG of Geothermal Fluid	.004-1	.004-1	.004-1
G/MMBTU of Heat Delivered	.07-24	.03-8.3	
G/MMBTU of Avail. Delivered	1-330	.3-83	14-3900
NH ₃			
G/KG of Geothermal Fluid	.007-.8	.007-.8	.007-.8
G/MMBTU of Heat Delivered	.1-16	.05-5.5	
G/MMBTU of Avail. Delivered	2-220	.5-55	23-2600
CO ₂			
G/KG of Geothermal Fluid	.2-22	.2-22	.2-22
G/MMBTU of Heat Delivered	4-460	1.5-160	
G/MMBTU of Avail. Delivered	60-6300	15-1600	690-74000
SALT			
G/KG of Geothermal Fluid	2-250	2-250	2-250
G/MMBTU of Heat Delivered	.7-72	.7-68	
G/MMBTU of Avail. Delivered	10-1000	7-680	.7-72

Source: References (3) and (4)

TABLE 3A. WESTERN COAL RESIDUALS

RESIDUALS	END USE			
	Space Heat		Process Heat	Electric Heat
	Res. Heat	Heat Pump		
PARTICULATES				
G/MMBTU of Heat Delivered	100	50	1400	---
G/MMBTU of Availability Del.	1550	730	14000	120
SO ₂				
G/MMBTU of Heat Delivered	170	80	700	---
G/MMBTU of Availability Del.	2600	1200	7000	200
NO _x				
G/MMBTU of Heat Delivered	930	440	330	---
G/MMBTU of Availability Del.	14000	6600	3300	1100
CO ₂				
G/MMBTU of Heat Delivered	4.2E5	2.0E5	1.9E5	---
G/MMBTU of Availability Del.	6.3E6	3.0E6	1.9E6	4.7E5
SALT				
G/MMBTU of Heat Delivered	46	22	21	---
G/MMBTU of Availability Del.	690	320	210	52

Source: Reference (8)

TABLE 3B. EASTERN COAL RESIDUALS

RESIDUALS	END USE		
	Space Heat (Res)	Process Heat	Electric Drive
PARTICULATES			
G/MMBTU of Heat Delivered	120	1400	---
G/MMBTU of Availability Del.	1800	1.4E4	130
SO ₂			
G/MMBTU of Heat Delivered	650	2500	---
G/MMBTU of Availability Del.	9700	2.5E4	690
NO _x			
G/MMBTU of Heat Delivered	1000	330	---
G/MMBTU of Availability Del.	1.5E4	3300	1100
CO ₂			
G/MMBTU of Heat Delivered	2.9E5	1.2E5	---
G/MMBTU of Availability Del.	4.4E6	1.2E6	3.2E5
SALT			
G/MMBTU of Heat Delivered	250	110	---
G/MMBTU of Availability Del.	3800	1100	270

Source: Reference (8).

TABLE 4. SECOND LAW EFFICIENCIES

ENERGY SOURCE	END USE		
	Space Heat	Process Heat	Electric Drive
GEO THERMAL	.104	.31	.57
WESTERN COAL	.022 (Res. Heat)	.078	.31
	.047 (Heat Pump)		
EASTERN COAL	.012 (Res. Heat)	.043	.17

GEO THERMAL SPACE HEATING

Figure 1

Figure 2

Fig. 3 ENERGY EFFICIENCY AND RESIDUALS COMPARISONS FOR SPACE HEAT

Fig. 4 ENERGY EFFICIENCY AND RESIDUALS COMPARISONS FOR PROCESS HEAT

Fig. 5 ENERGY EFFICIENCY AND RESIDUALS COMPARISONS FOR ELECTRIC DRIVE

HYDROTHERMAL-PIPELINE-SPACE HEAT-REINJECTION

Figure 6

WESTERN COAL-ELECTRICITY-RESISTANCE SPACE HEAT

Figure 7

EASTERN COAL-UNDERGROUND MINE-ELECTRICITY-SPACE HEAT

Figure 8

HYDROTHERMAL-PROCESS HEAT

Figure 9

WESTERN COAL-PROCESS STEAM-PROCESS HEAT

Figure 10

EASTERN COAL-PROCESS STEAM-PROCESS HEAT

Figure 11

HYDROTHERMAL - ELECTRICITY - MOTOR

Figure 12

WESTERN COAL-ELECTRICITY-MOTOR

Figure 13

EASTERN COAL - ELECTRICITY - MOTOR

Figure 14

APPENDIX A

ENGINEERED SYSTEMS

The Geothermal Hot Water System for Space Heat

The model space heating system used in this study is the cluster of garden apartments described in the MIUS system study (1) as MIUSA. The system is shown schematically in Fig. 1 and also in Fig. A-1. The latter figure is labeled to show the parameters needed for a thermodynamic analysis. In the analysis the assumption is made that hot water is withdrawn from the geothermal reservoir, run through a heat exchanger, and then reinjected into the same reservoir. The net effect of this circulation of geothermal fluid is to reduce the available work in the reservoir by $\Delta U'_r(1-T_0/T_1)$, where $\Delta U'_r$ is the total loss of internal energy of the reservoir.

The change of internal energy $\Delta U'_r$ is related to heat flux and work done on the heating system by

$$\Delta U'_r = Q'_A + Q'_B + Q'_R - W'_1 - W'_2 - W'_L$$

where Q'_A , Q'_B , and Q'_R are heat fluxes out of the system as shown in Fig. A-1 and W'_1 , W'_2 , and W'_L are work done on the system by pumps and fans.

The total availability lost in the operation of this system is the loss in the geothermal reservoir plus the loss associated with the operation of the motors, namely $(W'_1+W'_2+W'_L)/E_p$, where E_p is the efficiency of the power plant supplying the electric motors. Thus the total loss of availability is

$$\Delta U'_r(1-\frac{T_0}{T_1}) + \frac{W'_1+W'_2+W'_L}{E_p}$$

The availability delivered to the heated space is $Q'_R(1-\frac{T_0}{T_R})$, where T_R is the temperature of the heated space.

The system described above could supply all of the space heat required, but some cost reduction can be achieved by adding a fossil fuel peaking supply system. Adding the peaking system permits a reduction in the size of the piping and other components of the geothermal supply system. A typical peaking unit will supply about 10% of the space heat. The loss in availability of the combined supply is

$$\begin{aligned} \Delta \phi = & 0.9 (Q'_A + Q'_B + Q'_R - W'_1 - W'_2 - W'_L)(1-\frac{T_0}{T_1}) + 0.1 \frac{(Q'_B + Q'_R - W'_L)}{E_f} \\ & + \frac{0.9 W'_1 + W'_2 + W'_L}{E_p} \end{aligned}$$

where E_f is the efficiency of the fossil fuel backup system based on high heating value.

The appropriate values of the parameters are (per year):

$$\begin{array}{lll} Q_R = 27.6 \times 10^9 \text{ BTU} & W_L = 1.1 \times 10^9 \text{ BTU} & E_p = .32 \\ Q_A = 0.1 Q_R = 2.8 \times 10^9 \text{ BTU} & W_2 = .65 \times 10^9 \text{ BTU} & E_f = .6 \\ Q_B + Q_R = 29.1 \times 10^9 \text{ BTU} & W_1 = \text{small} & T_1 = 406^\circ \text{K} \\ T_o = 273^\circ \text{K} & T_r = 294^\circ \text{K} & \end{array}$$

With these values the second law efficiency is .104. A calculation was also carried out for the case where the geothermal fluid is not reinjected back into the same reservoir but is instead reinjected "downstream" into a separate reservoir or else is released as waste water. The efficiency is not very much different.

The Base board and Heat Pump Systems for Space Heat

The supply systems in these cases incorporate a coal-fired power plant producing electricity that is then transmitted to the garden apartment complex and used either directly in a base board heater or in a heat pump mode.

Geothermal Process Heat System

The geothermal process heat system selected for analysis is a modification of an existing potato processing plant. The modified plant is described by Lienau (2) and is shown schematically in Figure 2 of the main report. The plant can process two million pounds of potatoes per day and uses process heat for peeling, blanching, water heating, and plant heat.

In order to calculate second law efficiency for this application it is necessary to define the end use supplied. For this report the end use is considered to be the supplying of heat to raise the temperature of the several process streams involved in the processing. The availability delivered by supplying heat Q to a system that is thereby increased in temperature from T_1 to T_2 is

$$\Delta\phi = Q \left(1 - \frac{T_o}{T_2 - T_1} \ln \frac{T_2}{T_1} \right).$$

For the process streams shown in Figure 2 the results are

Process Stream	T_1 (°F)	T_2 (°F)	Q 10^6 BTU/hr	$\Delta\phi$ 10^6 BTU/hr
Peeling 1.	200	260	4.1	.90
Peeling 2.	150	200	5.6	.84
Peeling 3.	100	150	14.6	1.12
Hot Blanch	100	200	16.5	1.86
Warm Blanch	100	150	8.9	.68
Water Heating	100	150	2.6	.09
Plant Heat	100	150	11.0	.84
				<u>6.32</u>

The availability lost from the geothermal reservoir, assuming reinjection of the brine into the same reservoir is $Q_1(1-T_0/T_1)$ where Q is the heat removed from the reservoir, T_0 is the temperature of the atmosphere (80°F), and T_1 is the temperature of the reservoir (300°F). Using as the value of Q the sum of the values shown above for the process streams the total availability lost from the reservoir is 10.4×10^6 BTU/hr. Availability is also lost through the energy expended in pumping the geothermal fluids and the processing liquids through the plant. Leinaw (2) reports the pumping requirements to be about 210 hp. Based on this figure the availability is $\frac{Q'}{\epsilon_1 \epsilon_2}$ where Q' is the pumping energy, ϵ_1 is the efficiency

of the electrical supply system taken to be .32, and ϵ_2 is the efficiency of the motor pump system taken to be 0.8. The value of Q is $.53 \times 10^6$ BTU/hr and the availability lost through pumping is 2.1×10^6 BTU/hr.

GEOTHERMAL SPACE HEATING SYSTEM

Figure A-1

APPENDIX B

GEOHERMAL RESIDUALS

GEOHERMAL ENERGY UTILIZATION: PROCESS FLOW CHART

Extraction

Conversion

Transportation

End Use

Waste Disposal

Environmental residuals associated with the use of geothermal energy resources are tabulated below. The geothermal utilization flow chart (Figure A-1) show the specific activities associated with each process in the energy system, from extraction to end use. The flow of the resource from stage to stage in the energy utilization system is indicated by arrows, and the occurrence of residuals is indicated by an "R" at that stage. Activities which have residuals associated with them are analyzed below. The reference numbers refer to the references at the end of this appendix.

1. EXTRACTION/REINJECTION

AIR EMISSIONS

Raw steam releases have the following quality characteristics:

TABLE 1

residual	g/kg steam*	g/10 ⁶ Btu**
H ₂ S	0.18	348
NH ₃	0.19	368
CO ₂	3.26	6306
B ²	1.46 x 10 ⁻³	2.824
As	6.4 x 10 ⁻⁷	1.24 x 10 ⁻³
Hg	3.14 x 10 ⁻⁶	6.08 x 10 ⁻³
Rn-222	2.02 x 10 ⁻⁸	3.9 x 10 ⁻⁵
Particulate	3.37 x 10 ⁻³	6.52
Ch ₄	0.19	368

* Based on Geysers (II Table 10.2)

** Based on 240° C steam, 517 Btu/kg.

TABLE 2

Range of variation in steam quality:

Residual	Average Concentration	Low*	High*
H ₂ S	222	.023	7.21
CO ₂	3260	.089	9.39
NH ₃	194	.048	5.46
CH ₄	194	.067	7.46

Based on variability shown in wells at Geysers, (5; Table 9, 10; Table 4-4)

* For all figures given below, to find range over which they may vary for a given residual, multiply the emission stated times the number given in the "low" column to get the low extreme, and times the value in the "high" column to get the high extreme.

Raw steam is emitted during well drilling (8.3×10^6 kg/well) and during well cleaning and flow test (6.3×10^6 kg/well) (each well is cleaned and tested for approximately 5 days). These emissions are concentrated at one time (when the well is opened) and relate best to the plant capacity being developed. After all wells are drilled, tested and cleaned, plant operation continues without further contribution from these sources. Emission per 10¹² Btu are given in Table 3, for the vapor dominated case. These residuals apply to the dry steam geothermal-fired power plant.

In a liquid dominated system, 13-25% of the fluid flashes to steam as it rises in the well, and is released (6). Since most of the noncondensable gases should come off at this time, it is assumed that for the hydroconvective system the steam is released at the same temperature and pressure, and has the same quality characteristics as the dry steam reservoir.

TABLE 3

Emissions During Drilling & Cleaning (g/10⁶ Btu)

Residual	Range	Average
CO ₂	753-1253	1003
H ₂ S	512-853	682.5
NH ₃	447-737	591.2
CH ₄	202-337	268.4
B	3.37-5.61	4.491
As	1.5×10^{-3} - 2.5×10^{-3}	1.968×10^{-3}
Hg	7.2×10^{-3} - 12.1×10^{-3}	9.653×10^{-3}
Rn-222	4.6×10^{-5} - 7.8×10^{-5}	6.211×10^{-5}
Particulates	7.78 - 12.96	10.37

90-150 wells are required for a 1000 MWe geothermal plant, or .09-.15 wells/MW. Plant life is 30 years. Well life is 10 years. Therefore, at any given time .03-.05 wells supply 1 MW of capacity. Each well produces 1 MW ÷ .15 (efficiency of conversion) = 166.7 MW of raw steam. If a well runs for 10 years this amounts to 1,667 MW-years, or 5.7×10^9 Btu. Emissions from well drilling and cleaning are calculated against this raw energy output per well.

Natural background is not pure, but is contaminated by about 2.2 kg steam released/hour from natural fumaroles. This steam has the same quality characteristics as given in Table 1 (10).

Emissions also occur when a blowout happens, which is "an uncontrolled release of geothermal fluids through or in association with a well hole" (11). There are rare, Geysers has had 2 of 160 wells blow. They may be large and continue up to several months, or small and quickly controlled. Steam released is assumed of same quality as shown in Table 1(11).

Dust emissions during drilling range from .09-195 kg/hr/well. This is assumed suppressed by spraying with water from the sump which collects the run-off as well.

Steam is released when the power plant is shut down for a short time for maintenance. These amount to 140-540 kg/hr of the same quality as in Table 1 (10). Steam released while plant is down may be controlled by cross-over lines to other units (10). Assume 100% control.

NOISE

Federal geothermal leasing regulations set a standard of 65 dBA at 660 feet.

Source 10, Table 6-8 shows in 21 sources tested at the Geysers is at least partially violated the standard.

Noise levels associated with various components of extraction are compiled from several sources:

TABLE 4

Operation	Source # (See References)			
	10	6	11	5
Drilling Pad Construction			90dBA at 50'	
Mud drilling			90dBA at 50'	
Air drilling				
Muffled (cyclonic)			90dBA at 50'	93dBA at 25'
Unmuffled	59-93 dBA at 660'	125dBA at 25'	100dBA at 50'	120dBA at 50'
Well cleanout & Testing	65-86 dBA at 660'	100dBA at 35'		85dBA at 50'
Unmuffled			120dBA at 50'	
Muffled (cyclonic)			95dBA at 50'	
*Steam line vent	65-76dBA at 660'	100dBA at 50'		
Shut in Well				
Vent			75dBA at 50"	
Bleed	59-63dBA at 660'			
Blowout			86dBA at 8,600	
Steam well	42-108dBA at 660'			
Free venting well	88-99dBA at 660'			

* This noise release removed by use of cross-over lines.

Source 11, Table 5.2 gives frequency of occurrence of these activities.

LAND

Land Use

For 1,000 MWe installation, 90-150 wells, at 60 acres/well spacing, or 5400-9000 acres. 5.4-9.0 ac/MW. (8)

Access roads needed to move drilling equipment. About 45' wide (11). About 3-4 miles graded and compacted. 2 ac/well affected (5). So 180-300 ac/1000 MW, or .18-.3 ac/MW.

Drill pad of 1.25-2.5 ac/well must be leveled and cleared of vegetation (8). Works out to .113-.375 ac/MW.

Sump contains solid waste-drill cuttings, and waste fluid. After drilling, contents are allowed to dry, mixed with native soil and buried in the sump. Sump water is used for dust control. Sump is in form of a basin whose size depends on expected hole depth. To store 10⁶ gallons effluent and cuttings requires .287 ac/well. Works out to .0258-.0431 ac/MW (5).

Generally, geothermal development isn't incompatible with typical rural uses - e.g. agriculture, hunting and fishing (provided reinjection is practiced), grazing. The noise level it would make is incompatible with recreation.

Subsidence

Not a problem for dry-steam fields.

Reinjection will mitigate subsidence by returning water to reservoir to support ground.

Subsidence is result of interaction of fluid production and local geology. Caused by a decrease in porosity due to decreased pore fluid pressure, leading to pore collapse and crack closure (4).

Degree of subsidence highly variable, as it depends on character of local formation (porosity, density, etc) which may vary greatly from location to location.

Subsidence at Wairakei: ~48½ feet maximum, with 5 feet horizontal movement. 5'-48.5' subsidence contours occur over an area about 13,000' radius. About 93 acres are affected. Associated pressure drop 0.34-1.77 bars/yr; compaction .215'/yr. Common to have an increase in rock compressibility over time as fluid production occurs. Subsidence rate .0215'/10⁹ kg fluid produced. At 714.3 Btu/kg: 0.031/10¹² Btu removed (4).

Characteristics of 101 KGRA's:

Land Surface Form - considerable similarity. Only 8% on smooth plains, the rest on elevated lands. More than 50% of land is "gently sloped", meaning inclination of less than eight degrees.

Land use - more than 40% are "desert shrub grazed", next most common uses are: ungrazed desert shrubland, grazed and ungrazed forest and woodland, grazed open woodland. Some contain irrigated land. Most encompass several types of environments.

Population density - of counties containing KGRA's, one-third have less than one person per square mile, two-thirds less than six persons/mi². Only 10% are above national average density of 57/mi².

Seismic Activity - A general trend towards being areas of seismic activity.

Surface geology - tremendous variety.

Seismicity

Geothermal areas tend to be those of natural seismic activity.

Earthquakes may be induced by:

1. Water injection at pressure sufficient to lubricate fault, causing stress release.
2. Water removal, increasing friction along fault, promoting large earthquakes.

This impact is ambiguous because (1) injection of fluids is used to control earthquakes by providing local stress release, (2) the two postulated causes are from opposing actions.

Wildlife/Habitat

Access roads cross habitat. Wells, sumps, drilling pads occupy it.

Noise from various extraction activities may disturb wildlife.

Subsidence or landslides as a result of development may permanently alter habitat.

WATER

Surface Water

Reinjection technology as practiced at Geysers would mitigate all impacts of brine disposal (5). Practical problems of corrosion and scaling must be solved before reinjection can be considered feasible (8).

Siltation occurs during construction of power plant, drill pads, access roads.

Spills of drill fluids may contaminate surface waters. Data unavailable as to volume, frequency of such spills.

Ground Water

Ground water may be contaminated by well rupture. Data unavailable to characterize this event.

Reinjection has the potential to pollute ground water. Depends on quality of fluid and character of formation, both highly variable from site to site (8). Important parameters that vary are formation porosity, grain density, permeability, and conductivity, fluid density, temperature, pressure, salt saturation, and general geochemical environment (4). Dissolved solids may precipitate at lower effluent temperatures or react with minerals in receiving formation to plug pores and close disposal space (8). Drinking water aquifers previously protected by layers of impermeable strata may be infiltrated when drilling opens vertical channels between aquifer and brine. May occur during drilling, from abandoned exploratory well or during operation if casing leaks (8). Only a problem if aquifer is above the reservoir (6).

Reinjection at the Geysers occurs at rate of 193t/hr from a surface condenser unit. About 5×10^4 gallons of brine/MW are produced per year, containing 5×10^4 tons of dissolved solids (based on 1,000 MWe plant, 6). Brine can run 250,000 ppm TDS. At the Geysers, if 3% of H_2S into is oxidized into plant SO_4 ; 0.06g/kwh of SO_4 leaves in reinjectate.

Cooling tower discharge reinjected (Geysers, from 6).

	(tons/10 ¹² Btu to plant)	
Carbonates	NO ₄	.007
(alkalinity) 29.3	Cl ⁴	.24
NH ₃ 10.1	Ca	.36
SO ₂ 0.14	Mg	.07
SO ₄ 8.9	Si	.25
S ₄ 0.6	B	1.17
		Total Solids from evaporation 12.6
		Organics & volatile solids 14.1

Blowouts also have potential to contaminate ground and surface waters.

II. TRANSPORTATION

PIPELINE

Since power plant is located at reservoir, pipeline transportation residuals apply only to hydroconvective, direct-use case.

A pipeline rupture may contaminate surface and ground water, and cause 100 dBA (unknown distance) excessive noise (5). Data are unavailable to characterize volume or frequency of such events. Hot water would flash to steam of same or better quality than shown in Table 1 (better quality for reasons covered in section IV)

Pipeline venting emissions are routine, but can be collected and disposed via reinjection. Assume 100% control (11).

Land Use

Pipes are 10"-30" diameter, raised no more than 12' above ground level. 10'-300' are cleared, depending on need for access roads.

From examples in (2), pipe lengths are:

- 18 km (11.2 mi) from Reykir field in Iceland
- 3 km (1.9 mi) from Reykjavik field in Iceland
- 11.5 km (7.1 mi) from Sarukura field in Japan

Therefore, assume 2-12 miles piping distance to end use, with 30' cleared. 7.76-43.6 acres affected for pipe land occupation.

Wildlife/Habitat

Pipes run above ground, crossing and possibly disturbing habitat (8).

TRANSMISSION LINES

Same as for coal.

Land impact only: 778 ac-yr/10¹² Btu produced at plant. This is share of 4 million acre right-of-way allocated to 1,000 MWe plant, based on share of 1970 U.S. electric production by same plant (.0043%)

III. CONVERSION

LAND

Land Use

Conversion at site of fluid extraction (8).

About 125 acres for power plant itself. (1000 MWE plant requires steam at 1.8×10^7 lb/hr, or 127 wells producing 150,000 lb/hr ea-6).

Solid Waste

Disposal of air effluent control-system sludge required. Volume unknown (8).

Radioactive materials recovery may add to volume (8).

Landslides

Induced in Geysers area by plants. Geothermal field has steep slopes, unstable mantle.

Wildlife/Habitat

Noise may disturb wildlife.

Plant occupies habitat, landslides may alter it, roads and pipes cross it.

NOISE

Noise from steam venting mitigated by use of cross-over lines to other units.

Steam separator - 80 dBA at 25" (5)

"Power plant muffler" - 70-79 dBA at 660' (violates federal standards of 65 dBA) (10).

Steam jet gas ejector - 59-63 dBA at 660' (10).

Cooling tower - 54-62 dBA at 660' (10).

Outside turbine generator building - 51 dBA at 660'

WATER

Cooling water make-up is from condenser in surface-condenser-equipped plants.

Thermal discharge is 5.4×10^{10} Btu/yr at Wairakei (reinjection removes this)

Chemical discharges to Waikato Rv. from Wairakei plant are shown in (8 App. E) Depending on flow, this river has .04-.25 ppm: As (5 x US Std.) and .5 mg/kg Hg concentration in trout (about maximum for human consumption).

Si is a problem in siltation and clogging channels. Discharge to a surface water is removed by reinjection.

Condensate spills may contaminate surface and ground waters. Frequency: 7 at Geysers 5/74-9/74. Some unreported. Assume for 1,000 MW plant 17.5 spills/yr. Spills average 375 million tons (range 11-740 million tons) (11).

Total spillage is 6562.5 million tons/yr, then, from 1,000 MW plant. Effluent contains (g/yr).

SO ₄	7.87×10^5	Hg 1.57
*B ₄	1.55×10^6	As 2.07
NH ₃	7.55×10^5	S 78.75

(Based on Geysers, units 5 & 6, in 11, Table 10.1)

*Boron is concentrated in condensate, spills become increasingly severe with regard to Boron.

AIR

The following gives an idea of the range of variation in uncontrolled emissions from geothermal plants:

TABLE 5

Plant	CO ₂	H ₂ S	Emission g/kwh NH ₃	H ₃ BO ₃
Larderello (Italy)	403.8	8.406	2.864	2.759
Matsukawa (Japan)	100.6	11.187	1.757	6.407
Wairakei (New Zealand)	11.97	0.444	0.030	0.009
Cerro Prieto (B.C.)	95.63	3.268	0.045	
Geysers (California)	29.01	1.975	1.726	

The following breaks down the uncontrolled emissions to in-plant origination for Geysers uncontrolled. (Based on 11, Tables 6-4, 6-5; 10, Tables 10.2, 8.1)

Uncontrolled Emissions with Contact^a Condenser (g/kwh)

TABLE 6

Residual	Cooling Tower	Off-Gas Ejector	Total in Steam
As			2.9×10^{-5}
CO ₂ ^c	1.74	27.27	29.01
H ₂ S ^b	1.39	0.53	1.98
NH ₃ ^d	1.73	---	1.73
B			3.3×10^{-2}
CH ₄	---	0.78	0.78
Hg			3.7×10^{-5}
Rn-222			2.1×10^{-7}
Particulates			.223

- a. Breakdown for surface condenser, uncontrolled is unknown.
Total is same
- b. California standard is 30 ppb (24-hr). 0.06 g/kwh H_2S of total in steam is oxidized and reinjected as SO_4 (11). These figures based on 222 pp, H_2S .
- c. Background CO_2 -320 ppm. This adds 5.1 ppm in vicinity of plant.
- d. Background NH_3 6-20 ppb. This adds 12.2 ppm.

Controlled case. Surface condenser causes 90% H_2S to come off in noncondensable gases at off-gas ejector, allowing use of Stretford process for removal. Assume 90% of all noncondensable gases through gas ejector, 95% control thus 14.5% of gas in steam is released.

Controlled Releases (Based on Geysers)

Residual	(g/kwh)
As	4.35×10^{-6}
CO_2	4.35
H_2S	.297
NH_3	.259
B	4.95×10^{-3}
Hg	5.55×10^{-6}
CH_4	.117
Rn-222	3.15×10^{-8}

IV. DIRECT USE

For district heating a closed-circuit pipe is assumed. No residual to air or water between well extraction and reinjection. Further, a higher quality fluid than average will probably be used for (1) health reasons and (2) to prevent corrosion and scaling (10). This implies either a control system on the flow → use of only high quality wells. Assume latter → no control wastes.

Air emissions occurring during use of fluid for process steam would be at least as good or better than quality given in Table 1. Same for release during accidental pipe rupture.

Since quality is so good, no expected impact from reinjection.

Noise limited to mechanical noise - e.g. pumps. Steam line break-100 dBA (5)

V. RANGE IN GEOTHERMAL QUALITY

There is a general lack of data on geothermal quality characteristics in the U.S., outside of the Geysers. This is attributed to: (1) information that exists is in corporate hands, withheld from the public; (2) it is a young industry, few measurements have been made outside of the Geysers.

Ranges of quality for air emissions from KGRA's in the U.S. in terms of steam quality are nowhere reported. All sources that refer to air emissions give them for the group of geothermal systems that are reported in Table 5.

Regulatory interest is also fairly recent; of the air emissions listed in the tables above, H_2S , NH_3 , CO_2 , B, As, Hg, Rn-222 CH_4 and particulates, only H_2S , Rn-222 and particulates have applicable standards to which we can refer.

The range of quality in air emissions among U.S. KGRA's might be inferred from much more available data on water quality (local surface waters) of known KGRA's. From the tables in (3) the following ranges of contaminants for KGRA's in Alaska, Idaho, California, Nevada, Oregon, and Utah have been compiled, (data from other states unavailable):

Contaminants	Concentration Range (mg/l)
SO_4	3.2 - 1,450
B	.01 - 390
NH_3	.02 - 3.4
Hg	0.0 - .004

This data might give some hints as to the expectable range of variation for power plants in the emission of H_2S , Hg, B, NH_3 if they operated over this range of sites.

Ranges of quality with respect to TDS are also available, and are compiled below, along with a table supplying information on the effect various concentrations of TDS have on the use to which water may be put.

<u>From 43 California Measurements</u>	
# of Measurements	TDS (mg/l)
7	<500
4	500 - 1000
19	1000 - 2000
9	2000 - 6000
2	30,000 - 50,000
2	>200,000
<u>From 101 KGRA's</u>	
9	<100
36	100 - 350
12	350 - 700
8	700 - 1200
7	1200 - 1800
12	>1800

<u>TDS Concentration (mg/l)</u>	<u>Restriction on Use of Water</u>
150	Max for textile industry use
500	Drinking water recommended max
500 - 1000	Irrigation water adversely affects sensitive crops
1000	Water tastes bad
1080	Max for pulp and paper industry
1000 - 2000	Adverse effects on many crops
2500	Max for chemical industry
2000 - 5000	Max irrigation range for tolerant plants
5000 - 15,000	Max range for livestock watering
15,000 - 20,000	Max for freshwater aquaculture
35,000	Boiler makeup

TDS includes mostly inorganic salts - carbonates, chlorides, sulfates, borates, nitrates, salts of Na, K, Ca, and Mg.

Standards

Under the Clean Air Act, states may set the numerical emission standard for national NAAQS's and NSPS's. No NAAQS exists for H_2S . Fifteen states which contain geothermal resources are listed in Source 3 and 9 have some sort of sulfur standard that might relate directly or indirectly to H_2S . The California standard is 30 ppb, one hour maximum. This was exceeded in 36% of 624 hours measured at the Geysers Source 10. It was also exceeded in 11 of 52 measurements 1.5 miles downwind of a generating unit over a two month period in 1975. It is stated that the frequency and occurrence of H_2S intensity varies inversely with distance from the source, and that Geysers operations have little effect on ground level air concentrations beyond a 10 mile radius (10).

Other California state H_2S standards applied to operations at the Geysers are: (1) Pre-power plant emissions: 68kg/hr; this standard is to be met by 12/31/78 and applies to emissions from well drilling, testing and cleaning, well and pipeline bleeds, uncontrolled wells, and power plant stacking. (2) Power plant emissions: A six month maximum of 386 kg/hr, effective 6/30/78, and a 24-hour maximum of 443 kg/hr, effective same date. The later is subject to change with further study of available control technology, air quality, emissions, and meteorological data.

In the 15 geothermal states, particulate emissions are commonly tied to the process weight per hour, where process weight refers to the weight of all materials introduced into a specific process which may cause particulate emissions, and standards range from 1.23 kg for the first 450 kg up to 31 kg at 450,000 kg production.

Federal standards require "reasonable" precautions to prevent fugitive dust from becoming airborne during well development, and only Idaho has added any qualifiers to clarify "reasonable"; Idaho regulations relate precautions to proximity of the activity to human habitations and to occurrence of other activities or atmospheric conditions which potentiate the movement of particulates. Generally suppression is by spraying.

For nonfugitive particulates, California's AAQS is 100 ug/m^3 , 24-hour maximum, and was satisfied in $3^{59/60}$ measurements at the Geysers. The Federal primary standard is 260 ug/m^3 , and the secondary standard is 150 ug/m^3 .

Cooling tower drift rate at the Geysers is $0.015\% = 700 \text{ kg/day/MW}$. This drift would release .09 kg B, $4 \times 10^{-5} \text{ kg As}$, and $2 \times 10^{-6} \text{ kg Hg}$ per day per MW. (This level of Hg release is said to be comparable to that from a fossil fuel plant - Source 10 Insoluble materials (As, Hg, other heavy metals) settle out in the cooling tower and are disposed of in landfill, soluble materials (e. g. B) are reinjected. No standards cover air emissions of Hg, B, As. Comparing Hg release to the standard for Hg from plants processing Hg ore (5 lb/day), Source 10 concluded that the emission is not significant.

The water quality standard for B is 0.5 mg/l (Calif.) and 0.75 (Federal). Federal criteria is 0.05 mg/l for As. The standard for B may be exceeded, but that for As is unlikely to be from deposition and entry into water systems following emission into the atmosphere from a power plant.

The following hypothetical situation was generated by Source 10: the drift from a 100 MW unit settles within a 1000-acre watershed of a stream for a 30-day period, then is washed into the stream by rains causing 1.3 cm runoff. The runoff contains: 0.002 mg/l As, 5.3 mg/l B, 0.001 mg/l Hg (based on Geysers).

Other stack emissions include Si, Al, Fe, Ca, Na, Mg, Ti, Sr (nonradioactive) in total amount less than 0.3 kg/day. This is an insignificant impact Source 10. Emitted at a total rate of less than 0.05 kg/day are Pb, Cu, Cr, Mn, Ni, and Zn. The only AAQS applicable to this group is that for Pb, 1.5 ug/m³, 30-day, which is not exceeded. It should be noted that Geysers steam is high quality as geothermal resources go.

Rn-222 occurs naturally in geothermal fields. The California standard of 3.0 pCi/l (uncontrolled areas) is not violated. Stack concentrations of 3660-5300 pCi/l are sufficiently diluted at ground level between the ground and 60 - 85 foot stack. Steam ranges between 0.8 and 8.4 pCi/l.

A final area to which air emission standards apply is that of sulfuric acid mist, which forms by oxydation and is a problem at the Geysers. Source 10 reports an Idaho standard, however: 24-hour maximum of 12 ug/m³ not to be exceeded more than once a month, and a one-hour maximum of 30 ug/m³ not to be exceeded more than twice a week.

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APPENDIX C

COAL RESIDUALS

Environmental residuals associated with the use of Western and Eastern coals are tabulated below for each activity comprising the energy use system. Residuals are taken from data provided in Hittman Associates, 1974, Environmental Impacts, Efficiencies and Costs of Energy Supply and End Use and are stated per 10^{12} Btu into the process. Footnotes which explain the data are likewise summarized from Hittman Associates. Residuals are given first for the Western coal utilization system, from extraction through conversion, and then for the East coal energy system. Additional data follow, reporting residuals associated with transmission lines (applicable to both system), noise and use of coal for industrial process steam.

The coal utilization flow chart (figure B-1) shows the specific activities associated with each process in the energy system, from extraction to end use, for the two types of coal resources considered. The flows of the resource from stage to stage in the energy utilization system is indicated by arrows, and the occurrence of residuals at any stage is noted by an "R" at that stage. Activities which have residuals associated with them are analyzed below.

The numbers in parentheses are data quality indices used by Hittman Associates, 1974. See last page of appendix for definitions.

1. Western Coal: Strip Mining (Controlled)

Energy Model Data Base: COAL/ESTRC/STRP-/NW/CONTL

Powder River Basin Coal: 8780 Btu/lb, 1.85%S, 6.77% ash

Stripping on <15° slopes

Control includes revegetate, stockpile and redistribute topsoil, segregation of toxic overburden, seed bed preparation, settling ponds to catch sediment-laden runoff.

per 10^{12} Btu:

Primary efficiency 98% (1)

*Ancillary energy 1.93×10^9 Btu (5) (0.2%)

<u>Water-</u>	Bases 0 (2)	Acid? (Control applies only to <u>active</u> mine)
	TDS 0 (2)	Trace metals?
	COD 0 (2)	
	TSS 0 (2)	
	TS+O 0 (2)	

<u>Air-</u>	Particulates .934 tons (4)	NO 1.03 tons (5)
	SO _x .0753 tons (5)	HC _x .103 tons (5)
	CO _x .628 tons (5)	RCOH .0167 tons (5)
	Total Air Pollutants 2.69 tons (5)	

Land- 3.87 ac-yr (3) (time-averaged, mine only)

Solid Waste- 811.5 tons (4)

*Ancillary energy: 8.89×10^9 Btu fuel, 9.61×10^4 kwh for extraction,
 5.93×10^6 Btu (3920 Hp-Hr/Ac) to level spoil banks

Footnotes:

Land

Average Coal Density 81 lb/cf

Average Seam thickness 39 ft

Incremental land turned over; $0.835 \text{ ac}/10^{12} \text{ Btu}$

Time average impact $10.4 \text{ ac-yr}/10^{12} \text{ Btu}$ (25 year time average)

COAL UTILIZATION FLOW CHART

R = Residuals

Box cut-5 acres
Solid waste pile (30' high) 0 1.285 ac-yr/10¹² Btu
(10 acres)

5-25 years reclamation, perhaps > 100 years, to support grazing
with self-sustaining cover at 5 years, time-average impact
is 3.87 ac-yr/10¹² Btu.

Settling basin- (5 acres) 0.140 ac/yr/10¹² Btu. Water reused
for dust suppression, irrigate reclaimed areas. 10' deep,
16 M gallon capacity.

Air Emissions include diesel excavation equipment, wind erosion
@ 428 lb/ac-yr = .893 T partic/10¹² Btu

Solid Waste Assumed produced only from spoils of FIRST cut.
Permanently situated. Given above coal-field characteristics,
0.05 t/cf refuse density, 60' average overburden, 50 MMT
production over 25 years from 5 acre strip, total solid
waste is 744.9t/10¹² Btu.

Sediment yield from waste piles: $E = Fc(S^{1.35}) (L^{0.35}) (P^{1.75})$
E = soil loss, /ac-yr = 76.86
L = slope length = 120'
F = slope factor (erodability) = 0.4
S = slope in pc/10 = 8.4
P = 2-year rainfall, 30- minute maximum intensity = 1.5"
C = crop factor = 1.0

Assume sediment from solid waste pile alone (spoil is in pit,
runoff contained there may seep, contaminate ground water).
Sediment = 0.285 (76.86) = 21.9 t/10¹² Btu, or 39 t/yr.

Haulage road sediment - 18.4 t/10¹² Btu
*Groundwater effluent: 4.3 t/t coal extraction/day.
Groundwater pumped from mine contains 44.7 t/10¹² Btu

Haulage road and groundwater sediment collected in a settling pond from
there added to 744.9 t/10¹² Btu solid waste from stripping operation itself.

Production: 8300 t/day, 2 MMT/yr, 25 year life, 50 MMT Total.

Western Coal: Strip Mining (Uncontrolled)

Energy Model Data Base: COAL/EXTRC/STRP-/NW/UNCON

Primary Efficiency 98% (1)_g
Ancillary Energy 1.92 x 10⁹ Btu (0.2%) (5)

Water- Base N.A.
Total Dissolved Solids .894 tons (3)

Suspended Solids 23.2 tons (3) -(during period of activity only.
Total - Solids & Organics 24.1 tons (3) erosion/sedimentation may continue
COD 0 (1) long after mine closes)

Air- Particulates 2.27 tons (4)
NO 1.03 tons (5)
SO^x .0753 tons (5) (S=.03765t)
CO^x .628 tons (5)
HC .103 tons (5)
RCOH .0167 tons (5)
Total Air Pollutants 4.12 tons (5)

Land- 10.825 ac/yr (time-average, solid waste plus mine)

Solid Waste- 744.9 tons

2. Western Coal: Trucking

Energy Model Data Base: COAL/TRNSP/TRUCK/NW/CONTRL

Primary Efficiency 100% (1)

Ancillary Energy 1.94×10^8 Btu (3) (diesel fuel)
(0.02%)

Water- Suspended Solids 0 (2)
Total Solids & Organics 0 (2)

Air- Particulates 9.1×10^{-3} tons (3) Co₂ = 15.61
NO .259 tons (3) Trace Metal?
SO^x .0189 tons (3) (S=.00945 tons)
HC^x .0259 tons (3)
CO .175 tons (3)
RCOH 2.1×10^{-3} tons (3)
Total Air Pollutants 0.49 tons (3)

Land- .303 ac/yr (haulage road and settling pond)

Footnotes:

Average haul to tipple from mine 1.5 miles
Average truck capacity 62 tons
Gross/Tare Wt 2.5:1
Roundtrip: 217 ton-miles
Fuel consumption: 7 gal/1000 t-mi
920 trips to haul 10^2 Btu - 1400 gal diesel fuel (5.83×10^6 Btu/BBL)

Haulage roads watered to control fugitive dust. Runoff from haulage roads diverted to settling ponds at intervals along roadway (only 1 needed for 1.5 mile road). With low precipitation in region it will be adequate to contain runoff, which is reused to water haulage roads.

Haul road land impact $0.274 \text{ ac/yr}/10^{12} \text{ Btu}$
settling pond land impact $0.0285 \text{ ac/yr}/10^{12} \text{ Btu}$
(1 acre, 5' deep, 16×10^6 gallon storage)

Assume most carbon in fuel is $-\text{CH}_2-$, and essentially all is converted to CO_2 . Weight of carbon is $12/14 \times \text{Wt fuel}$ and CO_2 emission is $44/12 (\text{Wt. carbon}) (1400 \text{ gal}/10^{12} \text{ Btu})$.

$$= 9.143.1400 \text{ gal.} \frac{3.95 \times \text{tons}}{10^{-3} \text{ gal}} = 15.61 \text{ tons}$$

(based on fuel specific gravity of .82-.88)

Energy Model Data Base: TRNSP/TRUCK/NW/UNCON

Primary Efficiency 100%
Ancillary Energy $1.94 \times 10^8 \text{ Btu}$

Water- TSS 21.1 tons (3)
TS+0 21.1 tons (3)

Air- Particulates $9.1 \times 10^{-3} \text{ tons (3)}$ $\text{CO}_2 =$
SO_x $1.89 \times 10^{-2} \text{ tons (3)}$ ($S=9.45 \times 10^{-3}$)
NO_x .259 tons (3)
HC_x $2.59 \times 10^{-2} \text{ tons (3)}$
RCOH $2.1 \times 10^{-3} \text{ tons (3)}$
Total Air Pollutants .49 tons (3)

Land .274 ac-yr (haulage road)

Footnotes:

sedimentation @ rate of $21.1 \text{ t}/10^{12} \text{ Btu}$ in runoff
fugitive dust on roads still assumed controlled by watering roads

3. Western Coal: Processing

a. Primary Breaking

Energy Model Data Base: COAL/PROCE/BREAK/NW/CONTL & UNCON

Primary Efficiency 100% (1)
Ancillary Energy N.A. (1)

Air- No Residuals
Particulates 0 (2)
Total Air Pollutants 0 (2)

Water- No Residuals

Land- N.A.

(Fugitive dust from handling confined to preparation plant)

b. Breaking and Sizing

Energy Model Data Base: COAL/PROCE/BRKSZ/NW/CONTL & UNCON

Primary Efficiency 100% (1)
Ancillary Energy 2.19×10^9 (4) (~0.2%) (1.92×10^5 kwh, 3.18×10^8 Btu oil)

Water- Acid 0 (1) Base 0 (1)
TDS 0 (1) TSS 0 (1)
COD 0 (1) Non-Degradable Organics 0 (1)
TS+0 0 (1)

Air- Particulates 0 (2)
Total Air Pollutants 0 (2)

Land- .997 ac-yr (1)

Solid Waste- 3.42 tons (4)

Footnotes:

Air- Fugitive dust from coal handling confined to preparation plant

Water- V.S.M. quan. water used to suppress dust, discharged.

Negligible impact. V.S.M. is very small quantity.

Solid Waste- Tramp iron removed, .006% of feed. Figures are for plant processing 1000T/hr.

Land- 35 acres for plant and 10,000 ton unit train loading facility

c. Rough Cleaning

Energy Model Data Base: COAL/PROCR/RCLN/NW/CONTL & UNCON

Primary Efficiency 100% (1)
Ancillary Energy N.A. (1)

Water- No Residuals

Air- Particulates 1 (2) Total Air Pollutants 0 (2)

Land- N.A. (1)

Solid Waste- 3.42 tons (4)

Footnotes:

Solid Waste is same tramp iron removed noted above.

d. Raw Coal Sizing

Energy Model Data Base: COAL/PROCE/RWSIZ/NW/CONTL & UNCON

Primary Efficiency 100% (1)
Ancillary Energy N.A. (1)

Water- No residuals

Air- No residuals (Part 0 (2), Total Air 0 (2))

Land- N.A.

Solid Waste- No Residuals

Total Processing Residuals

Primary Efficiency 100%
Ancillary Energy- 2.19×10^9 Btu (0.2%)

Land- .997 ac-yr (plant and unloading facility)
Solid Waste- 3.42 tons (tramp iron)

4. Western Coal: Above-Ground Storage

Energy Model Data Base: COAL/STORA/AGRND/NW/CONTL & UNCON

Primary Efficiency 99% (3)₈
Ancillary Energy 2.13×10^8 Btu (5)

Water- No Residuals (Acid, Base, TDS, TSS, TS+O - N.A., COD-O all (1))

Air- No Residuals (Part, Tot Air-N.A., (1))

Land- 1.08 ac-yr (2)

Footnotes: Primary Efficiency - negligible heat content loss to oxydation,
1% loss in reclamation from pile with proper technique.

Ancillary Energy- 2.08×10^4 kwh for movement of coal via
conveyer belts.

Land- Storage of coal in 30" high pile requires 1.08 acres of land.

5. Western Coal: Electrical Conversion

Energy Model Data Base: COAL/PPCVR/ELGMR/NATL/CONTL & UNCON
(adjusted for coal of 0.85% S, 6.77% ash)

	CONTL 37% (2)	UNCON 33% (2)
Primary Efficiency		
<u>Water</u> - Acid	0 (3)	25.7 tons (3)
TDS	18.2 tons (4)	58.1 tons (3)
TSS	0 (3)	6.84 tons (3)
Organics	0.003 tons (3)	2.71 tons (3)
TS+O	18.2 tons (4)	67.7 tons (3)
Thermal	0 (1)	5.62×10^4 Btu (2)
<u>Air</u> - Particulates	15.9 tons (2)	61.7 tons (2)
NO _x	369 tons (3)	369 tons (3)
SO _x	66.3 tons (1)	662.9 tons (1)
HC _x	6.15 tons (3)	6.15 tons (3)
CO	20.5 tons (3)	20.5 tons (3)
(assume fixed C=35%)CO ₂	73,082 tons	73,082 tons
RCOH	.103 tons (3)	.103 tons (3)
		tons (2)
<u>Land</u> -	9.93 ac-yr	8.49 ac-yr
<u>Solid Waste</u> -	8182.9	3792.2 tons

Footnotes:

Primary efficiency- coal-fired power plant has heat rate of 8960 Btu/kwh or conversion efficiency of 38%. Control equipment for water quality, chemical and thermal; FGD and particulate control.

Solid Waste- 57,000 tons/ 10^{12} Btu coal burned. 6.77% or 3858.9 are ash. 61.7 tons of this emitted as flyash and rest, (3797.2 tons) is refuse. For control case, additional 45.8 t/ 10^{12} Btu collected flyash, and .076 tons sludge per ton coal, or 4339.9 tons/ 10^{12} Btu/ Total solid waste is 8182.9 tons/ 10^{12} Btu.

Land- 300 MWe plant with fly ash control occupies 1200 acres including 350 for ash disposal and 40 acres coal storage. Based on 33 cf/ton fly ash 26 cf/ton lime sludge, incremental volume is 1.14×10^5 ft³/ 10^{12} Btu. @ depth of 30'; is .087 ac, or (30-year time-average) 1.31 ac-yr/ 10^{12} Btu. Cooling towers occupy 10 acres for 1000 MWe plant or .13 ac/ 10^{12} Btu. These are in addition to baseline plant impact of 8.49 ac-yr/ 10^{12} Btu.

Water- Water pollutants are from demineralizer regeneration, ash sluicing, boiler blowdown, clarification and coal pile runoff. Control is based on EPA NSPS and Effluent Limitations, 3/74: pH between 6-9, TSS $\leq$ 10 mg/l.

Air- Control is wet lime scrubber for SO_x and Particulates, efficiencies are 90% and 99.5 %, respectively.

6. Western Coal: Unit Train

Energy Model Data Base: COAL/DISTB/UNITT/NW/CONTL & UNCON

Primary Efficiency 100% (3)
Ancillary Energy 9.90×10^9 Btu (3) (~1.0%)

Water and Solid Waste- No Residuals

<u>Air</u> - Particulates - 23.7 tons (4)	CO 2.50 tons (3)
NO _x 2.67 tons (3)	RCOH .392 tons (3)
SO _x 2.32 tons (3)	Total 33.4 tons (4)
HC _x 1.78 tons (3)	CO ₂ 795.50 tons

Land- 75.1 ac-yr

Footnotes:

Land- Based on 119,000 mile railroad West of Mississippi (1971). 6 ac/mi right-of-way, % of freight as coal freight Northwest area.

Air- Emission freight diesel fuel combustion for 10,000 unit train with 4 2400 horse power locomotives, @ 690 Btu/t-miles over are haul of 150 miles (71,300 gal/ 10^{12} Btu), plus .04% of tonnage as windage loss, or 22.8 tons particulate/ 10^{12} Btu

7. Eastern Coal: Room and Pillar Mining

Energy Model Data Base: COAL/ESTRC/ROOMP/NAPPL/CONTL

North Appalachia coal: 11,800 Btu/lb, 3.07% S, 14.7% ash. Control includes reclamation of refuse pile, eliminating air emissions from burning, water effluent from drainage (3-year lag to establishment of plant cover on the refuse pile), a hydrated lime system to control acid drainage with water storage and settling ponds.

Primary Efficiency 57% (1)₉

Ancillary Energy 4.47×10^9 Btu (5) (~0.4%)

Water- Acids 0 (1)
Bases 1.19 tons (4)
TDS 39.9 tons (4)
TSS .595 tons (2)
TS+O 40.5 tons (4)
COD 0 (1)

Air- Particulate 0 (1)

NO_x 0 (1)
SO_x 0 (1)
HC_x 0 (1)
CO 0 (1)
RCOH 0 (1)
Total 0 (1)

Land- 129.8 ac-yr (3)

Solid Waste- 1,191.45 tons (3)

Footnotes:

Production 2 MMT/yr, 25 yr life, 50 MMT TOTAL

Land- Average Coal Density 85 lb/cf

Average Seam Thickness 5.1 ft
4.49 ac undermined/ 10^{12} Btu

25% or 1.12 ac of that undermined subsides
additional 9.17 ac on perimeter of subsidence are affected
Time-averaged over 25 years, 129 ac-yr/ 10^{12} Btu are affected

Refuse pile 30' high occupies .0429 ac. Time-average
is 5.53×10^{-4} ac-yr/ 10^{12} Btu

$0.781 \text{ ac-yr}/10^{12}$ Btu for hydrated lime treatment facility.
(61.6 ac surface area for ponds, 3 acre for plant)

Air- Underground mine equipment electric powered - no emissions.

Water- Acid drainage 905 tons acidity/day; 2.8×10^{-3} t/t coal mined.
Sulfate load is 2x acid load. Chemical composition of drainage:
(T/10¹² Btu)

Hardness	295.0	(in addition to 100 mg/l natural)
Fe	5.2	
Mn	2.2	
Al	0.65	
SO ₄	135.0	
Total	438.1	
Acidity	67.7	

Sediment from waste pile run-off 2.54 t/ac-yr-in₁₂ of runoff
(20"/yr runoff average) - thus, 2.81×10^{-2} t/10¹² Btu

Final discharge from hydrated lime plant assumed in compliance with EPA guidelines (1973). Increasing pH in the treatment precipitates metallic salts. Solubility of CaSO₄ increases water hardness.

	Final discharge	
	PPM	t/10 ¹² Btu
TSS	30	0.595
Acid	0	--
Base	60	1.19
Fe	4	0.079
Mn	4	0.079
Al	1	0.020
CaSO ₄	2000	39.7

Facility process 1.9 MMG/day of 3000 ppm acid-load water, discharges 85% of in-flow volume (1.61 MMG/day) operates 245 days/yr.

Solid Waste- Waste comes mostly from opening the mine. Average mine depth 600 feet, adit 100 SF; 3000 tons earth removed to sink shaft. Solid waste produced at 60 T/MMT coal, or 1.45 T/10¹² Btu.

Acid load in hydrated lime plant is 3000 ppm, Iron load, 220 ppm. 1.9 MMG/day processed. Solid waste is produced at 63.8 ac-ft/yr. At 71 lb/cf, total 98,660 t/yr are generated or 1190t/10¹² Btu.

Ancillary Energy- 4.21×10^9 Btu (electric equivalent) are consumed for actual mining operation and an additional 1.257×10^9 Btu for operation of the hydrated lime treatment plant.

Energy Model Data Case: COAL/EXTRC/ROOMP/NAPPL/UNCON

Primary Efficiency 57% (1)_g
Ancillary Energy 4.21×10^9 Btu (4) (~0.4%)

<u>Water-</u>	Acid	67.7 tons (3)
	TDS	438 tons (4)
	TSS	.0281 tons (4)
	TS+O	438 tons (4)
	COD	0 (1)

<u>Air-</u>	Particulate	0 (1)	HC	0 (1)	Total	0 (1)
	NO _x	0 (1)	CO	0 (1)		
	SO _x	0 (1)	RCOH	0 (1)		

Land- 129 ac-yr

Solid Waste- 1.45 tons

8. Eastern Coal: Mineral

Energy Model Data Base: COAL/TRNSP/MINRR/NAPPL/CONTL & UNCON

Primary Efficiency 100% (1)

No residuals of any kind (1-2). Rails are electrically powered. Use very little land.

9. Eastern Coal: Processing

a. Primary Breaking

Energy Model Data Base: COAL/PROCE/BREAK/NAPPL/CONTL & UNCON

Primary Efficiency 100% (1)

Ancillary Energy 1.65×10^8 Btu (2) (<0.02%)

Water, Air and Land Residuals- none (1-2)

Footnotes:

Same as Western Coal

b. Breaking and Sizing

Energy Model Data Base: COAL/PROCE/BRKSZ/NAPPL/CONTL & UNCON

Primary Efficiency 100% (5)

Ancillary Energy 1.72×10^8 (4) (<0.2%)

Water and Air Residuals- none (1-2)

Land- .741 ac-yr (2)

Solid Waste- 2.54 tons (3)

Footnotes:

Air- fugitive dust confined to preparation plant

Water- Small quantity of water to suppress dust discharged-negligable

Ancillary Energy- 1.5×10^5 kwh, 2.42×10^8 Btu oil.

Land- 35 acres for crushing and sizing plant and 10,000 tons unit train loading facility.

c. Rough Cleaning

Energy Model Data Base: COAL/PROCE/RCLN/NAPPL/CONTL & UNCON

Primary Efficiency 100% (1)

Ancillary Energy N.A. (1)

Water, Air and Land Residuals- none (1-2)

Solid Waste- 2.54 tons (3) (tramp iron removed, as above)

d. Raw Coal Sizing

Energy Model Data Base: COAL/PROCE/RWSIZ/NAPPL/CONTL & UNCON

Primary Efficiency 100% (1)

Ancillary Energy N.A. (1)

No residuals of any kind (1-2)

e. Washing to Meet Specification of Steam-Electric Utilities

Energy Model Data Base: COAL/PROCE/STEAM/NAPPL/CONTL

Primary Efficiency 96.4% (2)

Ancillary Energy 2.29×10^9 Btu (4) (~0.2%)

Water- TSS 10.9 tons (4)
TDS 0 (3)
Acid 0 (2)
COD 0 (1)

Air- Particulates - 0 (3) NO_x 0 (3)
CO 0 (3) SO_x 0 (3)
RCOH 0 (3) HC_x 0 (3)
Total 0 (3)

Land- 2.225 ac-yr

Solid Waste- 5,971 tons

Footnotes:

Primary Efficiency - Given efficiency weighted average of 72% of feed through 95% efficiency dense media process (above), and 28% through 100% efficient unwashed.

Air- Emissions associated with burning refuse pile eliminated by reclamation of same. Baghouses control fugitive dust.

Water- Seepage from refuse pile eliminated by soil cover established in reclaiming it. 3-yr lag in plant cover establishment, with 2.54 tons SS/ac-yr in runoff and 0.215 ac-yr land use allows total of 10.9 tons TSS/ 10^{12} Btu escape. Suspended solids in plant controlled by settling pond.

Solid Waste- 500 t/hr R.O.M. coal crushed to 1.5 topsize, the 1.5 x 3/8 inches washed in dense media at 1.6 specific gravity generates 19.5% of feed or 5960 t/ 10^{12} Btu waste. Also magnetite at 11 t/ 10^{12} Btu and tramp iron at 2.54 t/ 10^{12} Btu come from preparation plant.

Ancillary Energy- Includes processing energy requirement plus that for settling pond and baghouses. Reclamation energy not quantified.

Land- Refuse in 30" pile impacts .076 ac/ 10^{12} Btu; with 3-yr lag, time average is .215 ac-yr/ 10^{12} Btu. Plant requires 5 acres plus 40 acres for unit train loading + 50 acres settling ponds, or 2.01 ac-yr/ 10^{12} Btu time average.

Energy Model Data Base: COAL/PROCE/STEAM/NAPPL/UNCON

Primary Efficiency 96.4 % (2)

Ancillary Energy 2.17×10^9 Btu (4) (~0.2%)

Water-   Acid 31.6 tons (5)
              TDS 59.2 tons (5)
              TSS 84.5 tons (5)
              TS+O 143.6 tons (5)
              COD 0 (1)

Air-   Particulate - 2.51 tons (5)
              NO 1.25 tons (5)
              SO^x 3.7 tons (5)
              HC^x 1.25 tons (5)
              CO 7.52 tons (5)
              Total 16.23 tons (5)

Land- 3.15 ac-yr

Solid Waste- 5,9171 tons

Footnotes-

Land- Unreclaimed refuse pile adds $1.14 \text{ ac-yr}/10^{12}$ Btu (time average
30' pile occupying 0.0915 acres) to $2.01 \text{ ac-yr}/10^{12}$ Btu of plant.

Air- Emissions due to smoldering refuse pile.

Water- Seepage from refuse pile contains:

	lb/gal	T/10 ¹² Btu (at 1670 gal/ac-yr)
Fe	.0258	9.0
SO ₄	.144	80.1
Mn	.000378	0.1
		<u>59.2</u>
Acid	.091	31.6

Sediment yield is 2.54 t/ac-yr-in, or $58.0 \text{ t}/10^{12}$ Btu

10% of <100 mesh coal as black water discharge, or .5 t/hr.
Assume 37.5% control (loss through leaks, overflows, improper
settling). Discharge = .312 t/hr or $26.5 \text{ t}/10^{12}$ Btu.

Total Processing -	<u>Control</u>	<u>Uncontrol</u>
Primary Efficiency	96.4%	96.4%
Ancillary Energy	4.175×10^9 Btu (~.4%)	4.055×10^9 Btu (~.4%)

<u>Water-</u>	Acid	0	31.6 tons
	TDS	0	59.2 tons
	TSS	10.9 tons	84.5 tons
	TS+0	0	143.6 tons
	COD	0	0 tons

<u>Air-</u>	Particulate	0	2.51 tons
	NO	0	1.25 tons
	SO ^x	0	3.7 tons
	HC ^x	0	1.25 tons
	CO	0	7.52 tons
	Total	0	16.23 tons

<u>Land-</u>	2.225 ac-yr	3.15 ac-yr

<u>Solid Waste-</u>	5,973.54 tons	5,973.54 tons

10. Eastern Coal: Unit Train

Energy Model Data Base: COAL/DISTB/UNITT/NAPPL/CONTL & UNCON

Primary Efficiency 100% (3)
 Ancillary Energy 1.58×10^{10} Btu (~1.6%) (3) (diesel fuel)

Water residuals - none

<u>Air-</u>	Particulate	18.4 tons (4)	CO ₂	1260.76 tons
	NO	4.28 tons (3)		
	SO ^x	3.71 tons (3)		
	HC ^x	2.85 tons (3)		
	CO	4.00 tons (3)		
	RCOH	.627 tons (3)		

Land- 27.6 ac-yr

Solid Waste- none

Footnotes:

Land- based on total miles of railroad in area (54,000), % of freight in coal from area, 6 ac/mi right of way.

Air- Average haul 320 miles. Emissions are from diesel fuel combustion at 690 Btu/t-mi or 1.13×10^5 gal/10¹² Btu, plus windage losses of .04% of tonnage providing 17 tons particulates/10¹² Btu.
 CO₂ based on same calculations as made for Western Coal Trucking.

11. Eastern Coal: Above Ground Storage

Energy Model Data Base: COAL/STORA/AGR/ND/NAPPL/ CONTL & UNCON

Primary Efficiency 99% (2)₈

Ancillary Energy 1.59×10^8 Btu (5) (<0.02%)

Water, Air and Solid Waste - No residuals

Land .763 ac-yr

12. Eastern Coal: Electrical Conversion

Energy Model Data Base: COAL/PPCVR/ELGNR/NATL/CONTL & UNCON

Residuals and efficiency are same as plant burning Western Coal, except:

		CONTL	UNCON
<u>Air-</u>	Particulates	17.2 tons	69.0 tons
	SO _x	119.7 tons	1197.1 tons
	CO ₂	85,452 tons	85,452 tons
<u>Land-</u>		10.37 ac-yr	8.49 ac-yr
<u>Solid Waste-</u>		8,933.5 tons	3066.6 tons

Footnotes:

Air- (adjust for 1.535% S, 7.35% ash, 11,8000 Btu/lb) Flyash is 1.6% of ash, 42,400 + coal burned/ 10^{12} Btu, for 3116.4 tons ash; 49.8 tons flyash. Control removes 37 t/ 10^{12} Btu.

Solid Waste- 3066.6 t/ 10^{12} Btu refuse from ash. Control adds 37.0 t/ 10^{12} Btu flyash and, at .137 tons sludge/t coal, 5829.9 t/ 10^{12} Btu sludge. Total is 8933.5 t/ 10^{12} Btu.

Land- Incremental control solid waste is 1.53×10^5 ft³/ 10^{12} Btu. At depth 30' is .117 acres; time-average is 1.75 ac-yr/ 10^{12} Btu. (Plus base land impact and cooling towers is 10.37 ac-yr)

13. Transmission Lines

Energy Model Data Base: COAL/PPCVR/TRNSM/CONTL/ & UNCON

Primary Efficiency 91.2%

Land- 778 ac/yr (share of 4 mile acre right-of-way by 1000 MWE plant)

No other residuals

14. Process Steam

Primary Efficiency

Water- Fuel specific energy-related industrial water emissions unavailable. Will be small relative to process-related emissions in most cases

Air- (tons/ 10^{12} Btu)

	Eastern Coal	Western Coal
SO _x	2225.5 (3.07% S)	616.2 (0.85% S)
Particulate	1823.4	839.76
NO _x	287.6	287.6
HC _x	19.0	19.0
CO	38.2	38.2
CO ₂	835452	73082

Source- Fuel specific Environmental Emission Coefficients for Industrial Processes by A.W. Reisman and M.D. Goldberg. BNL 50511

15. Noise

- a. Distribution - Trains cause 90-95 dBA day and night outside residences. Average house attenuation: 20dBA; 70-75 dBA interior noise level.

NW - Train carries 10,000 tons of 8780 Btu/lb coal per haul, or 1.756×10^{11} Btu per haul. Passing through Montana average density is 4.8 persons/mi². Average haul is 150 miles. Assume noise >70 dBA inside houses can be heard 1/10 mile on each side of tracks. 144 persons are impacted/haul, or 820 per 10^{12} Btu.

NAPPL- Coal is 11,800 Btu/lb or 2.36×10^{11} Btu/haul. Average haul is 320 miles. Density of Penn. is used, or 262.3/mi². 16,787 persons/haul or 71,132 per 10^{12} Btu impacted.

- b. Conversion - Environmental noise release (external to plant) assumed mitigated to insignificant level. Noise exposure is occupational, not environmental hazard.
- c. Extraction- Mining operations in range of 100-109 dBA. This is not released to environment in deep mining case, as it is contained underground (occupational hazard). With 4.8 persons per mile² in Montana and 10^7 tons/acre production, noise impact on persons/ 10^{12} Btu is also negligible for strip mine.

<u>Hardness</u>	<u>Definition</u> *	<u>Example</u>
1	Very Good - Highest confidence. Error probably ≤ 10 percent. Data well accepted and verified.	Nationwide consumption based on accurate reporting technique.
2	Good - Reputable and accepted. Error probable ≤ 25 percent.	Data from several major companies used to represent U.S.
3	Fair - Error probably ≤ 50 percent. Validity may be uncertain due to method of combining or applying data.	Data from one company used to represent U.S.
4	Poor - Low confidence in data. Error probably 100 percent. Validity questionable.	Telecon estimate used in absence of measurement.
5	Very Poor - Validity of data unknown. Error probably within or around an order of magnitude.	Assumption based on related reference. Several Fair or Poor sources combined.

* Error levels cited refer to cases where the data are non-zero. For zero or "negligible" values, the definitions Good, Fair, etc. should be applied to the various hardness levels.

Figure 4. Hardness Number Definitions

APPENDIX D

Optimum Resource Allocation

The problem is to maximize the amount of demand for two energy end uses that can be supplied from two energy resources, each of which can supply either end use. The notation used was introduced in the main body of the report and is illustrated below:

Mathematically the problem is maximize

$$E_1 = \alpha \epsilon_1 A_1 + \beta \epsilon_3 A_2 \quad (1)$$

subject to

$$\frac{(1-\alpha)\epsilon_2 A_1 + (1-\beta)\epsilon_4 A_2}{\alpha \epsilon_1 A_1 + \beta \epsilon_3 A_2} = k = \text{constant} \quad (2)$$

Note that $\epsilon_1, \epsilon_2, \epsilon_3, \epsilon_4, \alpha$, and β all lie in the interval $(0,1)$. The quantities α and β are to be varied to achieve the maximum value of E_1 and incidentally, also E_2 because of equation (2).

The forms of equations (1) and (2) are such that E_1 is maximized by a pair of values (α_0, β_0) , one of which is at one end of the interval $(0,1)$. In order to find the values of α_0 and β_0 , eqn (2) is solved for β and the result is substituted into (1).

The result is

$$\epsilon_1 = \alpha A_1 \epsilon_2 \epsilon_4 \frac{\frac{\epsilon_1}{\epsilon_2} - \frac{\epsilon_3}{\epsilon_4}}{k\epsilon_3 + \epsilon_4} + (\epsilon_2 A_1 + \epsilon_4 A_2) \frac{\epsilon_3}{k\epsilon_3 + \epsilon_4}$$

It is clear from this expression that if $\frac{\epsilon_1}{\epsilon_2} > \frac{\epsilon_3}{\epsilon_4}$ the value of E_1 is

greater when α is as large as possible. There are two subcases.

When $\frac{k\epsilon_1}{\epsilon_4} \frac{A_1}{A_2} < 1$, the solution is

$$\alpha = 1$$

$$\beta = \frac{1 - \frac{k\epsilon_1 A_1}{\epsilon_4 A_2}}{1 + \frac{k\epsilon_3}{\epsilon_4}}$$

On the other hand when $\frac{k\epsilon_1}{\epsilon_4} \frac{A_1}{A_2} > 1$, the case $\alpha=1$ implies a negative value of β .

This solution is not permitted, and the largest permissible value of α is the one that corresponds to $\beta=0$. This solution is

$$\alpha = \frac{1 + \frac{\epsilon_4}{\epsilon_2} \frac{A_2}{A_1}}{1 + \frac{k\epsilon_1}{\epsilon_2}}$$

$$\beta = 0$$

The other two cases given in the main body of the report correspond to $\frac{\epsilon_1}{\epsilon_2} < \frac{\epsilon_3}{\epsilon_4}$.

They will not be repeated here.

ANNOTATED BIBLIOGRAPHY

Anspaugh, L. R. et al. 1977. Summary. An Overview of Environmental Issues: The Geysers-Calistoga KGRA. Environmental Sciences Division, Lawrence Livermore Laboratory.

Summary document, identifying and prioritizing key environmental issues of the Geysers-Calistoga KGRA. A brief review and assessment is provided for each issue. High priority is given to hydrogen sulfide emissions, other issues covered and assigned lower priority are: landslides, noise, rare and endangered species, groundwater and water management, and location of future development, among others. Recommendations for future research with regard to these issues are made.

Armstead, C. H., ed. 1973. Geothermal Energy: Review of Research and Development. Paris: UNESCO.

A collection of technical and introductory articles offer a general review of geothermal energy. Exploration; extraction; utilization for power production, district heating, and industrial applications; economics; corrosion control; field management are among the topics covered.

Atherton, R. W., E. J. Finnemore, and M. L. Gilliam. 1976. The Analysis of Subsidence Associated with Geothermal Development, Vol. 1, Handbook, and Vol. 2, Research Report. NSF/RA-760414, NSF/RA-760415. Palo Alto, Calif.: Systems Control, Inc.

This study evaluates the state of knowledge of subsidence associated with geothermal development, and provides preliminary methods to assess the potential of land subsidence for any specific geothermal site. Volume 1 is a concise reference handbook for the evaluation of the potential for land subsidence from the development of geothermal resources. Volume 2 provides a compendium of research results on subsidence and geothermal energy. It provides backup information to the subsidence Handbook. Topics treated include the fundamentals of geothermics, the geology and physical processes of subsidence, a survey of subsidence and reservoir models, and methods for evaluating subsidence potential via analogy or analysis methods.

Beeland, G. V., D. J. Sebian, and D. K. Whitenight. 1978. Geothermal Development of Federal Lands - The Impediments and Potential Solutions. U. S. Department of Energy, Geothermal Division, Contract #EG-77-C-01-4114. Washington, D. C.: U. S. Department of Energy.

This study found that the regulatory program devised by the Bureau of Land Management and the U. S. Geological Survey to implement the Geothermal Steam Act of 1970 has been ineffective thus far in encouraging private enterprise to invest in and develop this resource. Developers point to the complexity of Federal geothermal leasing and post-lease requirements as the major impediment, and specifically, the repetitive environmental review procedures involved. A fundamental fault in the regulatory process is that there is no provision for identification of the resource before a lease is issued, yet a large percentage of exploratory holes drilled must be abandoned as nonproductive of a usable resource. A streamlined regulatory process was designed to overcome these and other problems and to provide for orderly development of the resource while protecting the public interest, as well as the environment.

Beeland, Mrs. G. V. (Draft). Study of Relationship of Geothermal Reservoir Character, Environment, and Use. Cincinnati, Ohio: U. S. Environmental Protection Agency, Energy Systems Environmental Control Division. Contract #68-03-2371.

This report examines the interrelated effects of (1) the character of the geothermal resource in any given reservoir and the surface environment where the reservoir is located on the use for which the resource can be exploited; and (2) the resource character and use on the local environment. The report also recommends development of a data bank on each identified geothermal system correlating all of the information about it which will influence its potential for use and environmental impact. Extensive data profiles for ten randomly selected geothermal areas are included.

Bloomster, C. H. et al. 1976. The Potential Benefits of Geothermal Electrical Production from Hydrothermal Resources. Richland, Wash.: Battelle Pacific Northwest Laboratories.

Potential national benefits of geothermal electric energy development from the hydrothermal resources in the West are estimated for several different scenarios. The U. S. electrical economy is simulated by computer, using a linear optimization technique. Under most scenarios, benefits are estimated at \$2 - \$4 billion over the next 50 years on a discounted present value basis. Electricity production from hydrothermal plants is projected to reach 2 - 4% of the national total, with installed capacity of 9,000 - 17,000 MWe in 1990. Improvements in technology which reduce costs 10 - 35% percent are shown to more than double the quantity of economically competitive geothermal resources. Supply curves were developed based on recent U. S. Geological Survey resource assessment, and on resource conversion and projected power conversion technology and costs.

Burnham, J. B. 1977. A Preliminary Assessment of the Health and Environmental Effects of Coal Utilization in the Pacific Northwest. PNL-RAP-21. Richland, Wash.: Battelle Pacific Northwest Laboratories.

One of six regional studies prepared under the National Coal Utilization Assessment, this document analyzes the impact of two development scenarios for coal utilization, one based on recent trends, and one assuming a coal fuel mix 25% greater than the proportion of coal-fired power generation in the recent trends case. Regional energy supply and demand is characterized in detail, as are coal conversion technologies. Candidate counties for siting coal-fired development are identified, and an impact analysis including air quality, water resources, land use, ecosystem effects, health effects and socioeconomic impacts is carried out.

California State Lands Commission. 1976. A Draft Environmental Impact Report for Geothermal Exploration Permit at Boggs Mountain State Forest, Lake County, California.

Geothermal Kinetics, Inc., California, proposes to undertake exploration drilling for geothermal resources within Boggs Mountain State Forest, Lake County, California, to determine available commercial capacity to generate electrical energy for use in northern and central California. The project would include field exploration, followed by test drilling of two wells to determine resource

type and potential. Most of Boggs Mountain State Forest is mixed Ponderosa pine and Conifer oak. The area is slightly tectonic and does not represent a unique wildlife resource. An analysis of the cultural environment of Lake County has been made to identify major areas of potential social impact. Geothermal Kinetics has requested a three-year permit with a possible two-year extension from the California State Lands Commission. Project setting, impacts, alternatives, short- and long-term effects and irreversible effects are evaluated.

Farah, D. G., and F. Williams. 1976. Methodology for Ranking Geothermal Reservoirs in Nonelectric Industrial Applications. C00/2693-76/2. McLean, Va.: Mitre Corporation.

A large number of geothermal reservoirs exist and to perform a thorough study of each of these reservoirs to determine those most desirable for demonstration projects can be costly and time-consuming. A methodology for assigning rankings to these reservoirs, given a limited amount of data is presented. The top ranking reservoirs would then be studied more thoroughly. In addition, a methodology for ranking the large number of industries that could possibly utilize geothermal energy in nonelectric application is given to determine those industries which will have the most impact on national energy demand if converted to geothermal use.

Federal Energy Administration. 1974. Geothermal Energy. FEA Project Independence Blueprint Final Task Force Report. Washington, D. C.: Federal Energy Administration.

The final technical analysis of the Project Independence interagency geothermal task force is presented. The task force was formed to estimate the production potential of the geothermal industry. It evaluated two different strategies: the first strategy, termed "business-as-usual", assumed the continuation of all current policies that could affect levels of geothermal production; and the second, called "accelerated demand", assumed selected changes in policies or practices that would allow a greater expansion of potential production. The U. S. geothermal resource base compares favorably with current gas and oil reserves. Development of geothermal resources, located mostly in the Western third of the U. S., could considerably contribute to meeting U. S. power needs. Only one geothermal resource, dry steam, is presently utilized for power generation in the U. S. However, several other resource types appear favorable: brines, moderate-temperature/low salinity fluids, geopressured reservoirs, hot rock formations, and magnetic deposits. Private investment in these resources is estimated to be: \$10 million for exploration, \$35 million for land leases, \$25 million for exploratory wells; and \$5 million for power plant and component technology. Major problems restricting the growth of geothermal energy include: (1) lack of confidence by major industrial energy users in geothermal reserves as reliable long-term supplies of energy; (2) institutional, legal and environmental problems; and (3) unsolved technical problems and economic uncertainties concerning the use of geothermal energy in an environmentally acceptable manner. The recommended strategy would involve short-term governmental participation with the geothermal industry. The primary goal of the national geothermal energy program is to encourage the private sector to augment commercial production of electric power by 20,000 - 30,000 MW by 1985, thereby conserving the equivalent of one million BPD of oil. The national program is aimed at: (1) providing the necessary technology to improve the economics of geothermal power pro-

duction; (2) expanding the knowledge of recoverable geothermal resources; and (3) resolving environmental, legal, and institutional problems.

Federal Energy Administration. 1975. Coal Conversion Program - Final Environmental Statements. FES 75-1. Springfield, Va.: National Technical Information Service.

This report describes the specific authorities delegated to FEA by the Energy Supply and Environmental Coordination Act of 1974 in relation to converting certain power plants and major fuel burning installations from petroleum to coal as a source of energy. The study describes the current national environment in which coal conversion will take place, and includes the following: assessment and availability of pollution control equipment; critical air pollutants most directly affected by the Act, including the effects of coal supply, coal quality and the availability of pollution control equipment on emissions; adverse effects of coal utilization; economic implications and environmental impacts of conversion; economic impact of programs to convert existing power plants; and the potential of coal supplies available for conversion.

Gordon, R. L. 1974. "Coal's Role in the Age of Environmental Concern," pp. 225-235 in M. S. Macrakis, ed. Proceedings of the NSF Conference on Energy: Demand, Conservation, and Institutional Problems, Massachusetts Institute of Technology, February 12 - 14, 1973. Cambridge, Mass.: MIT Press.

This paper expresses a view on coal's role in the future contrary to the view usually advanced that coal is the answer to future energy needs. It is felt that economics will dictate which energy system, be it coal, nuclear power, or oil, will dominate the future. The many problems of coal, some of which are environmental, regulatory, and legislative, seem to add up to cost pressures for coal that are greater than for many other fuels. The prospects for Western coal are seen as somewhat brighter. A brief description of computer programs designed to quantify the forecasts for coal demand is included. The programming considers three basic options for Western coal: gasification, liquification, and pretreatment for boiler fuel use. It is concluded that the final answers do not lie in short-run miracles using coal, but in technological developments that bring long-run success, irrespective of the energy source to which they apply.

Hittman Associates, Inc. 1974. Environmental Impacts, Efficiency and Cost of Energy Supply and End Use, Vol. 1, Final Report. HIT-593. Columbia, Md.: Hittman Associates, Inc.

This report presents tabular, footnoted, and referenced data quantifying the broad range of energy-related environmental impacts on land, water, air, solid waste and occupational health. The information contained in this report is also available in the computerized Energy Model Data Base, updated and managed by Brookhaven National Laboratory. This analysis considers the entire sequence of activities, from extraction to end use, associated with energy development that cause environmental impacts; these sequences are called "trajectories". Trajectories may be aggregated to the subsystem and system level for energy impact analysis, or disaggregated to activity, process or single element levels to discover residuals. Data in Volume 1 cover coal, oil, and natural gas supplying power plant, residential and selected commercial and industrial end uses.

Hollander, J. M., and M. K. Simmons, eds. 1976. Annual Review of Energy, Vol. 1. Palo Alto, Calif.: Annual Reviews, Inc.

This first volume of a continuing series dedicated to review and discussion of the significant issues related to energy constitutes an overview of the energy system of the United States. It emphasizes no single issue, but covers energy supply and distribution, detailing resources and technologies; energy economics; energy conservation; impacts of energy on environment, health and safety; energy policy and politics; and international aspects of energy. Twenty-eight chapters by numerous authors present a scholarly review and analysis of the literature in the interdisciplinary field of energy research.

Layton, D., and D. Ermak. 1976. A Description of Imperial Valley, California, for the Assessment of Impacts of Geothermal Energy Development. UCRL-52121. Lawrence Livermore Laboratory. Springfield, Va.: National Technical Information Service.

Impending geothermal development in the Imperial Valley of California has raised concern over the possible impacts of such development. As an initial step in impact assessment of geothermal projects, relevant features of the Valley's physical and human environments are described. Particular attention is placed on features that may either influence development or be affected by it. Major areas of consideration include the Valley's physical environment, and economic, fiscal, and social characteristics of Imperial County, as well as geothermal laws.

Lewis, R. A., N. R. Glass, and A. S. Lefohn, eds. 1975. The Bioenvironmental Impact of a Coal-Fired Power Plant, Second Interim Report, Colstrip, Montana. Springfield, Va.: National Technical Information Service.

This document describes the progress of an investigation that attempts to characterize the impact of air pollutants on a total (grassland) ecosystem. Moreover, it is the first to attempt to generate methods to predict bioenvironmental effects of air pollution before damage is sustained. The authors expect to observe complex changes in ecosystem dynamics as a function of relatively long-term, chronic pollution challenge. By studying a broad range of interacting variables, they hope to isolate some as sensitive and reliable measures of air pollution impact. The approach employed requires (1) the use of reasonably comprehensive models of component populations of the ecosystem; (2) the use of appropriately structured field and laboratory experiments; and (3) evaluation of physiological and biochemical functions that may serve as specific indicators of air pollution stress. The study establishes one part of the cost/benefit matrix that will provide for the normalization of environmental impact information. Included in the study are the characterization of the effects of coal-fired power plant emissions on plant and animal community structure; primary production, invertebrate animal consumers and decomposers; plant and animal diseases; both beneficial and harmful insects; indicators and predictors of pollution (e.g. lichens and honeybees) and production; the behavior, reproduction, and development, population biology, health and condition of vertebrate animals. Supportive and integrative components include field experimental studies; mathematical modeling; remote sensing; micrometeorological investigation; chemical analyses (e.g. sulfur, fluoride) of biological specimens; and air quality monitoring that includes integrated aerosol characteristics.

Manon, A. et al. 1977. Extensive Geochemical Studies in the Geothermal Field of Cerro Prieto, Mexico. LBL-7019 UC-66 TID-4500-R66. Springfield, Va.: National Technical Information Service.

This communication makes available a wealth of data, including analyses of dissolved ions and gases in exploration and production wells, compiled by the chemical laboratory at Cerro Prieto. This data (27 figures, 11 tables) is preceded by a discussion of the geochemical pattern of the Cerro Prieto fluids, ion correlations, and preliminary consideration of a few other topics.

McFadden, J., Principal Investigator. 1977. Northwest Energy Policy Project, Energy Supply and Environmental Impacts, Conventional Energy Sources. Study Module III-A, Final Report. Portland, Ore.: Northwest Energy Policy Project.

In this study module natural gas, petroleum, coal and electrical energy are discussed. Supply sources for each form of energy from 1965 - 1974 are considered, with energy cost and price data. Additionally, possible future sources from 1980 - 2000 are identified, and factors determining the amount and price of each made available are discussed. Impacts are reviewed for extraction, processing, transportation, conversion and transmission and distribution of each energy form, and end-use environmental impacts are considered. Three scenarios, of moderate, high and low rates of growth in energy supply and demand are related to supply, price, and impacts for each energy form. Specific Northwest-region energy supply issues are considered.

Miller, S. G. 1974. Environmental Impacts of Alternative Conversion Processes for Western Coal Development. Old West Regional Commission Contract #10470040. Washington, D. C.: Thomas E. Carroll Associates.

An examination of potential coal conversion schemes, to determine environmental impacts associated with extracting the requisite coal and possibly locally converting it to a clean energy source for export out of the region is made. The study considers seven coal gasification processes, two coal liquification processes, electric power generation including steam cycle, gas turbine, magneto-hydrodynamics, and various combined cycle generation systems. All these are operational or expected to be so within 15 years. The processes are first described and their physical resource input requirements characterized; emissions and pollution potential are identified; pollutant effects on land, and in water and air are discussed. Discussion is supported by quantitative data where possible, and a range of potential environmental damage is presented.

Mitchell, D. R., ed. 1950. Coal Preparation. New York: The American Institute of Mining and Metallurgical Engineers.

In 23 chapters by numerous authors the various aspects of coal preparation are presented. Impurities removed by various operations are detailed, sometimes quantitatively. All types of operations are characterized, and separate chapters cover the economics, plant control and efficiencies, and coal characteristics and associated impurities.

Moseley, F. N. 1975. Environmental Considerations and Economic Implications in the Development of Geothermal Energy. Presented at the Energy Research and Development Administration/University of Texas First Geopressured Energy Conference, Austin, June 2 - 4, 1975.

The development of geopressed areas for electric generation and other uses presents an opportunity to employ data management in the decision-making process. A new resource and its development must be economically competitive with existing resources and processes. The initial phase of geothermal exploration, well drilling, and testing is the best time to consider environmental changes that might result from the development of the resource. Various options for handling potential changes must be determined so that management plans may be devised. Probably the most serious item of environmental concern about geopressed areas involves water used to produce the energy. Another potential critical problem is subsidence caused by removal of large quantities of water from deep subterranean reservoirs.

National Academy of Sciences. 1974. Rehabilitation Potential of Western Coal Lands. Cambridge, Mass.: Ballinger Publishing Co.

This book is one of a series of studies commissioned by the Ford Foundation under the Energy Policy Project. The study outlines the problem of rehabilitation of strip-mined land in the arid West, and defines the Western Coal Area. After exploring water resource problems relating to surface mining and reviewing rehabilitation techniques, rehabilitation potential is assessed and certain "larger scale" environmental impacts (e.g. land use, demographic change) are addressed. Findings and recommendations include that technology for rehabilitation is generally available and that areas receiving ten or more inches of annual rainfall can usually be rehabilitated if given proper attention.

Nehring, R., B. Zycher, and J. Wharton. 1976. Coal Development and Government Regulation in the Northern Great Plains: A Preliminary Report. Santa Monica, Calif.: Rand.

This report provides a basic framework for understanding the relationship between government regulation and coal development in the Northern Great Plains. It describes the characteristics and development of the Northern Great Plains coal resource, the adverse effects of coal development, and existing Federal and state regulation directed at these effects, and discusses possible state and Federal regulatory roles in Northern Great Plains coal development. Detailed tables give coal characteristics and development data for each deposit in Montana, North Dakota, and Wyoming which falls within the region. These data are discussed in the text. Coverage of adverse effects of coal development is extensive, though more qualitative.

Newkirk, H. W., ed. 1976. Environmental Effects of Energy Production and Utilization in the U. S., Vol. 1, Sources, Trends, and Costs of Control. UCRL-51930. Lawrence Livermore Laboratory. Springfield, Va.: National Technical Information Service.

This is the first of three volumes designed to provide a handbook data bank of environmental information that will be helpful in making cost/benefit choices regarding energy production and utilization. This volume deals with sources - characterizing emissions; trends - quantities of emissions and their dispersion with time; and costs of control, related to minimum standards. It is divided into sections addressing atmospheric, water, land and social environments affected by energy production and use. Chemical, radiological, and physical factors are discussed, as well as resource use and human factors. A large amount of data is presented in figures and tables.

Oak Ridge National Laboratory. 1973. Electrical Energy and its Environmental Impact, Progress Report, June 30, 1973. ORNL-NSF-EP-55.

This report summarizes work done in the past six months, including analysis of energy uses, a statistical analysis of U. S. electricity demand growth, research on policy alternatives in coal mining with emphasis on cost penalties attending various levels of land reclamation, and measurements of trace element buildup in the environment surrounding a coal-fired steam plant. The goal of the coal research program is to develop a quantitative picture of coal supply and demand in order to assess the impact of measures which would force an environmentally acceptable use of the coal resource.

Olson, H. J., and W. M. Dolan. 1976. "Geothermal Energy - An Industrial Appraisal," Mining Congress Journal, 62(3): 18, March, 1976.

Geothermal energy use is anticipated to increase for space heating, process heating, and desalination, but the user must be close to the source. The Geysers, north of San Francisco, has been a commercial production site for geothermal energy since 1960. The environmental virtues of geothermal far outweigh its impact, even though it displays characteristics that overlap both mineral and petroleum occurrences. Geothermal legislation is discussed. The industry's destiny is in the politician's hands, this paper concludes.

Pacific Northwest Generating Company. 1976. Environmental Analysis: Proposed Participation in Portland General Electric Company's Boardman Coal Plant. Hermiton, Ore.: Pacific Northwest Generating Company.

Portland General Electric Company proposes to undertake construction of a single coal-fired generating unit with a nominal design capacity of 550 MWe, located southwest of Boardman, in Morrow County, Oregon. The project would include the generating plant and supporting facilities, including coal-handling and storage facility, cooling pond, ash-disposal facility, rail loop, and transmission facilities. The Boardman site is a sparsely populated, semiarid, nonforested region of eastern Oregon. Adverse impacts analyzed include substantial socioeconomic disruption, potential impacts from gaseous emissions and ash disposal leachate, and water withdrawal from the Columbia river.

Phelps, P. L., and L. R. Anspaugh, eds. 1976. Imperial Valley Environmental Project: Progress Report. UCRL-50044-76-1. Lawrence Livermore Laboratory. Springfield, Va.: National Technical Information Service.

The Imperial Valley Environmental Project was conceived to establish an environmental data baseline for the Imperial Valley and to assess the potential environmental impact of future geothermal installations in the Valley. It consists of seven main elements: air quality, water quality, ecosystem quality, subsidence and seismicity, socioeconomic effects, health effects, and integrated assessment. This progress report covers the first year of this project. Status of most work is at the point of having established sampling monitoring systems, and data collection is in process.

Phillips, S. L. et al. 1975. Review of Geothermal Subsidence. LBL-3220. Washington, D. C.: U. S. Department of Energy, Division of Geothermal Energy.

This document provides a compilation of abstracts of literature on land subsidence related to geothermal fluid withdrawal, with selected nongeothermal references to provide background information on the theory, causes, effects, and means of controlling subsidence due to removal of subsurface fluids. The period covered is from 1970 to August, 1975. Recommendations for future data gathering, and a glossary of subsidence terms are included with 48 abstracts.

Pritchett, J. W. et al. 1975. Geohydrological Environmental Effects of Geothermal Power Production, Phase I. SSS-R-75-2733. La Jolla, Calif.: Systems, Science and Software.

Recent interest in the large scale exploitation of geothermal energy resources provides motivation for this investigation of environmental consequences of geothermal power production. The potential environmental hazards can be grouped into two broad categories - above-surface effects (noise, emission of noxious gases) and subsurface or geohydrological effects (land subsidence, induced seismicity, and groundwater contamination). The present research effort is intended to develop a computational capability whereby field information for a specific geothermal system can be used to make predictions of such geohydrological phenomena as land surface subsidence, mixing of geothermal brine into fresh water aquifers, and induced tectonic stresses near faults due to production and reinjection of geothermal fluids.

Pritchett, J. W. et al. 1976. Geohydrological Environmental Effects of Geothermal Power Production, Final Report, Phase IIA. SSS-R-77-2998. La Jolla, Calif.: Systems, Science, and Software.

This report describes research work to develop and validate a computational capability whereby field information for a given geothermal reservoir system can be used to reliably predict the behavior of the reservoir under specific conditions of fluid withdrawal and injection, and to evaluate three potential environmental hazards: land surface subsidence, induced seismicity, and groundwater pollution resulting from reinjection of spent geothermal brines. Reservoir simulators are applied to the Wairakei geothermal area.

Renne, D. S., and D. L. Elliott. 1976. Regional Air Quality Assessment for Probable Near-Term Coal-Related Energy Development in the Northwest. BNWL-2084 RAP-9. Richland, Wash.: Battelle Pacific Northwest Laboratories.

Regional impacts associated with the "possible" near-term scenario of coal-fired electrical generation and coal gasification development in the Pacific Northwest have been analyzed. This analysis is based on Federal New Source Performance Standards and a regional scale transport, transformation and removal model for sulfur dioxide, sulfates, particulates and nitrogen oxides. Results show that no significant incremental amounts of sulfur dioxide, particulates, or nitrogen oxides are added to background levels beyond the immediate vicinity of the plant. Air concentrations and deposition budgets are worked out, and areas receiving the greatest increases in ambient air concentrations and surface depositions are identified.

Resource Planning Associates, Inc. 1977. Western Energy Resources and the Environment: Geothermal Energy. EPA 600/9-77-010. Washington, D. C.: U. S. Environmental Protection Agency, Office of Energy, Minerals, and Industry.

Fundamentals of geothermal resource types, location, creation and development are covered. Energy potential and development technology are reviewed. An overview of environmental problems associated with geothermal development is provided and supported with quantitative data.

Science and Public Policy Program, University of Oklahoma. 1975a. The Geothermal Energy Resource System. Washington, D. C.: U. S. Government Printing Office.

The geothermal energy resource system and its contribution to U. S. energy sources are discussed. The quantity, quality, and location of the resource, and technologies for exploration, extraction, electricity production, transport and miscellaneous uses are discussed. Energy efficiencies, environmental considerations and process economics are presented. Although its national role is estimated at only 1% of total 1985 electricity production, geothermal power can be a significant local supplement to other electric power forms. Geothermal steam can also be employed directly for such uses as space heating.

Science and Public Policy Program, University of Oklahoma. 1975b. Energy Alternatives: A Comparative Analysis. Washington, D. C.: U. S. Government Printing Office.

This report provides descriptions and data on the major energy resource systems in the United States, and suggests procedures for using these descriptions and data. Part I contains descriptions of the coal, oil shale, crude oil, natural gas, tar sands, nuclear fission, nuclear fusion, geothermal, hydroelectric, organic wastes, and solar energy resource systems, plus descriptions of electric power generation and energy consumption. In addition to discussing the resource and development technologies, each resource system description contains data on energy efficiencies, environmental residuals and economic costs. Part II describes procedures for using the material of Part I in systematic comparison of energy alternatives, and suggests procedures for impact analysis.

Surprenant, N., R. Hall, and L. M. Seale. 1976. Preliminary Emissions Assessment of Conventional Stationary Combustion Systems, Vol. II, Final Report. EPA-600/2-76-0466.

A preliminary emissions assessment of the air, water and solid waste pollutants produced by conventional stationary combustion systems is given. Results are summarized for the following four principal categories: utilities - electric generation; industrial - steam generation, space heating and stationary engines; commercial/institutional - space heating and stationary engines; and residential - space heating. Process types and operating efficiencies, fuel consumption, pollutant sources and characteristics, major research and development trends, fuel consumption trends and technical areas where emission data are incomplete are summarized for each principal combustion system category. A uniform combustion source classification system was developed and the pollutant emissions from applicable unit operations summarized for 56 source classifications.

Trehan, R. K. et al. 1976. Analysis of Geothermal Energy Development Scenarios. MTR-7220. The MITRE Corporation, METREK Division.

Under contract to the U. S. Energy Research and Development Administration, Division of Geothermal Energy, MITRE/METREK has postulated three near-term geothermal development scenarios (3,600 - 6,000 MWe capacity on line by 1985) and a series of longer-term development scenarios at various growth rates, and has analyzed the implications of these developments for both Federal and non-Federal activities and resources so that goals and programs may be formulated. Eighteen sites in three groups comprise the near term analysis. Constraints on development are reviewed, including resource lifetime, market penetration, environmental considerations, and requirements for drill rig, land leasing, capital and cooling water.

Truesdell, A. H. 1973. ENTHALP, A Computer Program for the Calculation of Aquifer Chemistry in Hot-Water Geothermal Systems. USGS-GD-73-006. Menlo Park, Calif.: U. S. Geological Survey.

The program calculates the temperature and chemical conditions in a geothermal aquifer supplying a production bore. The input includes the enthalpy of the total fluid and the chemical analyses of water and steam separated and collected at known pressures. Alternatively, if a single water phase exists in the aquifer, the complete analysis (including gases) of a sample collected by a downhole sampler are sufficient without a measured value of the total enthalpy. The fundamental assumptions are that the fluid is produced from a single aquifer and is homogenous in enthalpy and chemical composition. The calculation, necessarily involving moderately large amounts of auxiliary information and frequent iteration, is well suited to computer methods.

U. S. Energy Research and Development Administration. 1975. Problems in Identifying, Developing and Using Geothermal Resources. RED-75-330. Springfield, Va.: National Technical Information Service.

Legislation and legislative history on U. S. Department of Interior's participation in the geothermal program are examined. The development of electric power from geothermal resources and their energy potential are discussed. Through 1985, geothermal resources will not be a major alternative energy source, and projections to the year 2000 involve great uncertainty due to technical and environmental problems. Problems in the Federal program for leasing public lands to private interests to develop geothermal resources stem from the lack of reliable information, insufficient requirements for early exploration, and legal matters involving the ownership and control over use of geothermal resources. Recommendations that can strengthen leasing regulations are offered, and a conceptual plan for geothermal development of Imperial Valley, California, is presented.

U. S. Energy Research and Development Administration, Division of Geothermal Energy. 1977. Guidelines to the Preparation of Environmental Reports for Geothermal Development Projects. ERHQ-0001. Washington, D. C.: Energy Research and Development Administration.

Geothermal-oriented instructions for the environmental assessment process are given. Comprehensive and detailed regarding elements to be considered, not a report on the nature and degree of impacts occurring.

- U. S. Environmental Protection Agency. 1974. Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Steam Electric Power Generating Point Source Category. PB 240-853. Springfield, Va.: National Technical Information Service.

This document presents the findings of an extensive study of the steam electric power generating point source category for the purpose of developing effluent limitations, guidelines, standards of performance for new sources, and pretreatment standards for the industry in compliance with and to implement Sections 304, 306, and 307 of the Federal Water Pollution Control Act Amendments of 1972. Effluent limitations guidelines contained herein set forth as mandated by the Act are: (1) the degree of effluent reduction attainable through the application of the "best practicable control technology currently available" which must be achieved by nonnew point sources by no later than July 1, 1977; (2) the degree of effluent reduction attainable through the application of the "best available technology economically achievable" which must be achieved by nonnew point sources by no later than July 1, 1983. The standards of performance for new sources set forth the degree of effluent reduction achievable through application of "best available demonstrated control technology, process, operating methods, or other alternatives". This report contains findings, conclusions, and recommendations on control and treatment technology relating to chemical wastes and thermal discharges from steam electric power plants. Supporting data and rationale for development of the effluent limitations, guidelines and standards of performance are contained herein.

- U. S. Environmental Protection Agency. 1976. Proceedings of the National Conference on Health, Environmental Effects, and Control Technology of Energy Use, February 9 - 11, 1976, Sheraton Park Hotel, Washington, D. C.

These proceedings include the addresses and papers presented at the conference, with a transcription of questions and discussions occurring at each of the conference sessions. They represent a compendium of current and planned work in research relating to health, environmental effects and control technology of energy use. Fifty-eight presentations are divided among the following sections: atmospheric transport, measuring and monitoring, environmental health effects, marine ecological effects, fresh water ecological effects, terrestrial ecological effects, energy resource extraction, fuel processing, flue gas technology, energy conservation, and integrated assessment.

- U. S. Environmental Protection Agency, Geothermal Working Group. 1977. Geothermal Industry Position Paper: EPA Regulatory Options and Research and Development Information Needs. EPA-600/7-77-092. Washington, D. C.: Environmental Protection Agency.

This is an EPA position paper on environmental issues associated with geothermal energy use. Identification and summary evaluation of environmental problems, outline of regulatory and nonregulatory options for their control, specific recommendations pertaining thereto, a schedule of action and research needs are included.

U. S. Fish and Wildlife Service. 1976. Geothermal Handbook. Washington, D. C.: U. S. Department of the Interior.

This report covers the effect of geothermal development on fish and wildlife resources and supporting ecosystems. Phases by phase impacts, from first exploration to full development are covered. Federal geothermal leasing agreements and the Service role in private-land development is also covered, as well as environmental assessment procedures.

Wapora, Inc. 1976. Survey of Environmental Regulations Applying to Geothermal Exploration, Development, and Use. Cincinnati, Ohio; U. S. Environmental Protection Agency, Energy Systems Environmental Control Division.

This report presents the results of a survey of existing legal requirements applicable to the production and use of geothermal resources. The report focuses on local, state, federal, and federally-approved ordinances, statutes, regulations and standards designed to minimize adverse environmental effects of pollution sources, most of which are general, but some of which relate specifically to geothermal development. Criteria mandating preparation of environmental assessments are detailed, along with information which they require and specific engineering and documentation requirements during well drilling and testing.

Wapora, Inc. 1977. Survey of Environmental Regulations and the Assessment of Pollution Potential and Control Technology Applications for Geothermal Resource Development, Draft Final Report, Phase II. Cincinnati, Ohio: U. S. Environmental Protection Agency, Energy Systems Environmental Control Division.

In this report the potential for exploitation of some 284 identified geothermal systems in the U. S. is evaluated. Assessment is based on such factors as size (heat content), subsurface temperature, pressure, flow, location and surface features. Covered are physical/chemical characteristics, location and environment of U. S. geothermal fields, exploration and development technology, geothermal resource use for generation of electric power and nonelectric uses, environmental implications of production and use (extensive data), control options, and control technology vis-a-vis environmental regulations.

Weres, O., K. Tsao, and B. Wood. 1977. Resource, Technology, and Environment at the Geysers. Contract #W-7405-ENG-48. Lawrence Berkeley Laboratory. Springfield, Va.: National Technical Information Service.

A comprehensive account of the Geyser's development, its environmental impacts and control technology is presented. The Lardarello (dry steam) geothermal development in Italy is also described. Coverage of the fundamentals of geothermal energy use, including types of geothermal resources, their creation, thermodynamics, and associated impacts is included. All phases of geothermal development at the Geysers are quantitatively covered: exploration, extraction, power plant conversion and associated emissions, effects and control technology. Hydrogen sulfide emissions are emphasized.

White, D. E., and D. L. Williams. 1975. Summary and Conclusions: Assessment of Geothermal Resources of the United States - 1975. USGS/ERDA Report 726 on Assessment of U. S. Geothermal Resources.

The geopressed fluids of the Gulf Coast have a huge geothermal potential. Much of this resource is probably paramarginal under present conditions, but some part is probably recoverable now from areas where the environmental impact is low. The high temperature convection systems (greater than 150° C) of interest for the generation of electricity are predominantly in the Western coterminous U. S., but some are in Alaska and Hawaii. The intermediate temperature convection system (90 - 100° C) have much potential for supplying thermal energy for home and industrial heating, thereby releasing oil and gas for more critical use. The hot igneous magma systems and some areas of high regional temperature gradients provide relatively favorable areas for utilizing the heat of hot dry rock, provided that satisfactory methods of recovery can be developed. Disregarding cost, the total magnitude of geothermal resources that can be recovered by present and near-current technology is very large. The resource base and recoverability are examined.

Williams, F. et al. 1978. Site-Specific Analysis of Geothermal Development (3 Volumes). HCP/T4014-01/3 UC-66. Washington, D. C.: U. S. Department of Energy.

Development scenarios for 37 hydrothermal and geopressed resource areas or prospects for electric power generation starting prior to 1990 are analyzed. Volume I contains a summary and Volume II the details of the site-specific analyses in terms of technological, economic, and other requirements for meeting postulated schedules. Volume I emphasizes recommendations for the Federal Geothermal Program. Volume III contains detailed descriptive data files for each of the 37 prospects.

Wollenberg, H., H. Bowman and F. Araro. 1977. Geochemical Studies at Four Northern Nevada Hot Spring Areas. LBL-6808 UC-66b TID-4500-R66. Springfield, Va.: National Technical Information Service.

As part of a program on the part of the Lawrence Berkeley Laboratory to define parameters for the assessment of geothermal resources and to develop and evaluate techniques to measure them, this report describes geochemical studies on hot and cold sources in hydrologic areas surrounding hot springs in northern Nevada. Analysis of major, trace, and radio-element abundances of the water and associated rock samples are made to attempt to indicate pathways of the water from source into and through the geothermal system. Possible diagnostic chemical geothermometers (tungsten and dissolved hydrogen sulfide) are examined. Mixing models for near-surface cold water and deeper hot water are calculated, and the use of uranium concentrations to age the system is considered.

ADDENDUM TO
COMPARISON OF GEOTHERMAL
ENERGY AND COAL FOR SELECTED USES

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Addendum to "Comparison of Geothermal Energy and Coal for Selected Uses"

Comparisons of geothermal energy and coal are here supplemented with data for two additional technologies, oil and natural gas. Each technology is applied to the same three end uses considered in the main report. The six energy supply - use trajectories evaluated are shown in Table Addendum - 1. Figures Add. - 1, Add. - 2, Add. - 3 summarize values for the energy efficiencies and for the environmental residuals previously selected as important indicators of the impacts of the technologies.

The basic data used for energy efficiencies, residuals, and other environmental effects came from the Hittman report (1), the Northwest Energy Policy Project conservation study (2), Energy Alternatives (3), and Distributed Energy Systems in California's Future (4).

The bar charts in Figures Add. - 1, Add. - 2, and Add. - 3 do not present a consistent indication of superiority for any of the technologies in all respects. For space heat and process heat hydrothermal and natural gas release somewhat smaller amounts of particulates, sulfur, and CO_2 than coal and oil. Natural gas has a clear environmental advantage for electric drive. The second law energy efficiency is in all cases highest for the hydrothermal resource.

A number of environmental effects are not included in Figures Add. - 1 through Add. - 3. Land subsidence, induced seismic activity, dedicated use of land, damage to sensitive ecosystems and organic solid wastes (for the oil system) are examples. These effects, some of which are very site specific, were judged qualitatively to be less serious in general than the five included and were omitted in quantitative assessment. More work to identify and quantify the dominant impacts should be carried out, especially for the site specific effects.

References

1. Hittman Associates. "Environmental Impacts, Efficiency, and Cost of Energy Supply and End Use." Final report HIT-593, V.1. Hittman Associates, Columbia, Maryland, 1974
2. W. Butcher et al. "Energy Conservation Policy - Opportunities and Associated Impacts. Study Module I-A. Technical Appendix." Environmental Research Center, Washington State University, Pullman, Washington, 1978
3. University of Oklahoma. "Energy Alternatives: A Comparative Analysis." University of Oklahoma, Norman, Oklahoma, 1975.
4. F. Balderston et al. "Distributed Energy Systems in California's Future. Interim Report Volume II." Report HCP/P7405-02; UC-13, 1978.

Table Addendum - 1. Oil and Natural Gas Supply Trajectories

	Source	Transportation	Conversion	Transportation	Conversion	Distribution	End Use
1.	Oil reservoir	Pipeline	Refinery-distillate	Pipeline-truck	Oil furnace	--	Space heat
2.	Oil reservoir	Pipeline	Refinery-distillate	Pipeline-truck	Boiler	--	Process heat
3.	Oil reservoir	Pipeline	Refinery-residual	Pipeline-transfer	Electricity	Transmission line	Electric motor
4.	Gas field	Pipeline	--	--	Gas furnace	--	Space heat
5.	Gas field	Pipeline	--	--	Boiler	--	Process heat
6.	Gas field	Pipeline	--	--	Electricity	Transmission line	Electric motor

ENERGY EFFICIENCY AND RESIDUALS COMPARISONS FOR SPACE HEAT

Figure Add. -1

ENERGY EFFICIENCY AND RESIDUALS FOR PROCESS HEAT

Figure Add. -2

ENERGY EFFICIENCY AND RESIDUALS FOR ELECTRIC DRIVE

Figure Add. -3