ENERGY DEVELOPMENT SCENARIOS AND WATER DEMANDS AND SUPPLIES--AN OVERVIEW

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# ENERGY DEVELOPMENT SCENARIOS AND WATER DEMANDS AND SUPPLIES--AN OVERVIEW

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## Abstract

On the basis of average mean annual flows, ample water exists in the upper Missouri River basin for energy development. The lack of storage and diversion works upstream as well as State compacts preclude the ready use of this surplus water. These surplus flows are impounded in mainstream reservoirs on the Missouri downstream from coal mining areas but could be transported back at some expense for use in Wyoming and North Dakota.

There are limited water supplies available for the development of coal and oil shale industries in the upper Colorado River Basin. Fortunately oil shale mining, retorting and reclamation do not require as much water as coal conversion; in-situ oil shale retorting would seem to be particularly desirable in the light of reduced water consumption.

Existing patterns of energy production, transport, and conversion suggest that more of the coal to be mined out West is apt to be transmitted to existing load centers rather than converted to electricity or gas in the water short West. Scenarios of development of the West's fossil fuels may be overestimating the need for water since they have assumed that major conversion industries would develop in the West.

Transport of coal to existing users will require all means of coal movement including unit trains, barges, and coal slurry pipelines. The latter is considered more desirable than the development of conversion industries in the West when overall water consumption is considered.

# ENERGY DEVELOPMENT SCENARIOS AND WATER DEMANDS AND SUPPLIES--AN OVERVIEW[a]

by F. A. Kilpatrick[(1)]

## Introduction

With the advent of the energy crisis attention has been focused on the development of the vast fossil fuel resources of the Rocky Mountain and the Northern Great Plains States (henceforth referred to as Western States.) Two factors have led to this emphasis on western coals: (1) air quality standards which restrict the use of the high-sulfur coal now mined in the East, and (2) the strippable low-sulfur coal deposits in the Western States are generally thick and economically attractive to mine. Figure 1 clearly indicates the contrast in the amount of strippable coal reserves in the Western States as compared to the country as a whole. Strip-minable western coal now can be shipped profitably great distances and can compete favorably with low-sulphur eastern coal, which usually is mined underground.

When we speak of water for energy needs, we are referring primarily to the water deficient Upper Colorado River and Upper Missouri River basins. The significance of the water needs can be seen if we look at the distribution of the two most significant energy resources, coal and oil shale, on the same map (fig. 2). In these two basins there are an estimated 150 billion tons of coal which can be economically mined. Of this, approximately 68 billion tons[1] of strippable coal are in the Northern Great Plains. By contrast, approximately 42 billion tons of strippable coal remain in reserve in the East, South, and Midwest, where

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the bulk of our coal is presently mined and consumed.

The 68 billion tons of coal are equivalent in heat value to 280 billion barrels of crude oil. In comparison, since its beginning in 1859, the United States oil industry has produced 100 billion barrels of oil![2] Recent estimates by the U.S. Geological Survey put the Nation's measured reserves of crude oil at 34.25 billion barrels, and estimates of undiscovered, recoverable oil resources at between 50 and 130 billion barrels[3]. Figure 2 also shows the oil shale areas in the Green River basin, where potential yields of 25 gal/ton or more of shale oil can be obtained from deposits at least 10 feet thick. These higher-grade deposits amount to the equivalent of about 600 billion barrels of crude oil, of which about 243 billion barrels equivalent are considered recoverable[4]. If both high- and low-grade deposits are included, our oil shale resource base is estimated to be at least 1,800 billion barrels of oil equivalent of which 1,300 billion barrels are located in Colorado[5]. The block diagram of figure 3 helps to place in perspective the vast energy resources of the two basins with respect to this Nation's oil supplies.

One of the major obstacles to the development of western coal is the availability of adequate water supplies. Numerous scenarios of development for the Western States have been advanced in an attempt to estimate needed water supplies and to compare these estimates with supplies available. In this paper we will look at: (1) water requirements for the various energy conversion processes; (2) water-supply requirements as suggested by different development scenarios; (3) water supplies available; (4) competing uses for these supplies by agriculture; and, (5) what may be a more viable approach to the use of western coal in light of present energy use, transportation modes, and water available.

## Water Requirements for Conversion and Utilization of Fossil Fuels

Total water requirements for the various development scenarios are based on the summing of the requirements for mining, reclamation, and the individual conversion processes. Numerous figures are advanced as to the water requirements for these various items, which vary principally due to differences in types and thicknesses of coal, amount of water contained in the coal, quality of water available, and method of cooling employed. Since closed cycle cooling is virtually mandatory, reasonable estimates of the water requirements can be made. Table 1 summarizes these estimates:

Table 1. Consumptive water requirements

| Energy source | For energy equivalent of 1 MBPD oil (in acre-feet per year) |
|---|---|
| COAL | |
| Mining | 3,200 to 6,200 (1) |
| Reclamation (Arid West) | 4,300 (2) |
| Conversion | |
| Electricity | 850,000 to 1,100,000 |
| Gasification | 225,000 (3) to 1,100,000 |
| Liquefaction | 200,000 (3) to 1,100,000 |
| OIL SHALE | |
| Surface Retorting | 120,000 to 190,000 (4) |
| Modified in situ | 58,000 to 86,000 (4) |
| COAL SLURRY PIPELINE | 53,000 (5) |

(1) Surface and underground mining respectively.
(2) In the case of surface mining the water varies drastically with thickness of coal and prevailing climatic conditions.
(3) The lower figure seems more probable, but actual amount varies with process utilized (see Reference 4).
(4) Includes water requirements for reclamation.
(5) Transport of coal only; consumptive use by one of above conversion processes remains.

Coal conversion to other energy forms (electricity, gas, or liquid fuel), is especially water consumptive, requiring as much as an acre-foot per year (AFY) per barrel of oil equivalent per day. By contrast, oil shale conversion takes as little as 10 percent as much water on an energy production equivalency. This figure excludes water for further refining of the shale oil; it is assumed this would be done elsewhere. As will be seen subsequently, if oil-shale conversion required as much water as coal conversion, there would indeed be serious doubts as to the feasibility of an oil-shale industry in Colorado, Utah, and Wyoming.

Slurry pipelines are one of the most water-efficient methods of moving energy from the Western States to points of utilization. Although the water used in transport may increase the total water required for conversion to usable energy, the conversion can be accomplished where adequate water supplies are readily available.

Mining and reclamation do not require large volumes of water, when compared to the amounts required for conversion of coal to other energy forms. Water use in the West can be minimized by moving the coal nearer areas of use and of surplus water before it is converted to other energy forms.

## Water Supply Requirements

With the rush to develop western coal and the realization that water supplies are limited for such development, different agencies and investigators are prophesying what type and how much development will take place. Figures 4 and 5 indicate estimates of water supply needs for the two basins related to various development scenarios. These water requirements are based on estimates of the numbers and types of coal conversion plants anticipated; also considered are mining, reclamation, and coal slurry transport needs. In almost all scenarios cooling water requirements for electric power production amount to about half of the total needs.

Table 2 indicates estimates of water requirements by products in the Upper Missouri River basin as made by the National Petroleum Council (NPC)[6] acting as an industry advisory board to the Secretary of the Interior. All estimates are for the case of maximum effort to develop domestic fuel sources projected to 1985. It should be noted that these NPC projections for 1985 are of the same order of magnitude as those projected for development by the year 2000 by the EPA[7] and the Water Resources Council[8].

Table 2.--Projections of Water Requirements for Energy in the Upper Missouri River Basin Through Approximately 2000 (Thousands of Acre-Feet Per Year)

| | Mont. | North Dakota | South Dakota | Wyo. | Total |
|---|---|---|---|---|---|
| Projected Water Requirement for Energy (Consumptive Use) | | | | | |
| Electricity | 148 | 98 | 20 | 160 | 426 |
| Coal Gasification | 144 | 46 | -- | 70 | 260 |
| Coal Liquefaction | 25 | -- | -- | 125 | 150 |
| Totals | 317 | 144 | 20 | 370 | 836 |

Table 3 summarizes projected energy developments and water requirements in the Upper Colorado River basin for the year 2000, based on the Department of the Interior Upper Colorado River Management Team Study[9]. As can be seen from figure 5, these estimates represent the highest projected level of development for the basin.

Table 3.--Summary of Pending Energy Development and Water Requirements, Upper Colorado River Basin

| State | Coal-fired electric generation plant | Oil shale project | Coal gasification plants | |
|---|---|---|---|---|
| Wyoming | 4 | 1 | 1 | |
| Colorado | 5 | 7 | - | |
| Utah | 6 | 3 | 1 | |
| New Mexico | 2 | - | 2 | |
| Arizona | 1 | - | - | |
| Totals | 18 | 11 | 4 | |
| | AFY | | | Total |
| Wyoming | 79,500 | 22,000 | 15,000 | 116,500 |
| Colorado | 134,000 | 101,000 | ------ | 325,000 |
| Utah | 144,950 | 46,000 | 52,500 | 243,450 |
| New Mexico | 32,000 | ------ | 72,000 | 154,000 |
| Arizona | 34,100 | ------ | ------ | 34,100 |
| Totals | 475,150 | 259,000 | 139,500 | 873,650 |

Taken from Reference [9]

Water Supplies Available

Upper Missouri River basin. Figure 6 shows the major rivers and reservoirs in the Western States. An analysis of historical record indicates that the undeveloped average annual flow of the Missouri River at Sioux City was approximately 28.4 MAF (million acre-feet). As of 1970, depletions resulting principally from irrigation withdrawals and evaporation from upstream reservoirs had reduced the average annual flow to about 21.8 MAF. Subtracting the average annual flows of the Eastern Dakota tributaries leaves a flow of approximately 18.5 MAFY (million acre-feet per year) at Oahe Dam and upstream. Figure 7 shows these average annual flows, as well as the average annual flows from the major subbasins upstream. Similarly, the projected water needs for energy development to the year 2000 are shown as vertical arrows (see table 2.) Note that projected agricultural needs are approximately double the projected energy needs. These data indicate ample water exists in the Upper Missouri River basin both for energy development and for agricultural needs if only part of the average annual flow at Oahe Dam is utilized.

However, the use of average annual discharge figures does not tell the whole story. On an individual stream basis, storage is not presently available. In the Yellowstone River subbasins, many of the tributaries are overappropriated and water rights have been filed in excess of water availability. Diversion structures to move water from points of availability to points of future need must be constructed. It has been pointed out by Gibbs[10] that the surplus water resulting from the storage of such large annual flows in Lake Sakakawea and Lake Oahe could be diverted for use in North Dakota and Wyoming. While the cost of delivery would be high, such diversions from the mainstem reservoirs would have the advantages of: (1) avoiding confrontation with the Yellowstone Compact[b]; (2) circumventing the conflicts with instream flow advocates; (3) eliminating the need for new storage; (4) providing industry with better quality water; (5) and precluding the need for transmountain diversions from the Upper Colorado River basin.

Upper Colorado River basin. Numerous studies have been made to determine the amount of water available for consumptive use in Colorado, New Mexico,

[b]Prohibits diversion of water out of the Yellowstone River except upon the unanimous consent of Wyoming, Montana and North Dakota

Utah, and Wyoming from the Upper Colorado River while meeting obligations under the Colorado River Compact. These studies have produced answers which vary widely. The Bureau of Reclamation[9] has estimated conservatively that the total supply of water available for consumptive use in the upper basin amounts to 5.8 MAFY.

The four Upper Division States do not agree with the 5.8 MAFY figure and believe that it is in the range of 6.5-7.5 MAFY. These differences notwithstanding, of the hypothetical 5.8 MAFY available for consumption in the upper basin, about 3.7 MAFY are now being depleted from the river system. Based on this depletion figure and the above range in total supply, 2.1 to 3.8 MAFY of water is potentially available in the upper basin.

Figure 7 indicates the water available to each of the Upper Colorado River basin States based on the 5.8 MAFY figure. These figures show that there is still water available in all the States, despite the fact that the supplies are exceeded by recognized filings which have been granted by most of the States. Obviously, appropriated rights granted to private parties by the various States are not being fully utilized. Figure 7 shows the expected depletions by States for energy development to the year 2000 (see table 3) and permits comparison with the available supplies. As is the case in the Upper Missouri River basin, approximately 50 percent of the water consumption is to be for cooling-water supply for coal-fired electric generation plants.

Fortunately, most of the oil shale and coal resources of this region are relatively close to the Colorado River or its principal tributaries.

A limited quantity of water in each of these States is now available for early diversion under direct flow rights or from existing storage reservoirs. In many cases, however, major storage projects will be required to provide a dependable day-to-day supply of water to meet the projected requirements.

## Alternatives

Present Energy Consumption and Movement. The Senate Report on National Energy Transportation[11] is very informative as to the existing pattern of coal production and consumption and energy movement. Figure 8, taken from the Senate report, indicates how extensively coal is both mined and consumed in the East. It is in the East and in the Ohio Valley that the Nation's major industry has been developed, due to an abundance of coal and water.

Figure 9 shows that coal is used primarily in the production of electric power, which, except for the Bonneville Power Administration and TVA, is used primarily in the State or region where it is produced. The presence of coal and the production of electric power are therefore synonymous, and to date, electric power is not widely transmitted outside the State or area of origin.

Plans to utilize the West's coal call for conversion to electric power and long distance transmission to existing load centers, contrary to present practices. As has been shown, production of electric power in the Western States would result in a major use of water. Thus the demand on limited western water supplies, plus the need to supply coal for onsite electric production for existing eastern users, would seem to be contradictory to the development scenarios previously mentioned.

Certainly there is the need for increased electrical power in the Western States in support of increased domestic and local industrial requirements. However, the movement of much of the future coal production via unit trains, slurry pipelines, and waterways to the demand centers in the east would seem the more viable approach than the transmission of electricity generated in a water-short area.

Figure 9 also shows the fuels used in the production of electricity. Noteworthy is the reliance on hydropower in Washington, Oregon, and Idaho; the dependency is on gas and oil in the Northeast and on gas in Texas, Louisiana, and Oklahoma. Replacing oil and gas requirements in these areas with coal may be a more viable alternative than producing their equivalent from coal in the Western States. For example, in 1974[11] Texas used 1,300,000 million cubic feet of natural gas for electrical production. This is equivalent to the amount projected by the NPC for a case of maximum production in 1985 in Montana from 14 standard size gasification plants[c]. This is not to suggest that gasification plants will not be needed in the future. However, western water deficiencies may dictate that the most practical approach will be to move the coal to present areas of oil and gas utilization before conversion; rather than converting and then transporting the gas. Evidently, industry views the energy picture the same way as is evidenced in Texas, where an initial 12-million-ton-per-year coal terminal is planned for the port of Galveston to handle up to 24 million tons annually. Much of this coal would replace gas presently used for the production of electricity as well as other industrial processes now using natural gas. The terminal would get coal by unit trains from Colorado or Wyoming. Texas

[c] A standard size plant is usually referred to as one that would produce 250 million scf (standard cubic feet) per day of pipeline gas at 954 Btu per cubic feet.

is also planning to mine lignite to use in electrical generation. Similarly, the Houston Natural Gas Corp. is planning a slurry pipeline from Colorado to Freeport, Texas.

Figure 10, a simplified version of Map. No. 19 of the Senate Report on National Energy Transportation, indicates total interstate energy movement as of 1974. Clearly, the Gulf Coast States are our primary fuel producers, and the fuel moves to the local user. Intrastate electric power transmission was insufficient in magnitude to show at the scale used. The reader is referred to the Senate Report for the details of nationwide energy movement.

Export of Water and Energy--an Enigma! Certainly a case can be established for moving coal out of the Western States, rather than onsite conversion and subsequent transmission. With the exception of unit trains, it is clear that from the standpoint of impacting the limited water supplies in the west, movement of coal by slurry pipeline uses less western water than onsite conversion. Strangely enough, the Western States strongly resist the idea of exporting water via slurry pipeline, and yet think little of exporting electricity--a much greater onsite user of water and hence indirectly a much greater exporter of water.

Competition Between Energy and Agriculture for Water. The Western States are most vocal in opposing the use of water for energy at the expense of agriculture. There is considerable concern that vast acreages of western farming and grazing lands will be destroyed by strip mining. The facts are that the Northern Great Plains area encompasses nearly 92 million acres, of which less than 3 percent are underlaid by minable coal.

It is also a fact that these strip-mined lands can and will be reclaimed concurrently with mining.[12] The reclaimed lands can be restored to original productivity or better[13]; furthermore, reclamation does not consume large quantities of water[14].

Figure 7 also shows water demands for agricultural expansion projected to the year 2000. These figures are probably in excess of what will actually occur unless a dual pricing system can be established, because agriculture cannot compete with industry for water in the market place.

Figure 11 shows the relative value of crop production by water resource regions projected to 1985, as well as the projected trends in crop production. Noteworthy is the fact that the Upper Colorado River and Upper Missouri River basins are expected to produce only 0.1 percent and 1.9 percent, respectively, as their shares of the national production. Perhaps we are fortunate as a Nation that these two highly concentrated energy resource areas are not also potentially high crop-yielding areas. Everything considered, the impact of coal mining and development on agriculture in the West should be minimal.

## Discussion

It becomes apparent from examination of water supplies available for energy development that ample water exists in the Upper Missouri River basin and that the primary need is for construction of adequate storage and diversion works. With this, however, must come resolution of water rights and priorities.

On the basis of average mean annual flows, ample water exists in the Upper Missouri River basin for energy development. The lack of storage and diversion works upstream as well as restrictive State compacts precludes the ready use of this surplus water. These surplus flows are impounded in mainstream reservoirs on the Missouri downstream from coal mining areas but could be transported back at some expense for use in Wyoming and North Dakota.

In the Upper Colorado River basin, water available and projected water demands indicate that little, if any, surplus water is available. While additional storage will help alleviate the stress on this basin, there likely will be an upper limit to the use of water for energy. The competition for water for various energy developments is more pronounced in this basin than elsewhere.

As has been noted throughout this paper, essentially 50 percent of the water needed for energy is consumed in the production of electric power. While much of this electric power is intended to support the various mining and conversion processes, as well as the anticipated increased populations involved in the energy industries, much of this electric power may be exported. The Western States must come to realize that such exports of power are also exports of water, just as are slurry pipelines.

Past performance indicates that fuels are consumed or converted to other forms of energy in close proximity to the user. Similarly, raw fuels can be transported great distances to load centers rather than being converted to electricity for subsequent transmission. The location of the Nation's industrial centers is well established, and coal is more apt to be transported directly to these areas. The need to transport large quantities of coal long distances will require all the means at our disposal including unit trains and slurry pipelines.

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# STRIPPABLE COAL RESERVES OF THE CONTERMINOUS UNITED STATES, BY REGION

Source: Strippable Reserves of Bituminous Coal and Lignite in the United States. U.S.B.M. Information Circular 8531

| Province | Pacific Coast | Rocky Mts. & N. Great Plains | Interior | Eastern |
|---|---|---|---|---|
| Coal, Total, Billion Tonnes | 0.15 | 24.1 | 7.8 | 4.7 |
| Coal, Low Sulfur, Billion Tonnes | 0.15 | 23.4 | 0.6 | 1.7 |

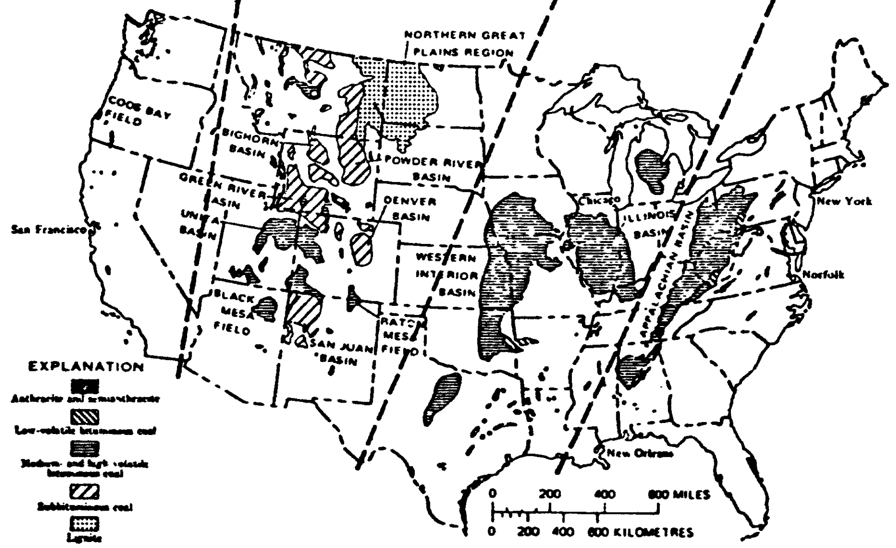



Figure 1.--Coal fields and strippable Coal reserves of the conterminous United States.

Map from Figure 1, U.S. Geological Survey Bulletin 1412, by Paul Averitt

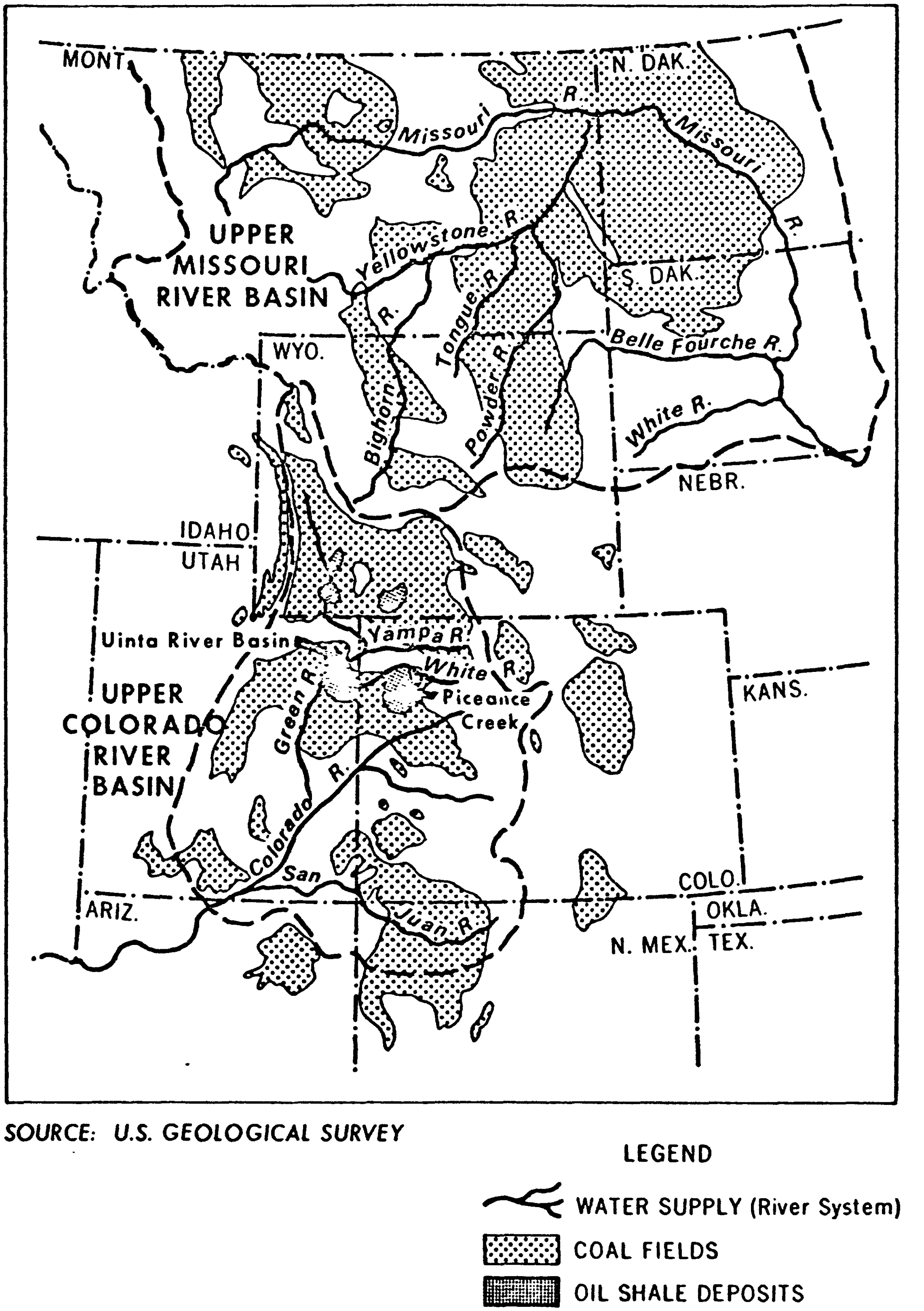
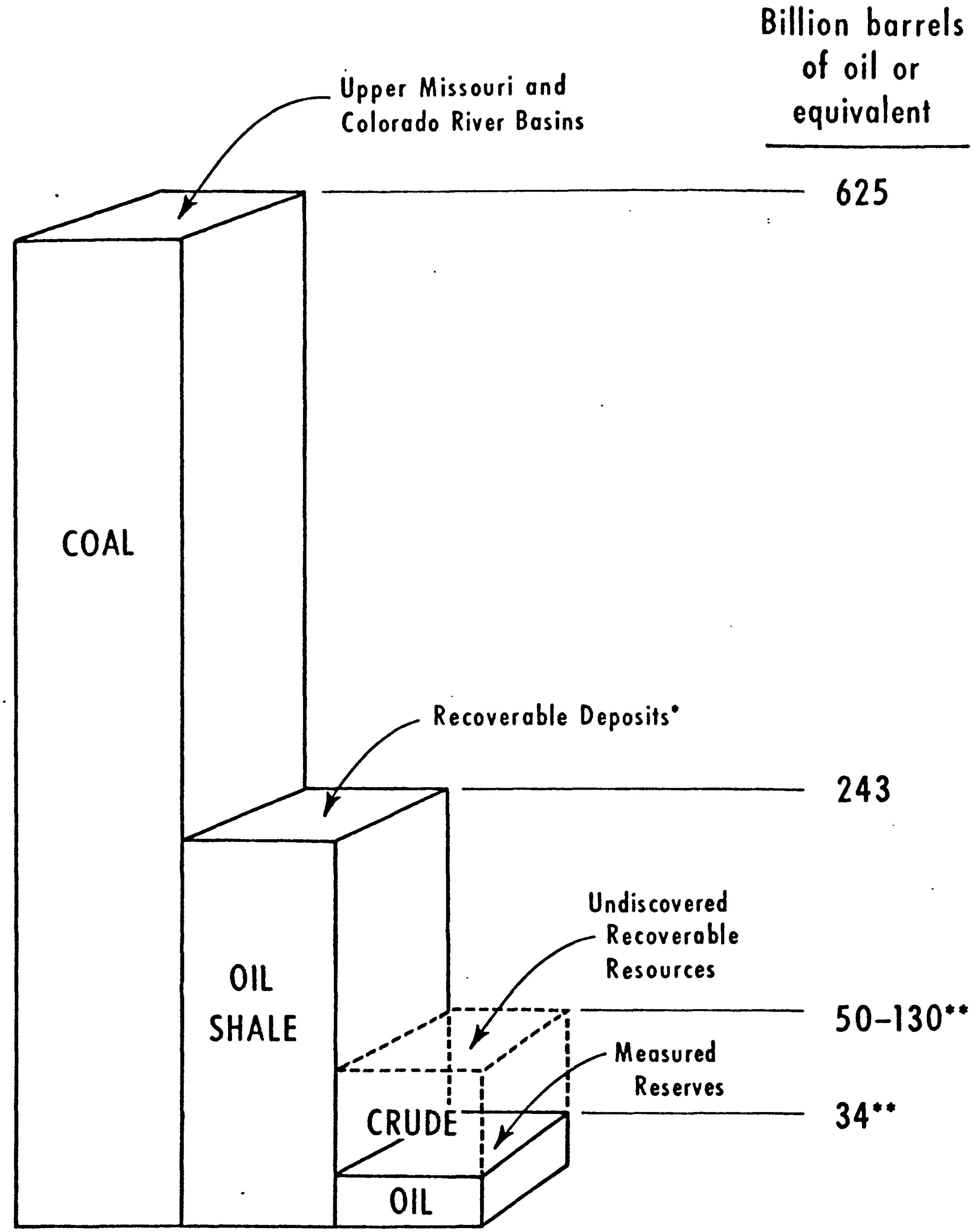



Figure 2.-- Energy Resources in the Upper Colorado and Upper Missouri River Basins




* Considered as 1/3 of the in-place, 25 gallons/ton oil shale deposits

** Does not include natural gas liquid – measured reserves of 6.35 billion barrels and estimated undiscovered recoverable resources of 11-22 billion barrels

Figure 3.--Recoverable Coal and Oil Shale Resources in Upper Missouri River and Upper Colorado River Basins as Compared with Nation's Crude Oil Supplies

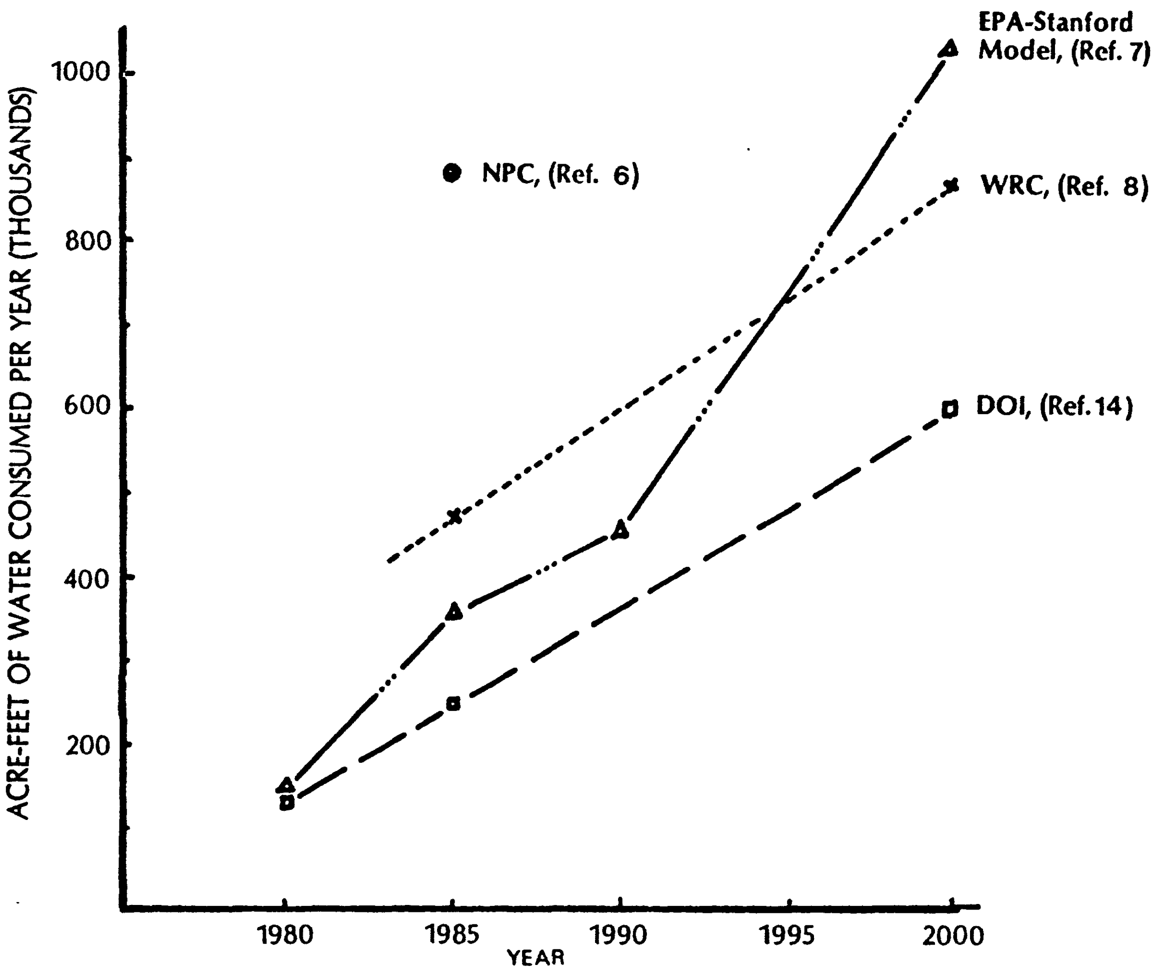



Figure 4.--Various Projections of Water Requirements for Energy Development in the Upper Missouri River Basin.

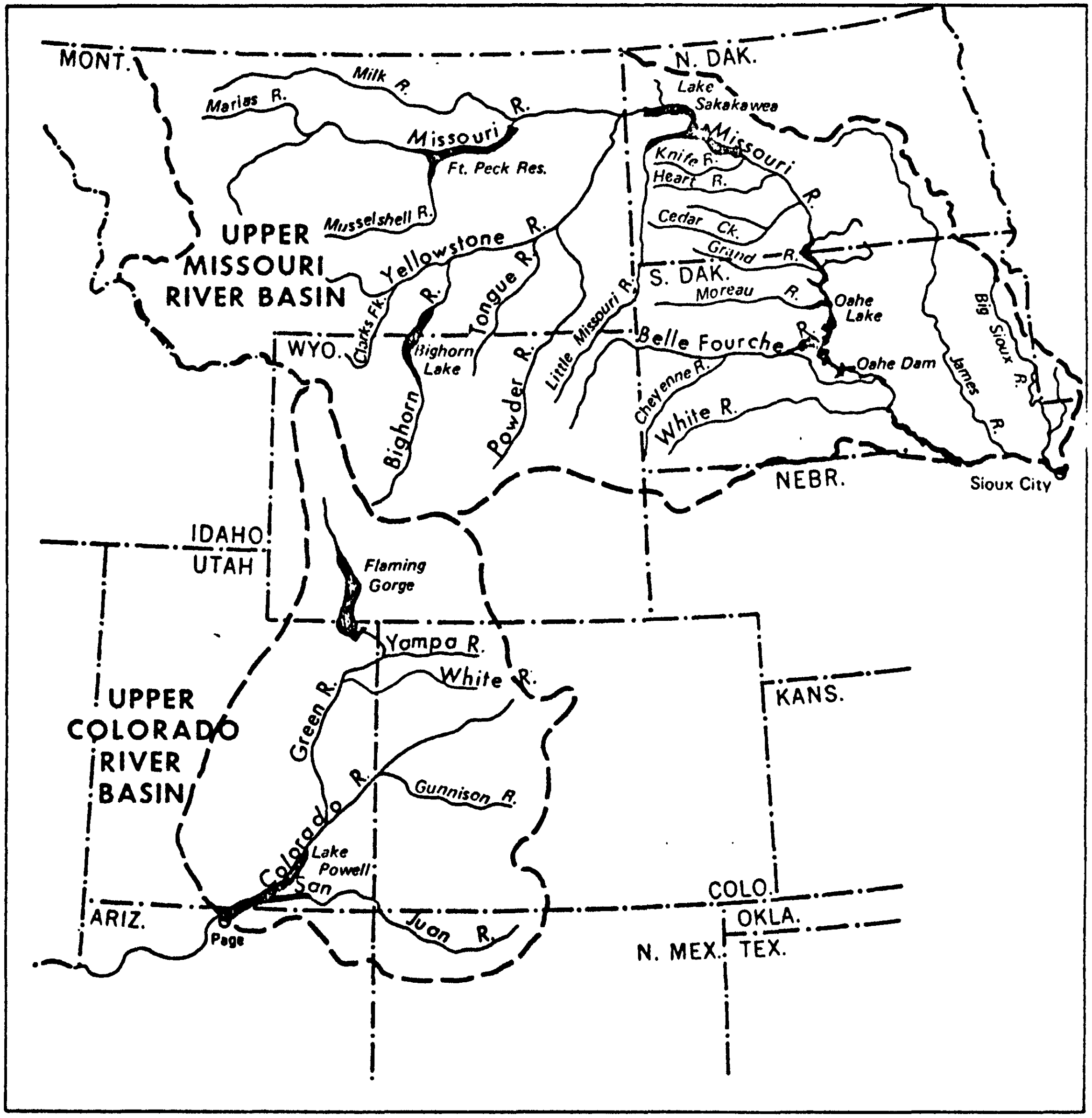



Figure 6.--The Upper Colorado and Upper Missouri River basins

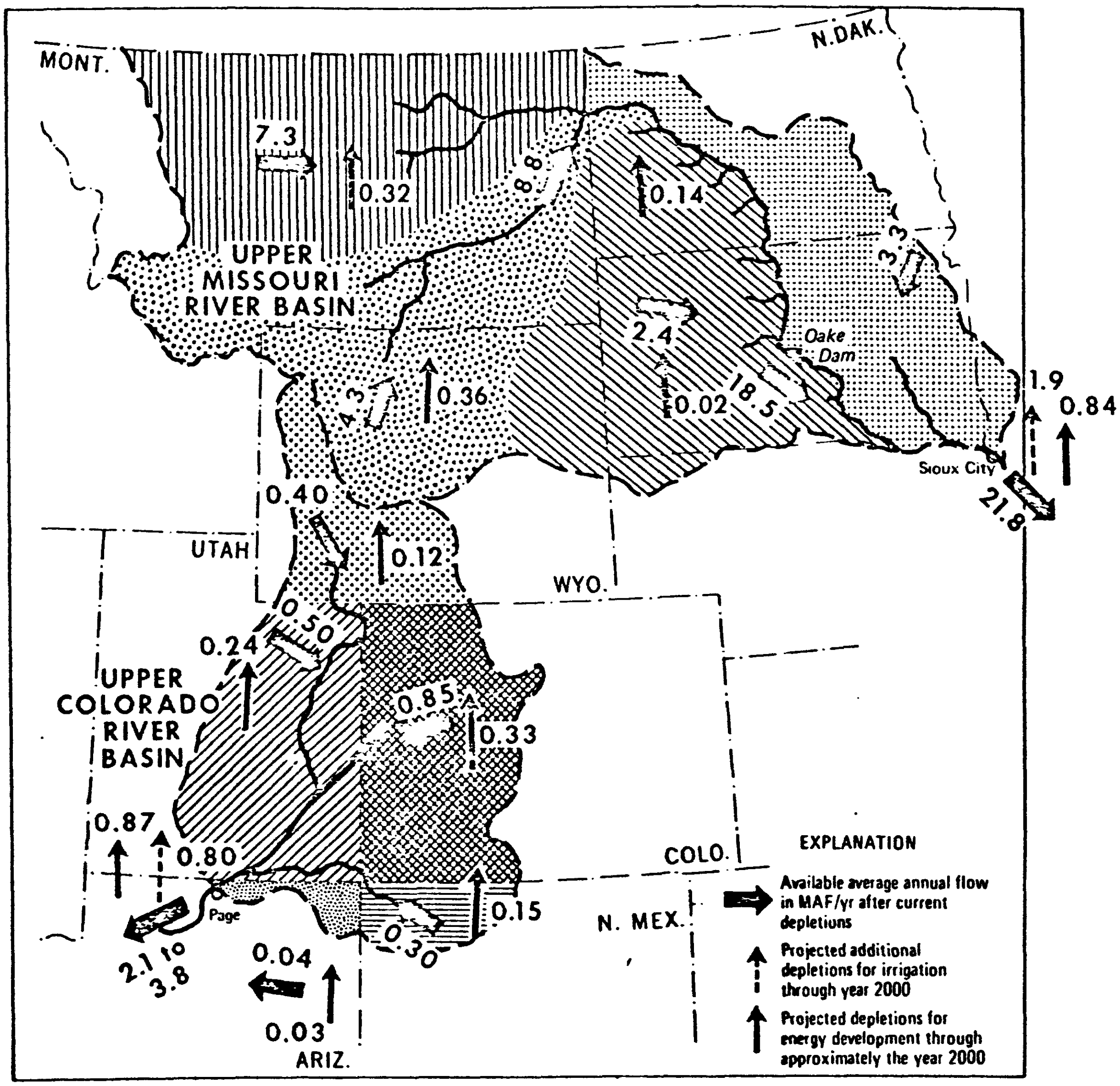



Figure 7.–Water Available and Projected Additional Depletions for Energy Development in the Upper Colorado and Upper Missouri River Basins.

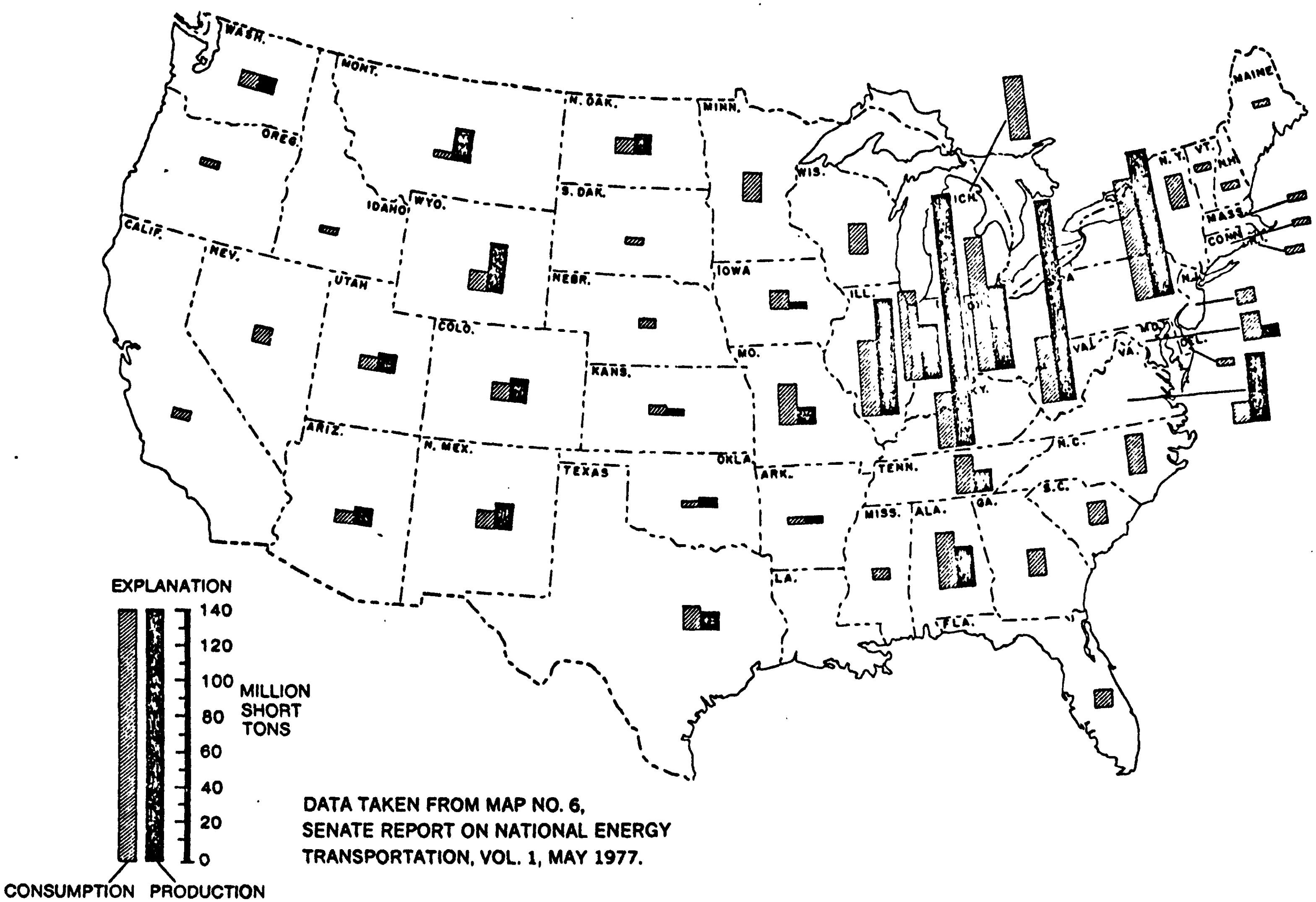



Figure 8.-- Coal Production and Consumption by States: 1974

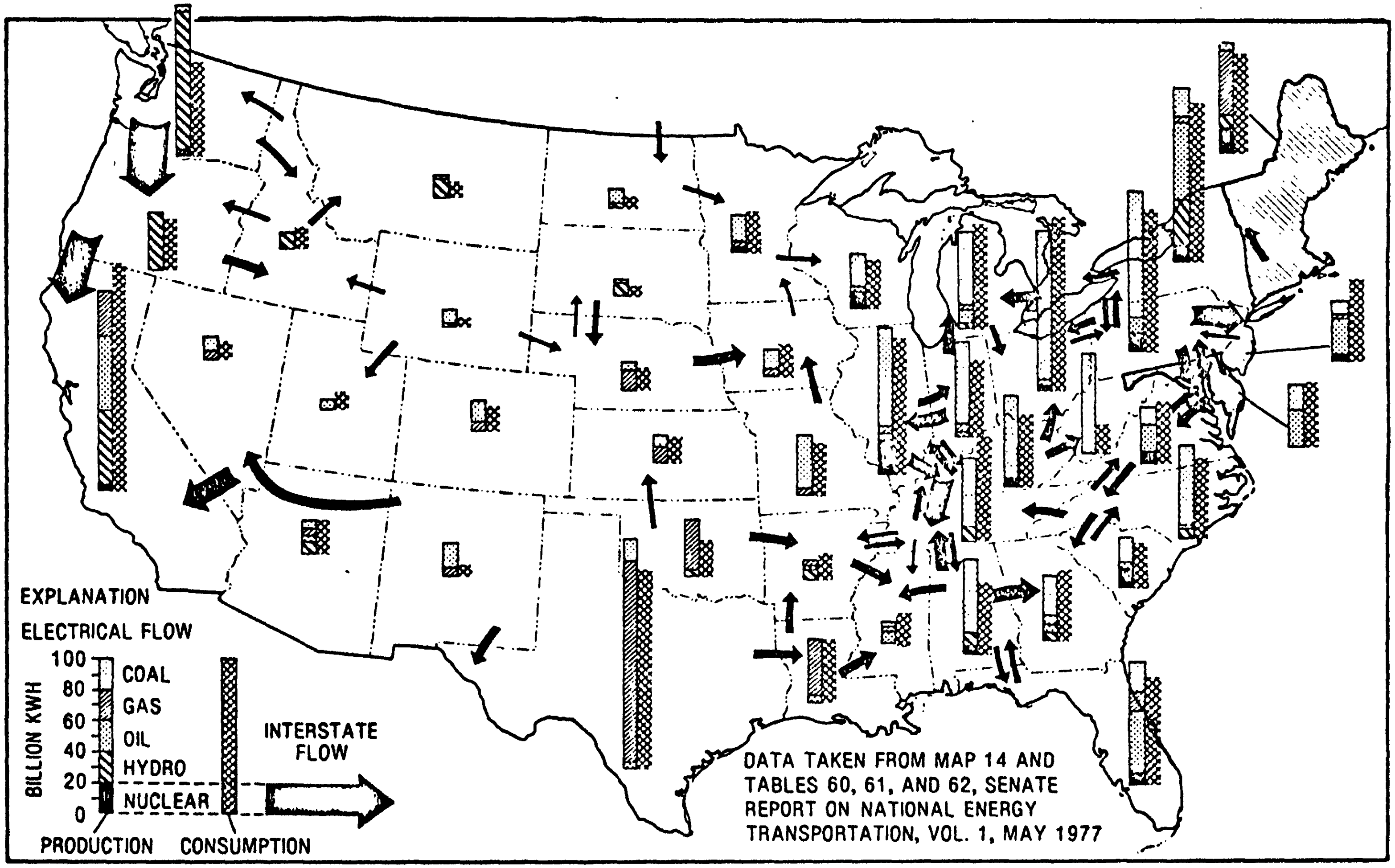



Figure 9.-- Electric Power Production, Transmission and Consumption: 1974

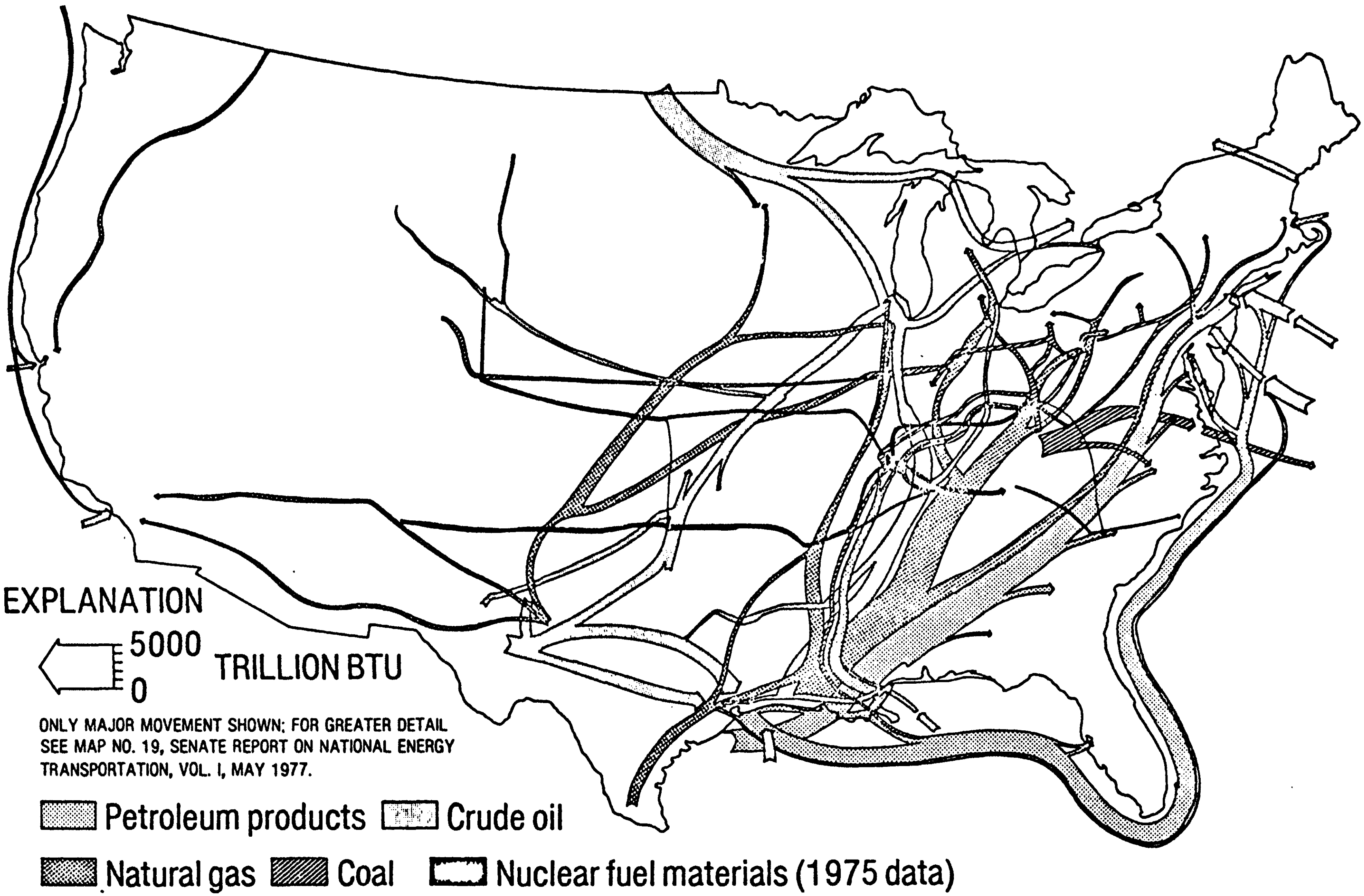



Figure 10.--Interstate Energy Movement: 1974