

ALTERNATE ENERGY AND MINERAL DEVELOPMENT:
GENERAL OUTLOOK AND COMPARATIVE ECONOMICS

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INTRODUCTION

Oil and gas reserves are declining at an alarming rate, but alternate energy resources such as coal (including lignite), uranium and geothermal energy will play dominant roles in the American economy in the near future. Fortunately, alternate energy resources are regionally abundant in the United States and if developed rapidly, with all due consideration to the environment, they will serve to bridge the energy gap between our present petroleum-based energy and future solar or fusion-based energy. It is clear that a diversified multiple energy base must be developed to serve our regional energy needs well into the 21st Century.

Alternate mineral resources are also being sought to substitute for many metals presently in short supply and for plastics that may decrease in availability as oil feedstock increases in cost. Engineering and economic feasibility studies will be based on regional resource availability, regional energy and mineral needs, and comparative economics in both energy and mineral development.

PRESENT AND FUTURE ENERGY REQUIREMENTS AND POTENTIAL

As of 1974, the United States consumed 74 quadrillion (10^{15}) Btu, of which petroleum supplied 45.8%, natural gas: 30.4%, coal (including lignite): 13.0%, hydropower

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and geothermal: 4.2% and nuclear: 1.6% (See Figure 1). Energy consumption is growing at an average rate of approximately 5.0% per year, but the growth rate is expected to decline slowly in the future. The Federal Energy Administration (FEA) conservatively estimates that the nation's total energy needs 16 years hence in 1989 will increase to 112 quadrillion (10^{15}) Btu, or about 53% more than the Btu consumed in 1974 (Ref. 24).

Placing these requirements in perspective, the total energy available from domestic fossil fuels and uranium is estimated at 55.6 thousand quadrillion (10^{18}) Btu (See Figure 2). It should be noted that coal contributes more than 60% of the available energy. Ranking second is oil shale, although no significant production has yet been achieved because of technological problems. Oil shales and sands have an uncertain role in the overall energy picture, but the federal government is supporting a vigorous R & D effort. Natural gas and petroleum account for only 10% of the total potential energy available from fossil fuel, although together they currently supply more than 75% of the total energy used (Compare Figures 1 and 2).

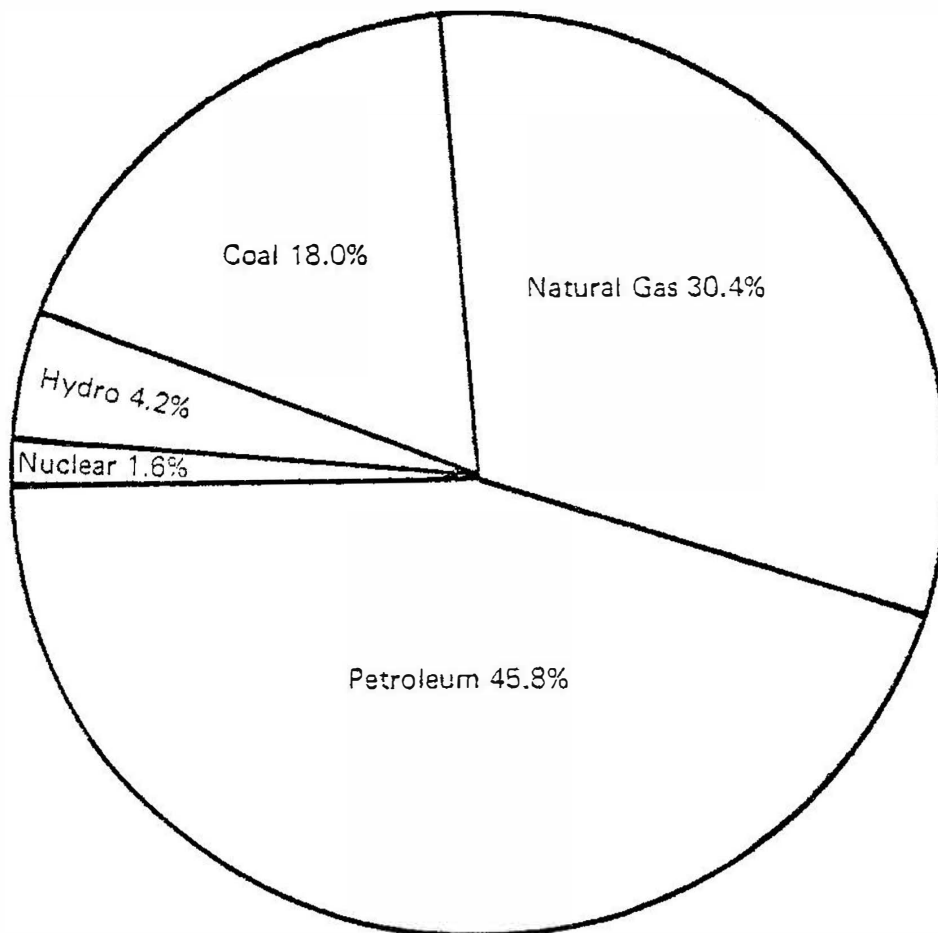
The present conventional energy potential of uranium resources is somewhat uncertain. However, with the development of the breeder reactor and possible new developments in nuclear fission technology, the present uranium resources would have an energy potential about twice as great as our coal resources.

In the United States, we are at present over utilizing our most limited resources (oil and gas) and under utilizing our most abundant resources (coal). This is one of the reasons we are now facing an energy crisis. Disproportionate utilization of resources has not only caused depletion of a large portion of our prime

Figure 1

ENERGY CONSUMED IN THE UNITED STATES BY SOURCE IN 1974

(Consumption 73.1 quadrillion Btu)

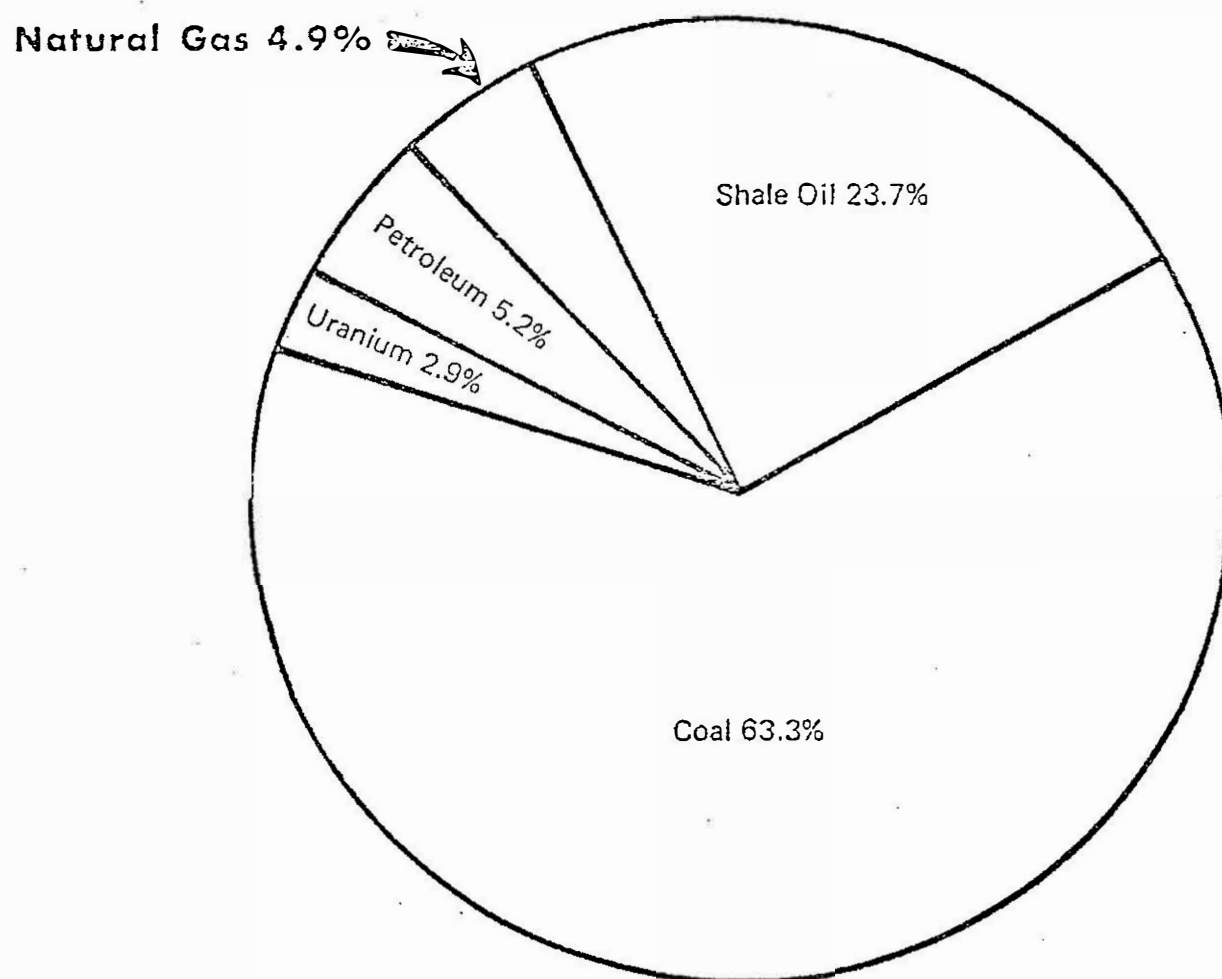


U.S. Department of Interior News Release, April 3, 1975

Figure 2

Sources Of Energy For Future Needs In The United States

Total available energy is estimated at 55.6×10^{18} Btu



Federal Power Commission "National Gas Survey," 1974

energy resources (oil and gas), but it has also made us increasingly dependent on foreign oil-producing countries for a substantial part of our energy needs. This condition clearly indicates that we must develop our alternate energy resources as quickly and as prudently as possible.

There appear to be two sleeping energy giants not considered in the previous discussion that may alter our immediate regional planning and utilization of alternate energy resources, i.e. (1) geothermal-geopressed energy resources of the Gulf Coast of Texas and Louisiana and of the western United States, (2) uranium resources for conventional use in the form of undeveloped uranium deposits of low, but economically recoverable grade and in the form of reserves as by-products from phosphate and copper mining activities.

EXPLORATION AND RESOURCE DEVELOPMENT

Exploration and development of alternate energy and mineral resources require specialized techniques and personnel. Each resource has its own special characteristics in terms of U. S. activity, exploration techniques, development methods and of the relative impact on the environment. Some of the important features with respect to the exploration and development of the major alternate energy and mineral resources will be briefly reviewed in this presentation. Coal will be considered in some detail first followed by uranium, geothermal energy and minerals.

COAL

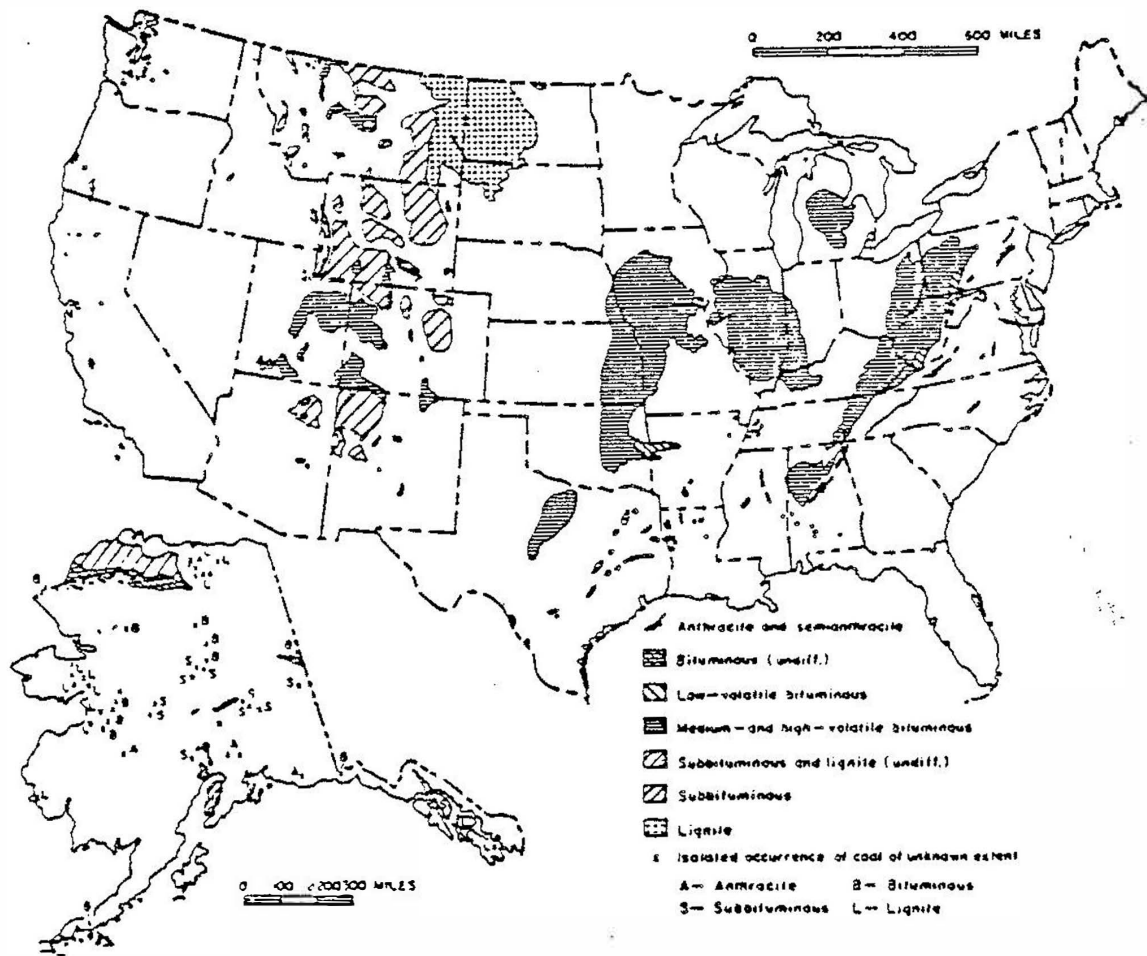
Coal is the principal fossil fuel resource of the United States, but no clear

indication has yet been given by state or federal regulatory agencies that coal is to be used to meet the growing energy needs, in spite of the fact that the technology already exists for extensive use of this resource to economically generate electricity, heat and power (Ref. 24). President-elect Carter is, however, expected to support coal development. Coal (including lignite) also offers significant potential for the production of synthetic fuels, such as low-Btu gas, pipeline-quality gas, petroleum, and solvent-refined products, that could substitute for the dwindling supplies of oil and natural gas (Ref. 2, 6 and 11).

Figure 3 shows the coal fields of the U. S., and Figure 4 illustrates the distribution of the known coal reserves by States and tonnage.

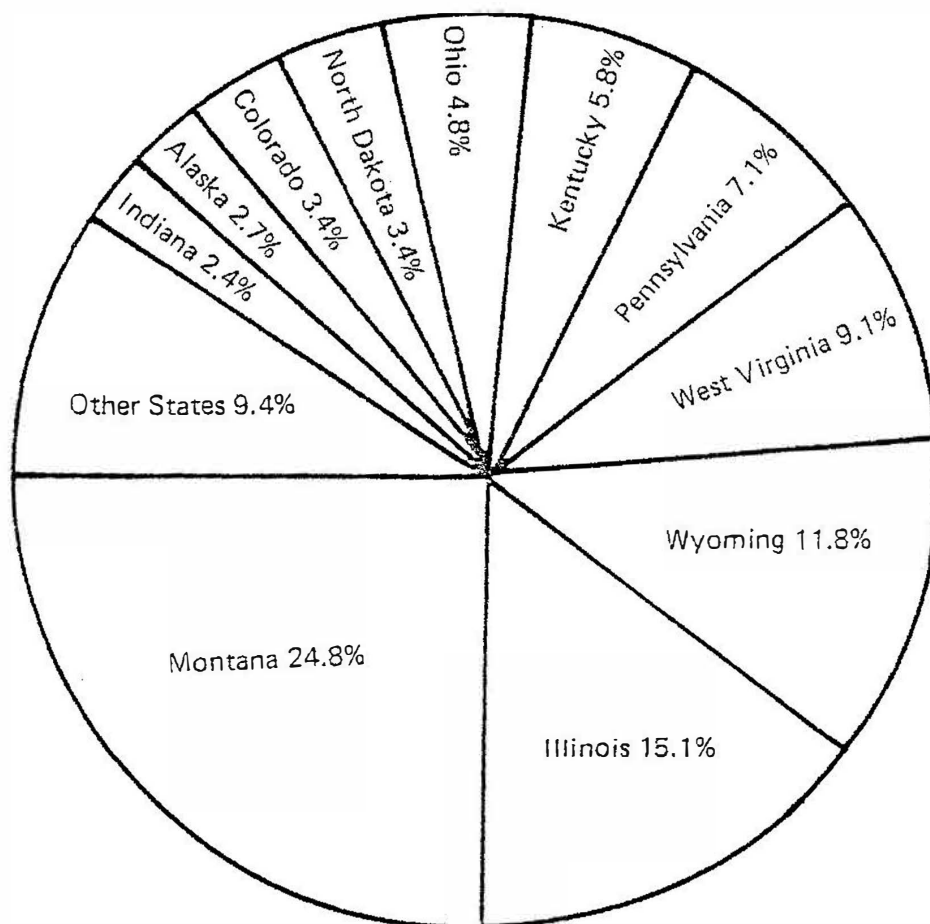
With the introduction of the Clean Air Act of 1970, the sulphur content of coals became a significant factor in the evaluation of coal resources. More than 88% of the total low-sulphur coal reserves is located in the western states; however, only 21% of the total current production of low-sulphur coal comes from the western states. Eastern states, where only 12% of the total low-sulphur reserves occur, are now supplying more than 79% of the low-sulphur coal used. More low-sulphur coal will have to come from the western states in the future unless either technology is developed and applied that will permit wider use of high sulphur coals or nuclear energy assumes a greater role in electrical generation, which is a distinct possibility. In light of the growing environmental concern about strip mining of western coal and the federal leasing problems involved, projected increases on western coal production may not come on stream without significant delay (Refs. 16, 20 and 23).

Figure 3
COAL FIELDS OF THE UNITED STATES



Source: U. S. Geological Survey, 1969

Source: U.S. Bureau of Mines, 1975



STATE DISTRIBUTION OF DEMONSTRATED COAL RESERVES BY TONNAGE

Figure 4

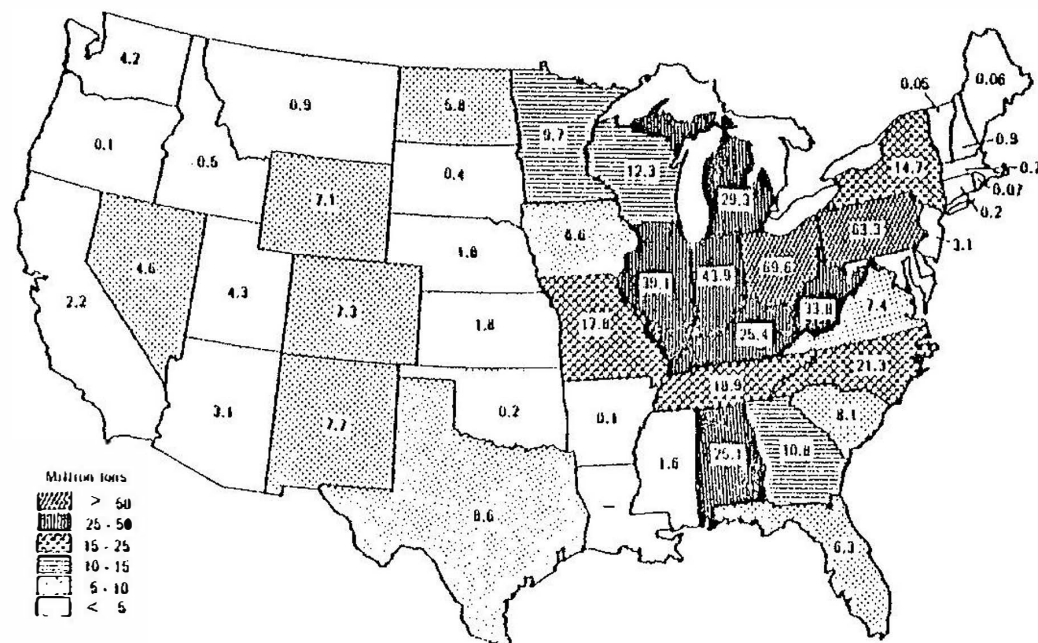
Coal consumption is shown in Figure 5. Forecasted future coal markets are listed for the years 1985, 1995 and 2000 in Figure 6. Potential new markets for industrial coal is shown in Figure 7. Present prices and related tonnage, and sulphur content are shown in Figure 8, as typical examples of selected contracts with utilities in the Midwest, the Central and the Western United States.

There are approximately 4,500 producing coal mines in the United States. Fourteen major coal companies produce 60% of the total current production. Considerable leasing and expansion activity is presently underway, however, among the major independent operators.

There is a substantial difference in lease forms around the country (Ref. 9). Until recently tax-sheltered investments in coal leasing prompted by rising coal prices and favorable tax legislation, once produced both large first-year write-offs and substantial long-term investment returns. The IRS has recently struck down the use of non-recourse notes and other tax sheltering investment advantages. The number of promoters of limited partnerships without the best interests of the investor in mind has been reduced considerably as a result of the elimination of the tax shelter for coal mining.

The independent and small coal operators are turning back to commercial banks for capital rather than seek limited partnerships. However, fluctuations in the price of coal and in escalating mining costs present problems to the independent coal producers because it tends to shut them out from public money markets and limits their use of debt or equity securities. Some small and medium-sized coal companies, especially producers of metallurgical coal, have

Figure 5
UNITED STATES COAL CONSUMPTION IN 1974



Source: Bituminous Coal and Lignite Distribution, Calendar Year 1974
Mineral Industry Surveys, U. S. Bureau of Mines, 1975.

Figure 6

FUTURE COAL MARKETS

(Million tons per year)

Market	1985	1995	2000
Electric utilities	700	1,225	1,600
Synthetic fuels	310	930	1,200
Metallurgical	120	150	160
General industry	65	70	70
Export	65	70	70
Total	1,260	2,445	3,100

POTENTIAL NEW MARKET FOR INDUSTRIAL COAL
(Total estimated 159 million tons)

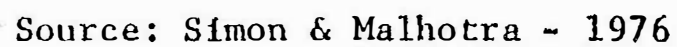


Figure 8

**SELECTED STEAM COAL DELIVERED TO ELECTRICAL UTILITIES
(July, 1976)**

	<u>Number of Contracts</u>	<u>Btu (2) Average</u>	<u>Btu Range</u>	<u>Sale Price (3) Average</u>	<u>Sale Price Range</u>	<u>Tonnage/Sale (4) Average</u>	<u>Tonnage/Sale Range</u>	<u>Sulphur Content, % Average</u>	<u>Sulphur Content Range</u>
I. BITUMINOUS COAL									
<u>Midwest</u>									
Ohio	18	11.8	10.3 - 12.1	90.0	73.1 - 100.8	10,047	3,000 - 67,900	3.47	1.10 - 4.80
Indiana	15	11.1	10.5 - 11.9	63.7	49.4 - 74.0	19,233	3,000 - 65,000	2.33	0.90 - 4.00
<u>Central</u>									
Iowa, Kansas, Missouri & Oklahoma	7	10.5	9.2 - 12.2	73.2	45.1 - 101.2	39,000	3,900 - 125,000	3.83	2.60 - 5.20
<u>Western</u>									
Colorado & Montana	3	11.7	10.4 - 12.5	115.9	63.4 - 148.6	5,913	5,700 - 8,000	0.80	0.70 - 0.90
II. SUBBITUMINOUS COAL									
<u>Western</u>									
Colorado & Montana	15	9.9	8.4 - 10.8	98.2	25.5 - 142.6	61,400	10,000 - 209,000	0.60	0.40 - 1.00
III. LIGNITE									
<u>Western</u>									
Montana, North Dakota & South Dakota	-	6.7	6.1 - 7.2	47.9	18.1 - 69.6	86,500	13,700 - 250,300	0.63	0.60 - 0.80

(1) Coal Week - October 4, 1976

(2) Thousands of Btu/lb

(3) Cents per million Btu

(4) Short tons

used recent good earnings to retire existing debt and have built up short-term investments in anticipation of their future capital needs. The small independents will continue to need conventional types of short-term bank loans for working capital and similar purposes, while utilizing vendor credits or leasing to finance new items of mining equipment, etc. (Ref. 30).

As coal and other alternate energy resources substitute for the traditional oil and gas resources, comparative potential energy resource calculations are necessary. The following is a hypothetical case based on realistic parameters involved in utilizing lignite in place of the traditional residual oil for a mine-mouth power plant (Figure 9). Lignite mining, as is most mining ventures, is capital intensive but long term, captive mining by utilities or suppliers could make the low-grade coal or lignite of Texas, Louisiana, Arkansas, Mississippi and Alabama a very attractive alternate energy source (Ref. 6). In addition, interest is being shown in lignite as a power source for small industrial plants and as a source for chemical by-products. Vast lignite reserves are available in the Gulf Coast region as well as in the North Central U.S. The critical requirements that must be met when evaluating coal projects are: 1) Reliable assessment of coal reserves and coal ownership, 2) Comprehensive evaluation of mine operator's history and practices, and 3) Sound analysis of future coal marketability.

Uranium

Uranium exploration, mine development and nuclear reactor construction and operation has proceeded cautiously over the past few years. Environmental problems

Figure 9

Comparative cost to supply 360 megawatt power plant with 3.6 billion Btu/hr. energy requirement

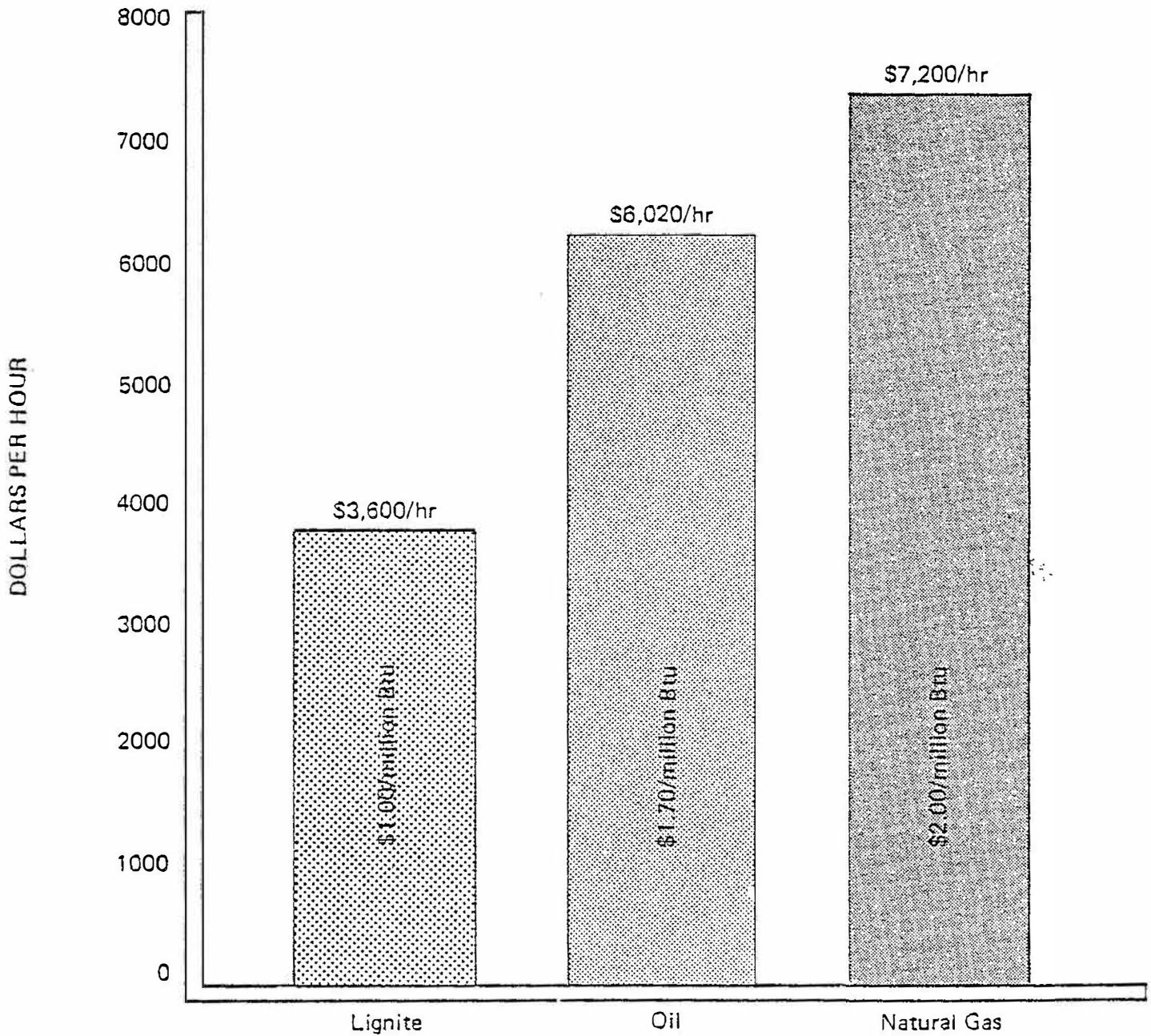


FIGURE 9A

COMPARATIVE ENERGY CALCULATIONS

ASSUME: A. Lignite

6000 Btu/lb of lignite

Heat Production: (6000 Btu/lb) (2000 lbs/ton) =
 12.0×10^6 Btu/ton lignite

B. Residual Oil (#6)

Heat Production: 6.3×10^6 Btu/bbl

BTU COMPARISON:

$$\frac{12.0 \times 10^6 \text{ Btu/ton lignite}}{6.3 \times 10^6 \text{ Btu/bbl oil (\#6)}} = 1.90 \text{ bbl oil/ton lignite}$$

POWER PLANT ENERGY CONSUMPTION:

Assume:

- A. 360 megawatt power plant
- B. Heat Rate: 10,000 Btu/kilowatt hour
- C. 90% Plant Operation
- D. 6000 Btu/lb lignite
- E. 6.3×10^6 Btu/bbl oil (#6)
- F. 3.6×10^9 Btu/hr

PLANT LIGNITE REQUIREMENTS:

- A. 300 tons/hr of 6000 Btu lignite or 2.4×10^6 tons lignite/yr
- B. For 30 yrs mine life requires 72.0×10^6 tons recoverable reserves
- C. Fuel Cost: @ \$12.00/ton lignite (\$1.00/million Btu):
 $\$28.8$ million/year or \$3600/hr

PLANT RESIDUAL OIL (#6) REQUIREMENTS:

- A. 5.6×10^2 bbl/hr of 6.3×10^6 Btu oil or
 4.4×10^6 bbl oil/yr
- B. Fuel Cost: @ \$10.75/bbl:
 $\$47.3$ million/yr or \$6020/hr

PLANT NATURAL GAS REQUIREMENTS:

- A. \$2.00/million Btu
- B. Fuel Cost: \$7200/hr

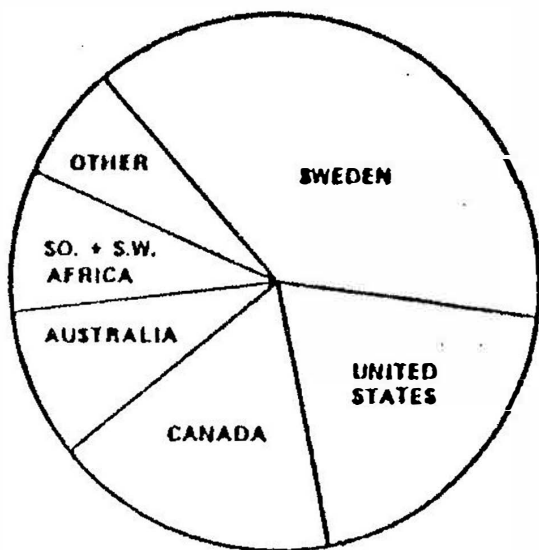
have received wide publicity, but voter referendums on nuclear development in six states were approved in the past year. (Chemical Week - November 17, 1976). Apparent shortages in uranium reserves have also increased speculation on the availability of sufficient reserves to meet domestic reactor demands within the next ten years and have driven prices to a record high. Many older contracts have been renegotiated to \$15/lb. yellowcake, but spot prices of \$40/lb. and higher may become common in the near future if additional U.S. reserves are not developed soon. The United States, however, is still in a good potential reserves position (Figure 10).

Uranium ore is not an easy exploration target and requires considerably more rigorous geologic techniques than employed for coal exploration (Ref. 7). Whereas coal usually occurs as a near horizontal or slightly dipping bed of a few feet in thickness extending continuously for tens of miles in all directions, uranium ore is most commonly found in sandstone only a few feet in thickness and only a few feet wide, although sporadic uranium mineralization may run along a sinuous tract up to a mile or more. Development drilling on 25 foot centers is common. Uranium ore cannot be identified with any certainty in hand-specimen, and sophisticated geophysical and geochemical techniques are needed to confirm its presence. Ore grades now average around 0.15% uranium oxide. Lead time is usually around eight years from the beginning of exploration in geologically favorable areas, through ore discovery, to commencement of mining operations (See Figure 11).

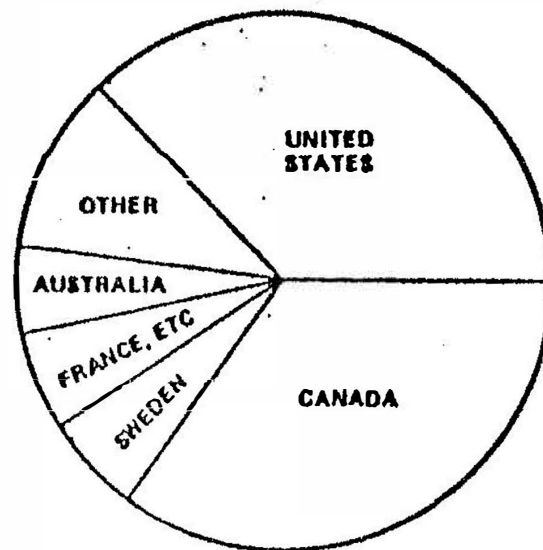
The present major uranium-producing districts are shown in Figure 12, i.e.

Figure 10

WORLD URANIUM RESOURCES - \$10 TO \$15 Per LB U_3O_8
(Excludes China, USSR and Eastern Europe)



REASONABLY ASSURED \$10-15 (RESERVES)	TONS $U_3O_8 \times 10^3$ *	%
SWEDEN	350	38
UNITED STATES	180	20
CANADA	180	17
AUSTRALIA	80	9
SOUTH & S.W. AFRICA	80	8
OTHER	70	7
TOTAL	820	100



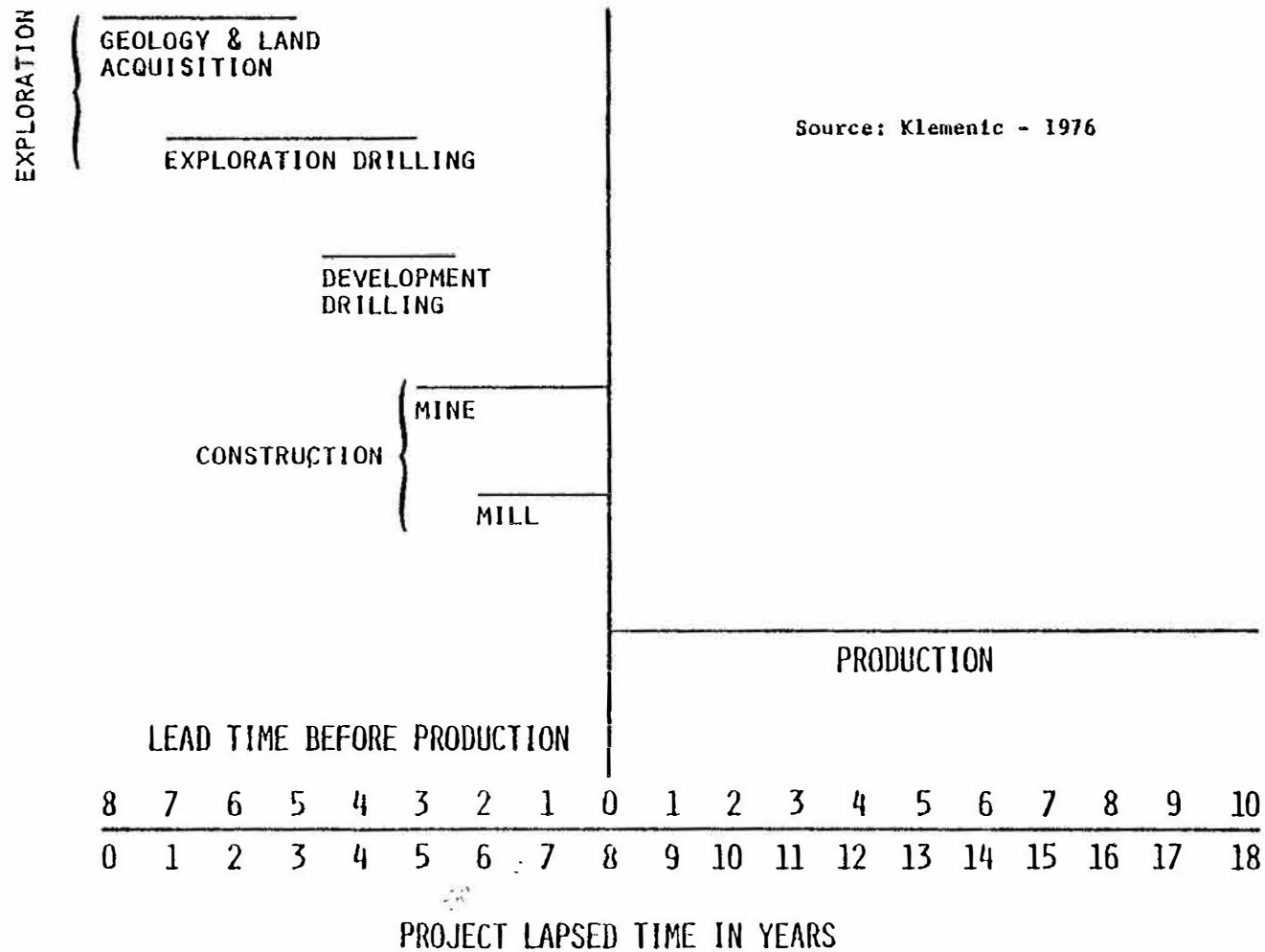
ESTIMATED ADDITIONAL \$10-15 (POTENTIAL)	TONS $U_3O_8 \times 10^3$ *	%
UNITED STATES	300	37
CANADA	280	35
SWEDEN	60	6
FRANCE, NIGER, GABON	60	6
AUSTRALIA	40	5
OTHER	100	11
TOTAL	820	100

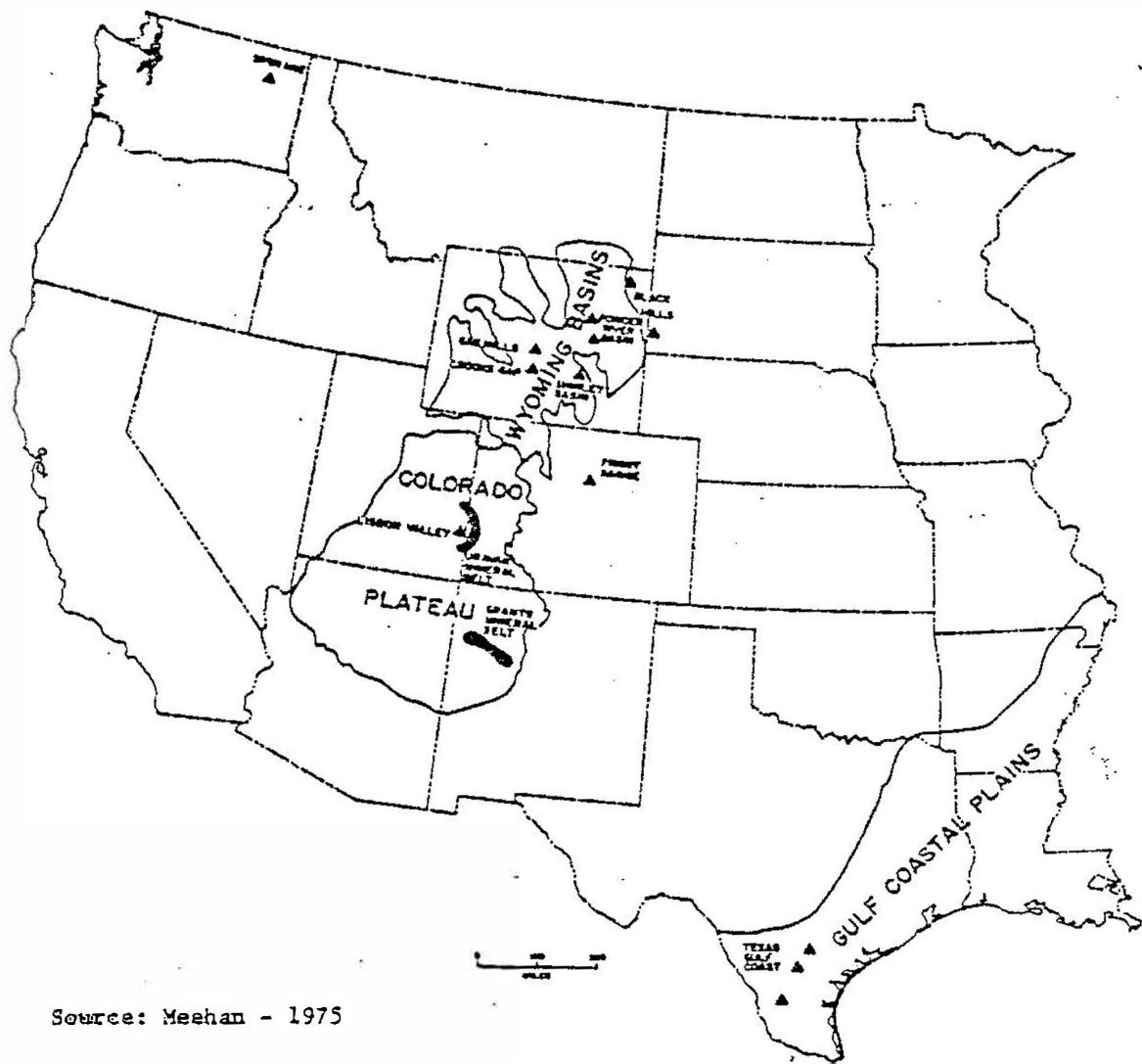
*1.3 Tons U_3O_8 = 1 Metric Tonne (1000 Kg) U

Source: Nininger - 1974

Figure 11

IDEALIZED LEAD TIME SCALE FOR PRODUCTION (URANIUM)





Source: Meehan - 1975

Figure 12
Principal Uranium Districts of the United States

Wyoming, New Mexico, Colorado, Utah and Texas, in order of relative production. Figure 13 illustrates the increase in drilling depths over the past decade (1964 and 1975). Comprehensive assessments of potentially-productive areas are now being conducted by the U.S. Geological Survey and U.S. Energy Research and Development Administration. Additional reserves are expected as a by-product from phosphate mining in Florida and from subsurface solution mining of low grade ore and other sources (Ref. 28). The latter mining technique may evolve into the major technique of mining low-grade uranium in sandstone. Open-cut mines are attracting environmental concern whereas subsurface solution mining is generally more environmentally acceptable than open-cut mining.

In evaluating a uranium project, the following factors must be considered: 1) Basis for calculation of ore reserves, 2) Characteristics of ore, 3) History of personnel involved in project, and 4) Ownership of the uranium ore and the access to mine the mineral.

As the number of conventional light-water reactors increase, so will the requirements of yellowcake, the partially-refined material used as feedstock in the conversion to uranium pellets ultimately destined for reactor loading. Figure 14 is the status of U.S. nuclear power plant construction and orders.

As of Mid 1976, nuclear power has assumed 8.3% of all electrical generation in the U. S., well above previous expectations. At years end, 9 million tons of 0.15% U_3O_8 ore production is expected. In approximate terms, the 1976 uranium and nuclear-power production is the equivalent of importing 100 million barrels

Figure 13

COMPARISON OF EXPLORATION/DEVELOPMENT DRILLING

<u>DEPTH</u>	<u>%</u> <u>1964</u>	<u>%</u> <u>1975</u>
0-100'	17	1
101'-200'	38	6
201'-300'	17	12
301'-350'	2	2
351'-400'	6	2
401'-500'	5	12
501'-750'	10	31
751'-1000'	2	8
1001'-1500'	0	5
1501'-2000'	1	6
> 2000'	2	15
	100%	100%

Modified after Chenoweth - 1976

Figure 14

STATUS OF U.S. NUCLEAR POWER PLANTS AS OF AUGUST 31, 1976

	<u>THOUSANDS OF MEGAWATTS</u>	<u>NUMBER OF PLANTS</u>
<u>UNDER ERDA ENRICHMENT CONTRACT</u>		
LICENSED TO OPERATE	43	61
CONSTRUCTION PERMIT GRANTED	77	72
UNDER CONSTRUCTION PERMIT REVIEW	67	60
ORDERED	14	12
ANNOUNCED	7	6
	<u>208</u>	<u>211</u>
<u>NOT UNDER ERDA ENRICHMENT CONTRACT</u>		
CONSTRUCTION PERMIT GRANTED	1	1
UNDER CONSTRUCTION PERMIT REVIEW	6	5
ORDERED	7	6
ANNOUNCED	18	15
	<u>32</u>	<u>27</u>

Source: Parks & Thomas - 1976

of oil or 27 million tons of bituminous coal at a cost exceeding \$1.3 billion. The economic advantages of nuclear energy are well established, only the environmental problems of safety and waste handling are to be solved. The overseas nuclear industry, however, is moving well ahead of the U.S. technologically because it is minimizing environmental considerations. President-elect Carter is considered to be pro-nuclear development but will press for controls on reprocessing and international handling of plutonium. (Chemical Week - November 17, 1976).

Geothermal-Geopressured Energy

This alternate energy resource is potentially large (Ref 29). The principal constraints on the development and application of energy from geopressured-geothermal resources are related to: (1) technical feasibility, (2) economic feasibility, (3) environmental effects and (4) institutional factors.

The western U.S. has many known geothermal areas. Keplinger (Ref. 13) states that promising discoveries outside the well-known Geysers area have been made recently, and geothermal electric plants may be constructed in New Mexico, Utah and Southern California in the near future. Papadopolous et al (Ref. 21) estimates that the geopressured brines of the Gulf Coast might be capable of producing 100 quads (1 quad = 10^{15} Btu-equivalent to about 170 million barrels of oil) of electricity from the heat content of the produced brine alone. The energy content of the associated natural gas, if present in saturated solution, could contribute an additional 500 quads (Ref. 12 and 26). These are rough estimates of recoverable energy, not in situ resources.

Figure 15 is an overview of what energy could be expected in terms of recoverable heat with present or near-term technology but without cost considerations. Geothermal-geopressured energy may, indeed, be a sleeping giant alternate energy resource. Its development is not mining related as is coal and uranium but is directly related to petroleum engineering and technology and should be relatively straight forward to develop, given due consideration to the economics involved, the technological problems and the environmental and institutional factors (Refs. 5, 10, 12, & 15).

Minerals

Alternate or substitute mineral resources will be needed to overcome the natural resource shortages we are presently experiencing in some minerals. Innovative substitutions will prove viable. Ceramics can apparently substitute for some metals and plastics. New ideas for oil substitutes are already viable. For example, the Pulp and Paper Institute of Canada reported on a study of various processes that could be used to make large tonnages of organic chemicals from bark, sawdust and other waste wood products (Ref. 4). Figure 16 shows that the U.S. is already dependent on certain mineral imports, no doubt in part due to political trade-offs. Many developing countries are beginning to mine their natural resources and can easily compete in the world market (Ref. 1). For example, titanium mineral supplies are still available within the U.S. (e.g. Georgia and Florida Atlantic coastline) but at a price that may not be competitive with Australian, Brazilian or African titanium without import tariffs.

Figure 15

GEOTHERMAL RESOURCES

ESTIMATED RECOVERABLE HEAT WITH PRESENT OR NEAR-TERM TECHNOLOGY
WITHOUT REGARD TO COST: (IN QUADS)⁽¹⁾

Source: Lombard - In Press

RESOURCE TYPE	KNOWN	INFERRED
<u>Hydrothermal Convective</u> ⁽²⁾		
Vapor Dominated (>150°C)	2	2
Liquid Dominated		
High Temperature (>150°C)	20	110
Low Temperature (90° - 150°C)	80	250
<u>Geopressured</u>		
Electrical Utilization	100	230
Methane Production	500	1500
<u>Hot Dry Rock</u>		
Scenario I ⁽³⁾	80	240
Scenario II ⁽⁴⁾	600	1900
<u>Magma</u> ⁽⁵⁾		
Scenario I ⁽³⁾	80	240
Scenario II ⁽⁴⁾	650	1900
TOTAL		
Scenario I ⁽³⁾	~900	~2500
Scenario II ⁽⁴⁾	~2000	~6000
GRAND TOTAL (Known plus Inferred)		
Scenario I ⁽³⁾	3400 Quads	
Scenario II ⁽⁴⁾	8000 Quads	

(1) Normal Gradients are not included at this time as they are not presently considered recoverable. 1 Quad = 10^{15} Btu's.

(2) Does not include less than 90°C systems, although such systems may be economically exploitable especially for nonelectric applications.

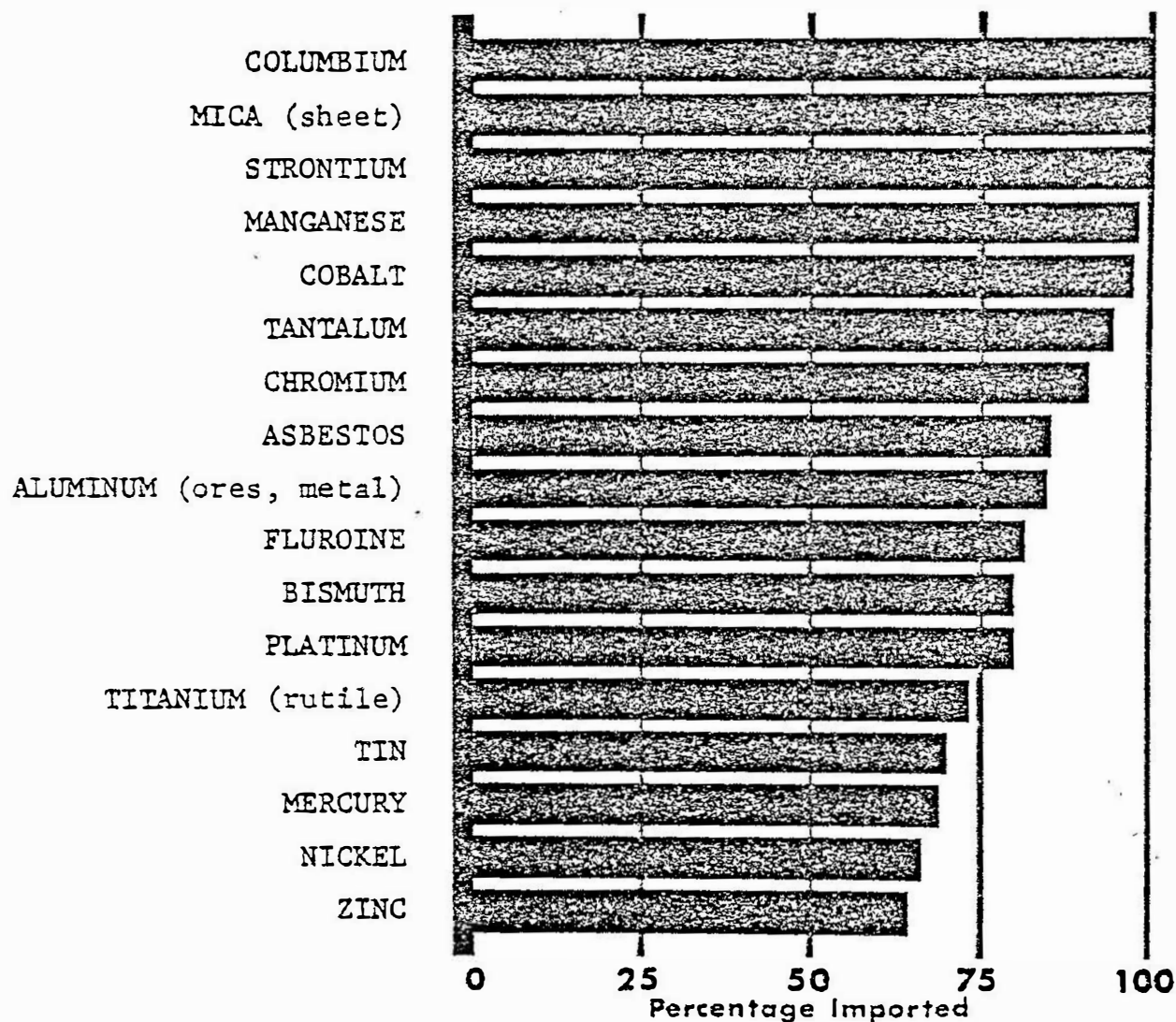
(3) Scenario I: Assuming 2% Extraction Recovery, 8% Conversion Efficiency.

(4) Scenario II: Assuming 12.5% Extraction Recovery, 10% Conversion Efficiency.

(5) Magma resources may be renewed by natural resupply from the interior of the earth; therefore, this estimate may be conservative.

Figure 16

U.S. dependence on mineral imports



Net import reliance equals imports - exports + government stockpile releases plus or minus industry stock changes.
Sources: Bureau of Mines, U.S. Department of the Interior; Import-export data from Bureau of the Census.

Chemical Week, Sept. 8, 1976

Aluminum ore import may also not be necessary if domestic primary and alternate sources and recycling were more seriously considered. At least some of the high grade U.S. deposits could be developed in environmentally-sensitive areas if innovative and environmentally-cognizant mining engineering were employed.

Environmental issues dramatically affect U.S. mining. It is clear that a reassessment of the long-range objectives of the Federal Water Pollution Control Act Amendments of 1972 is urgently needed. The alternative is to press on for the proposed 1983 level of treatment technology which will surely result in: (1) further loss of domestic production of the critically needed metals and minerals, (2) increased reliance on foreign sources of these materials and (3) an unnecessary negative impact on the mineral and mining industry (Ref. 3).

SUMMATION

In summary, the general outlook for alternate energy and mineral resource development is excellent:

1. Coal development will continue to expand rapidly in the eastern and central regions, whereas western coal will lag only a few years behind eastern coal until the federal leasing and environmental problems are resolved, and they will be resolved with significant environmental restrictions imposed. Low-sulphur western coal will remain at prices higher than coal from eastern and central U.S.
2. Uranium mining environmental problems will generally dissipate,

but problems in reactor safety and waste handling may linger.

Reserves will be adequate but prices will rise more than expected by ERDA. Nuclear power will reach 12% of electrical generation by 1980.

3. Geothermal-geopressured energy may dramatically expand in the western and Gulf states if petroleum companies support the development of the resource.
4. Mineral shortages will continue to increase, but mineral substitutes will take on some of the burden.
5. Environmental issues will continue to affect resource development. If industry and state and federal regulatory agencies develop rational environmental controls, the goals of both will be achieved. In closing, I suggest to you that the guiding philosophy of the future will be: "Alternate resources to achieve a better balance. Alternate choices to maintain the environment".

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