ENERGY: EXISTING SYSTEMS AND TRENDS (2.0)

Introduction and Overview (2.1)

The energy system in the United States today is highly centralized. Production of electricity for consumer use depends on an increasingly centralized system of large generating plants, which in turn depend on other centralized systems of fuel production, transportation, refining, and storage. Fuel deliveries to the consumer rely on similarly centralized systems of production, transportation, and storage.

The terms "centralized" and "decentralized" are not readily quantifiable terms, nor are the related concepts of "large-scale" and "small-scale." Generally, centralized power is the dependence of an energy system on a relatively small number of large components. This definition can be applied accurately to each of the various subsystems such as transportation which make up the U.S. energy system. As electrical generating plant sizes and their service areas increase, a centralized dependency emerges.[1]

A second important characteristic of our energy system is its energy-intensity. In every stage of its operation, today's energy system requires substantial energy to maintain itself. For example, four percent of each barrel of oil produced is consumed in the refinery operation.[2]

Converting energy from one form into another involves not only irreversible entropic losses but often is accompained by rejection of large amounts of waste heat to either atmospheric or water coolant systems. For example, converting oil into electricity by first burning it in a boiler to heat water to make steam to rotate a turbine usually results in a loss of about two-thirds of the intital energy introduced into the system. Most conventional electric utility power plants require about 10,000 Btus of fuel energy to produce one kilowatt-hour of electricity, whereas if the process where 100 percent efficient, it would require only 3,413 Btus.

These limitations on thermodynamic efficiency are especially significant because approximately 30 percent of all basic energy inputs in the U.S. are used for the generation of electricity. The equivalent of about 1.6 million barrels of oil per day are used for electricity generation. 1.1 million are irretrievably lost due to thermodynamic inefficiencies, energy conversion processes and waste heat rejection. This loss is an amount equal to about seventeen percent of all oil imports to this country.[3]

U.S. reliance on centralized energy systems has evolved over the last one hundred years. Aside from human and animal labor, wood was the primary source of energy in America until after the Civil War. From 1850 to 1865, when coal began to replace overcut forest, wood produced between 80 and 90 percent of the nation's energy requirements.[4]

The introduction of coal into the American economy in the 19th Century was not the first time this energy source had been used on the continent. The Hopi Indian tribe mined coal in what is now Arizona in 1000 A.D. By the time the Spaniards reached the area, more than 100,000 tons (90.7 million kg) had been mined. The European pioneers had an abundance of wood available to them and coal was unnecessary until they had decimated the forests in the mid-19th Century. Between 1850 and 1861, as the new iron and steel industries grew and coal replaced wood for boiler fuel, the consumption of coal tripled. By 1885, coal surpassed wood in overall fuel use in the U.S. Coal supplied 65 percent of U.S. energy needs in 1895, and remained the dominant fuel well into the 20th Century.[5]

Liquid fuels such as kerosene and petroleum were an important addition to the U.S. energy supply. Both were developed as cheap substitutes for whale oil, a common lamp fuel grown increasingly scarce. Coal oil, or kerosene, was a liquid fuel made from coal by processes invented in England. By the 1850s there were 50 to 60 kerosene plants making lamp fuel on the east coast.

Edwin Drake drilled America's first oil well in 1859, in Pennsylvania; wells produced more than 500,000 gallons (109 million liters) of this "kerosine" (the spelling was changed to differentiate it from coal oil) the next year. The production of oil quadrupled within a decade.

By the beginning of the 20th Century, energy consumption in America had increased substantially, following the changing character of the U.S. economy. Small towns and villages grew into cities. Industries from food processing to railway car manufacturing became mechanized. The most dramatic change in the American economy came with the invention of the automboile, which altered the entire pattern of land use as well as fuel consumption in America. The first workable gasoline engine, fueled by what was then considered a "useless" by-product of kerosine refining, was developed in Germany in 1877 by Nikolaus Otto. His engine became the model for production of all internal combustion engines, and was first used a decade later in the Benz automobile. In 1903, Henry Ford introduced the gasoline-powered automobile, and set up the first assembly lines of the Ford Motor Company. In the same year the Wright brothers, using a gasoline engine, fulfilled an age-old dream of flying.

There were 8,000 automobiles in the U.S. in 1900; by 1908 this number had increased to 194,000. Within three years, Americans purchased 600,000 of the new machines. By 1930, there were more than 23 million vehicles registered in the U.S.[6]

By the early part of the 20th Century, electricity had become an essential part of American life. It made possible the mass production of appliances, which in turn required electric power to operate. To meet this growing demand larger power stations with higher efficiencies were built. The resulting lower costs to the consumer further stimulated the use and growth of electric power. Since the beginning of World War I total electric power demand has doubled every decade.[7]

In the 20th Century, energy-consuming technology has become integral to the operation of households, factories, and farms. Electrical use by the American public since World War II has more than sextupled, and electricity now accounts for about one-fourth of the nation's energy use. From 1940 to 1971, annual consumption more than tripled--and while the U.S. exported 36 million barrels of oil in 1940, it had to import more than 64 times that amount (2.3 billion barrels) 39 years later. In this same period, natural gas consumption rose from 2.6 trillion cubic feet (73 billion cubic meters) per year to more than 19 trillion cubic feet (.603 trillion cubic meters) and liquid natural gas (LNG) consumption soared from 2.2 billion gallons (8.3 billion liters) to 24.8 billion gallons (93.9 billion liters).[8]

The federal government has been very involved in energy and mineral resource issues. As early as the Mining Act of 1866, which declared public lands to be "free and open" for mining, national legislation has encouraged the exploitation (mining and drilling) of minerals and energy resources, including oil, coal, and uranium. The Mineral Leasing Act of 1920 established the contemporary policies of issuing prospecting permits and leases for exploitation of energy and minerals on public lands.

In 1913 the first federal income tax law permitted "extractive industries" such as the oil industry, an exemption of five percent of their gross income taxes to compensate for the depletion of the resources. Until quite recently, this "depletion allowance" policy remained unquestioned.

The federal government has regulated the price of electricity and natural gas since the establishment of the Federal Power Commission in 1920. In the 1930s the government established the Tennessee Valley Authority (TVA) and the Bonneville Power Administration (BPA), agencies charged with building electrical generation facilities in addition to providing electricity. The Rural Electrification Administration (REA), was responsible for providing electrical service to the rural regions of the United States.

The federal government has regulated the energy industries to some extent through the Justice Department and the Securities and Exchange Commission. Due to violations of Anti-trust laws, the major oil companies (especially Standard Oil Company of New Jersey) were divided into competing companies.

The history of America in this century could be told largely in terms of the increasing use of energy, mineral, and other material resources. The largest jump in consumption was made with the Second World War. The United States was a major supplier of oil and oil-based products to Allied forces. Efforts to meet the war's energy needs initiated the construction of many new oil wells, production facilities, industrial plants, and new synthetic rubber plants. During the war, a scientific team led by Dr. Enrico Fermi built the world's first nuclear reactor, which led to the production of the atomic bomb and to the demonstration of nuclear fission power.

The economic boom following the war coupled with the country's new technological base, expanded U.S. energy use tremendously. Energy-consuming "mechanical" heating and cooling technologies became standard equipment for homes and buildings. The post-war development of the interstate highway system--history's largest public works project--and the popularity of the private automobile helped determine a transportation future linked to petroleum. Every use accelerated as the nation turned from rail transport to highway transport to move freight. Between 1946 and 1968, the U.S. population increased 43 percent, yet electric power consumption increased 276 percent, and motor fuel consumption increased 100 percent. In the past 30 years, changes in transportation, industry, agriculture, and housing have led to very high energy demands.[9]

Conventional Energy Systems (2.2)

The development of centralized energy systems in the U.S. economy occurred during a period when less-centralized energy sources such as hydro-power, windmills, and wood-fired processes were not capable of providing the vast amount of energy required by a rapidly industrializing society. The lack of precision in prime movers and early power machinery favored use of large amounts of fossil fuel for transportation and power processes. The energy could not be readily supplied by locally-available hydropower and biomass fuels.

This section describes in some detail the components of modern liquid and solid fuel systems, as well as electric utility systems. Conventional energy systems for petroleum, natural gas, coal, nuclear, and electric plants are summarized and future paths are indicated, illustrating the degree of dispersal and decentralization in these systems (synfuels, future power plants, etc.).

From a strategic energy perspective, understanding the possibilities for dispersal within the larger systems is a significant first step towards designing alternative approaches and for downsizing units for use in community-based systems.

Petroleum (2.2-1)

Almost 74 percent of the energy supply in the United States in 1979 came from oil and natural gas.[10] U.S. dependence on petroleum and gas has grown on the strength of three basic qualities of these fuels: (1) as resources they have been readily available; (2) they are very concentrated energy sources; and (3) they are easily transported.

Petroleum is America's premier fuel. It fuels transportation, converts to electricity, heats homes, powers industry and is also an important raw material in petrochemicals. A host of essential products are made from petroleum, including fertilizers, pesticides, medicines, industrial chemicals, and lubricants.

The technology for all fossil fuels begins with exploration, an expensive and time-consuming process based on trial and error. Suspected reserves of oil, gas, or coal can be confirmed only by actual drilling. More than one-fourth of the entire land area of the United States is now under lease for oil and gas exploration.[11]

The sites for energy consumption tend to remain constant because they are based on factors such as population, weather, industrial activity, and location of other resources. The sites for energy supply however, may change over a period as short as several years. America's current major energy supply region, the Gulf Coast area, has apparently reached its peak as a supplier of oil and natural gas, and is rapidly becoming a major energy consumer because of its concentration of refineries and shipping facilities.[12] Major new sources of domestic crude oil appear to be in Alaska and on the Atlantic and Pacific Outer Continental Shelves.

Extraction of petroleum is complicated by great variations in the configuration of deposits and the surrounding geology. Early oil wells were easily tapped by drilling to a pool relatively near the surface. Today secondary and tertiary recovery methods are being applied to oil fields which have been drilled a first time. These methods include injection of water or gas under high pressure into additional wells to force the oil toward the producing holes, or the use of detergents, solvents, or underground combustion to loosen the oil from rock.

American oil wells pump about 8.5 million barrels of oil per day which supplies approximately 48 percent of what the U.S. needs. U.S. domestic production has fallen 9.6 percent from its peak in the early 1970s. In 1979, U.S. domestic production of crude oil totaled 3.1 billion barrels; imports were up to 2.3 billion barrels that same year, equalling a total consumption of 6.4 billion barrels.[13]

Estimates of future availability of oil vary widely. Figures used by geologists are reserve figures. The U.S. Geological Survey defines a reserve as "that portion of the identified resource from which a usable mineral and energy commodity can be economically and legally extracted at the time of determination."[14] The United States is known to have 35.3 billion barrels of petroleum reserves, or about five percent of the known total world reserve of oil.[15] In addition, geologists estimate the quantity of undiscovered resources which may exist. An undiscovered resource is defined as an "unspecified body of mineral-bearing material surmised to exist on the basis of broad geologic knowledge and theory; in other words, a guess at probable supplies based on geological data."[16] Estimates of U.S undiscovered recoverable petroleum resources range from 55 billion barrels to 456 billion barrels. At the current (and constant) rates of consumption of six billion barrels per year, the U.S. domestic oil supply is predicted to last between one and seven decades.

As can be seen in Table 2.2-1, Texas remains the nation's largest producer of crude petroleum with more than a billion barrels in 1979. Alaska produced about half as much that same year, with Louisiana running third in terms of production. California, Wyoming, and New Mexico are major oil producers.[17] Table 2.2-1 also evidences the decline in American production. Production steadily decreased through 1977, but began to rise in 1978.

The United States now imports 6.4 million barrels of oil daily (36 percent) to help meet national consumption of 17.8 million barrels per day.[18] The U.S. Department of Energy expects this trend to continue until Alaskan oil makes a more substantial contribution to U.S. supply. The total amount of Alaskan oil that we can expect to recover has been estimated by the U.S. Geological Survey to be eleven billion barrels.[19] If Alaska were our sole source of oil, and we used it at current consumption rates--without allowing for increases--the U.S. would deplete the Alaskan resource in less than two years. America's offshore resources are estimated at six billion barrels, about one year's supply of oil at the current rate of consumption.[20]

Table 2.2-1[21]

U.S. CRUDE OIL PRODUCTION

(THOUSANDS OF BARRELS)

	1973	1979
Alaska	77,323	511,538
California	336,075	352,465
Louisiana	831,529	494,462
New Mexico	100,986	79,379
Texas	1,294,671	1,013,255
Wyoming	141,914	124,553
Other	578,405	538,901
TOTAL	3,360,903	3,114,553

The international sources of oil will assume even greater importance as domestic sources are depleted in coming years. At present, U.S. oil reserves represent about 7.2 percent of the world's recoverable reserves. The Soviet Union's oil reserves represent 14.3 percent of the world's petroleum reserves.[22] More than one-half of the recoverable oil in the world is concentrated in the region of the Persian Gulf.[23]

Contributions of foreign petroleum to the U.S. energy system come from many sources, and enter the system through ports throughout the country where it is distributed to the industrial Northeast by pipeline. The U.S. imports a major portion from the Middle East, including Iraq, Saudi Arabia, the Arab Emirates, Kuwait, Qatar, Oman, Bahrain, Turkey and Yemen.

The U.S. also receives substantial imports from South America, principally from Venezuela. We receive almost as much from Africa and the Caribbean, principally Trinidad-Tobago and the Netherlands-Antilles. The United States also imports petroleum from Europe including the Netherlands, Spain, Italy, Romania, West Germany, the U.S.S.R., England, Belgium, Finland, France, Greece, Portugal and Denmark, as well as Asia, (principally from Indonesia) and lesser amounts from Canada, Central America and Australia.[24]

In addition, the United States imports refined petroleum products[25] principally residual fuel oil and boiler fuel--from Caribbean and European refineries. In 1979 we imported from all sources a total of 730 million barrels of refined petroleum products.

As a hedge against the vagaries of world oil politics, U.S. energy planners are determining ways to increase domestic production. Aside from the production of oil from known reserves, a number of existing methods (and some proposed methods) have been advocated for producing oil from deposits not heretofore considered economically recoverable.

Techniques known as "secondary" and "tertiary" recovery methods recover additional oil from old, near-depleted wells. In the early days of oil drilling, gas and water pressure alone forced oil to the surface. In the 1930s oil producers began to use a secondary recovery process called water flooding, which pumped water into one well to force oil out of adjacent wells. This technique enabled a recovery rate in excess of the usual twenty percent. Today, about half of the nation's oil is produced using secondary techniques, and the average yield has risen to 34 percent of an oil field's resource total.

The oil industry first attempted teritary processing in 1952. Tertiary processes are a variation on the water flooding techniques, substituting various chemicals for water. The techniques have never proven economical and today only a few thousand barrels per day are produced in pilot plants.

Several new techniques for teritary oil recovery have been developed, including the injection of various gases, steam, carbon dioxide, and exotic chemicals. Successful tertiary techniques could add between 30 and 60 billion barrels to potential US. reserves, assuming that today's recovery rates can be raised seven to thirteen percent.[26] A basic limitation of all schemes to increase oil recovery by these techniques is the energy required to recover the oil. If the additional investment in energy and materials necessary for tertiary recovery is higher than the energy return from the oil or gas recovered, then there will be a net energy loss.

Almost all of the petroleum used in the United States requires transportation at one time or another. Of the 4.43 billion barrels of crude oil consumed by the U.S. in 1974, all but 45 million barrels were moved through the national energy transportation system.

Whether from sites of domestic production or points of importation, crude oil is transported to refineries as the next step in the petroleum fuel cycle. Once refined, it is transported to markets in much the same manner by pipeline, water carriers (tankers), motor carriers (trucks), or railroad tank cars.

Most domestic crude oil moves by pipelines. According to the Bureau of Mines, the U.S. has 60,800 miles (97,827.2 km) of crude trunk pipelines as of January 1, 1974. In addition, there were 36,5000 miles (58,728 km) of gathering pipelines bringing crude oil from individual wells and fields to common points for storage, refining, or trunk pipeline transport.[27] Figure 2.2-1 illustrates the total petroleum movement network for the continental U.S.

Water transport of crude oil has declined because of competition from motor carriers by still accounts for about thirteen and one-half percent of total transportation. Motor carriers moved about eleven percent of U.S. crude oil in 1974; railroads moved less than half of one percent.[28]

Crude oil is rarely used in its original form; it is almost always refined to some extent. Like oil production, oil refining is centered in the Gulf Coast region. In 1979, about 38 percent of the U.S.'s 5.6 billion barrels of petroleum products were refined there, mostly in Texas (1.463 billion barrels). The Great Lakes and Middle Atlantic regions account for another nineteen percent. Most other states do at least some refining.[30]

Table 2.2-2 shows the typical range of products refined from one barrel of oil. Refineries do vary the composition of products seasonally to some extent: for example greater concentrations of gasoline are refined in the summer for vacation travel.[31]

Table 2.2-2[32]

WHAT A REFINERY DOES WITH AN AVERAGE BARREL OF CRUDE PETROLEUM

Product	Percentage of Oil
Gasoline	39
Distillate oils (diesel fuel & heating oil)	18
Residual fuel oil (for industry & power plants)	14
Lubricating oil, asphalt, petrochemicals	11
Propane, butane, and other gas products	8
Jet fuel	6
Consumed in refinery operation	4

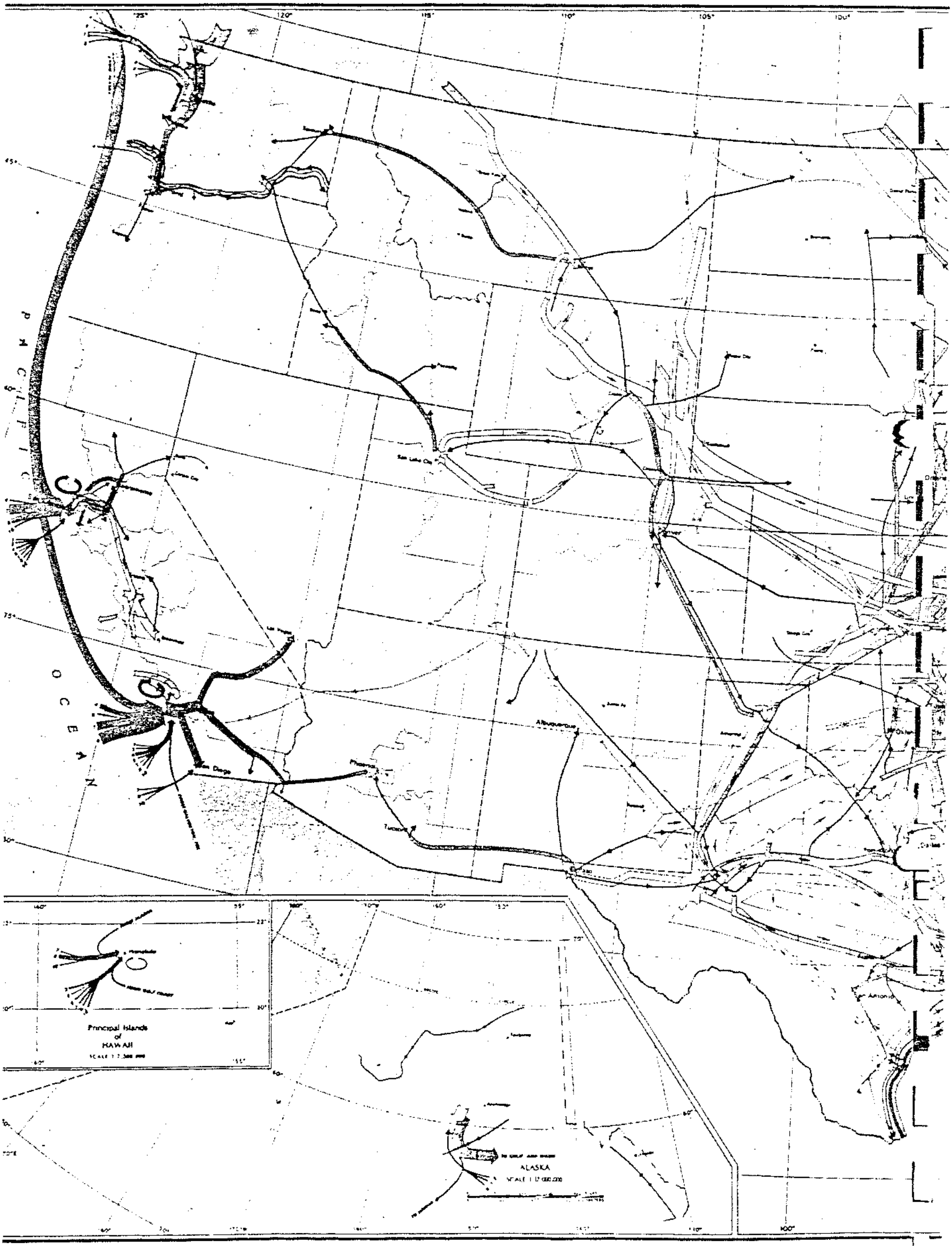
The distribution of refined petroleum products from the Gulf States to the Southeastern and North Central States is by pipeline, to New England by water, to Florida by water, to California by pipeline, and within California by truck. Interstate and regional movement of petroleum products is principally by truck.[33]

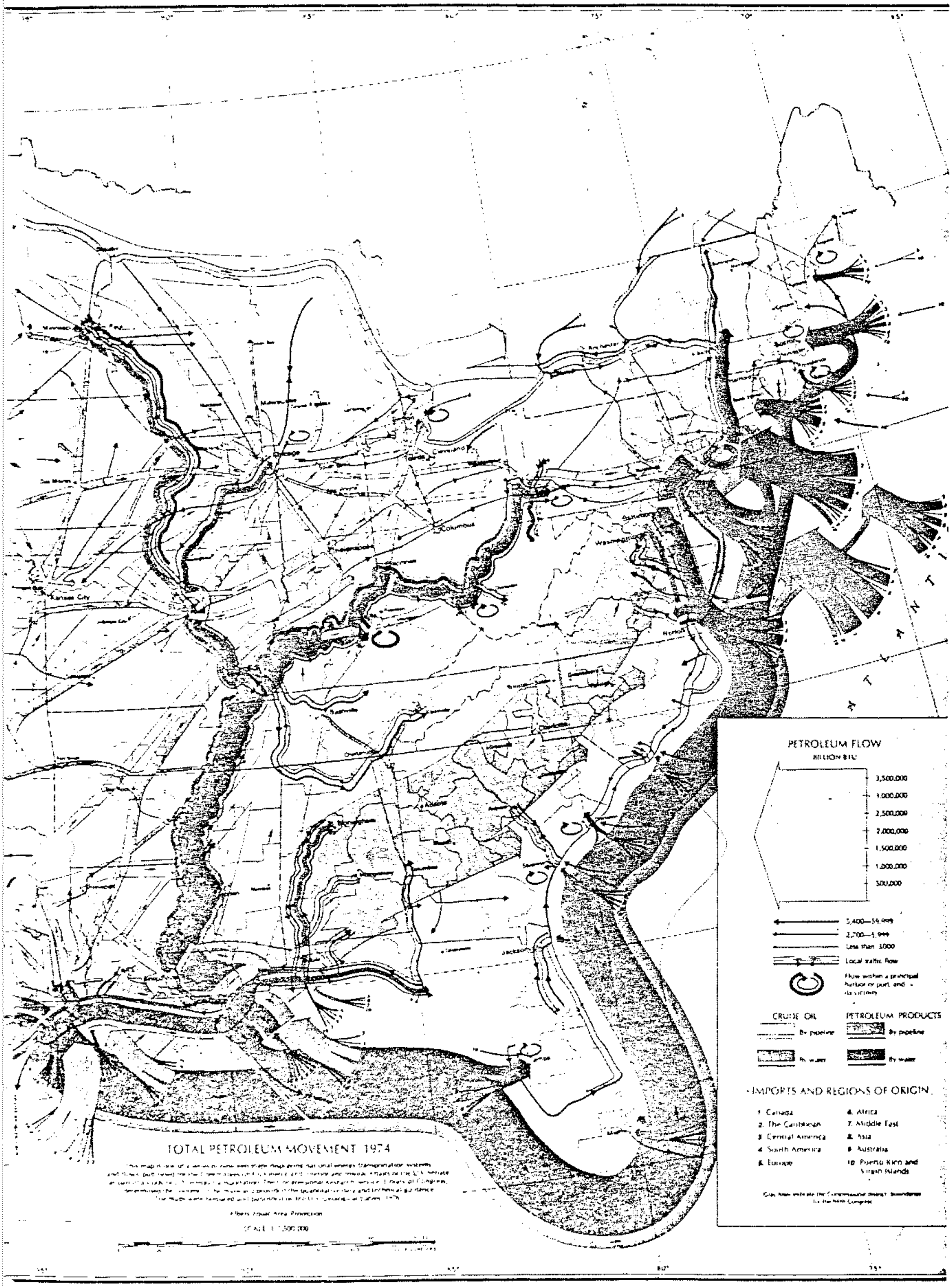
The basic movement of all petroleum is north and east from the Gulf region toward industrial and population centers. Petroleum contributed 47 percent of the total U.S. energy supply in 1979, including imports and domestic production.[34] Imported petroleum is particularly important to the Northeast, because of its lack of indigenous resources, and the Gulf region, where it is substituted for declining domestic supplies.

Within the United States, California and New York are the two greatest consumers of refined petroleum, followed by Texas, Pennsylvania, and Illinois. These same states, plus Ohio, also consume the most gasoline. The greatest quantity of distilled fuel oil, used predominantly for home heating, is consumed by New York, Pennsylvania, New Jersey, Massachusetts, and Texas. New York, California, and Florida lead the nation in consumption of residual fuel oil which is used to fire boilers. The same trends are apparent for jet fuel, asphalt, liquid petroleum gas (LPG) and ethane. Rural states such as Missouri, Iowa, and Indiana, where LPG and ethane are important in supplying energy to many farms, are also major consumers of these fuels.[35]

Figure 2.2-1[29]

TOTAL PETROLEUM MOVEMENT MAP





TOTAL PETROLEUM MOVEMENT 1974

Albers Equal Area Projection

SCALE 1:7,500,000

Natural Gas (2.2-2)

Clean-burning natural gas, once regarded as a nuisance by-product of oil wells, is now an important residential, commercial, and industrial fuel, as well as a favored fuel for electrical generation. Since 1900, consumption of natural gas has grown steadily (see Figure 2.2-2) outdistancing coal and falling just short of petroleum. Natural gas now supplies nearly 25 percent of overall energy demand in the U.S.[36] A major reason for its popularity may be its relative lack of polluting emissions when burned.[37]

The estimates of undiscovered domestic natural gas resources are as disparate as the estimates of oil resources. Estimates range from a maximum of 2,000 trillion cubic feet (52.5 trillion cubic meters) of gas to a minimum of 374 trillion cubic feet (10 trillion cubic meters). The total natural gas reserves in the U.S. in 1978, according to the Energy Information Administration (EIA) of the DOE, were 200 trillion cubic feet (5.5 trillion cubic meters). According to the EIA, current annual consumption is over 19 trillion cubic feet of gas per year, which leaves less than eleven years of proven gas reserves.[38] It is estimated that 26.2 percent of the world's total remaining natural gas reserves are located in the Persian Gulf. Only the Soviet Union has more estimated future gas reserves with 31.8 percent of the world's total. Domestic natural gas equals only 9.3 percent of the world's total.

The 1976 Department of Energy estimates suggest that Alaskan gas might supply somewhat more than one trillion cubic feet (30 billion cubic meters) before 1985, and imports of gas (shipped to the U.S. in liquified, cryogenic container-ships) might supply two trillion cubic feet by that year. This projected supply comprises thirteen percent of current U.S. consumption of natural gas in one year.[39]

Natural depressurization of an underground reservoir forces gas upward through producing wells. Because of natural underpressurization or gradual loss of natural pressure, a large fraction of the available gas at most wells must be used to pump the remainder out of the ground.[40]

Texas and Louisiana supply most of the natural gas to the rest of the United States. Together the two states produced 70 percent of the total national marketed production in 1978. Texas and Louisiana are also first and second, respectively, in consumption of natural gas. Oklahoma, Kansas and New Mexico contributed nineteen percent of total national gas supply in 1978. These five states continue to produce about 90 percent and consume 40 percent of national supply.[41]

Domestic U.S. production of natural gas is greater than domestic production of petroleum. Domestic production of both peaked and began to decline in the early 1970s. This decline has resulted in increasing curtailments of interstate natural gas commerce, though there is still substantial interstate commerce in producing states.[42]

To compensate, the United States is beginning to import liquified natural gas (LNG) and gasify domestic coal. Liquification of natural gas enables it to be stored and shipped compactly and in very large quantities. Natural gas liquifies when it is chilled to -162°C (-259°F). This reduces its volume more than 600 times, meaning that one tank of LNG contains about 600 times the amount of energy contained in a tank of regular natural gas. This tremendous concentration, plus the fact that LNG vaporizes on contact with air, means that is must be shipped with extreme caution.[43]

Most LNG comes to the U.S. in supertankers from Algeria, the principal exporter of LNG. Libya and Indonesia are also major exporters.[44] Tankers carrying LNG are of highly specialized design. Spherical tanks or "membrane" tanks carry the LNG within the hull of the ship. Because of economies of scale, the size of these tankers has grown over the years, until they are now up to 1,000 feet (304.8 metters) long with cargo tanks up to 100 feet (30.5 meters) tall. Such tankers cost approximately $200 million apiece. The world fleet of these ships is estimated at 79 vessels. Their standard cargo capacity is 125-130,000 cubic meters; ships with a capacity of 200,000 cubic meters are now on the drawing board. The standard cargo capacity is enough to heat 2.5 million homes on a 22°F (-5.6°C.) day or to provide electricity for a city of 85,000 people for one year.[45]

The United States has one export terminal at Kenai, Alaska where LNG is distributed to the lower 48 states. Two other Alaskan terminals are planned, at Cook Inlet and Point Gravina. Various gas companies maintain import terminals at Elba Island, Georgia; Cove Point, Maryland; and Everett, Massachusetts. There are proposals for more import terminals at Point Conception, California; Lake Charles, Louisana; West Deptford, New Jersey; Staten Island, New York; Newport, Oregon; Providence, Rhode Island; and Port O'Conner and Ingleside, Texas.[46]

Once imported, LNG is stored at either large "peak-shaving" stations or small satellite stations. Peak-shaving plants store LNG that gas companies buy at low summer rates and then resell at times of peak winter demand. There are now 63 such plants in the United States.[47] Peak- shaving plants in turn supply LNG to smaller satellite facilities in more remote areas. There are about 60 of these facilities in the U.S.[48]

Both types of facilities employ double-walled, insulated tanks to keep the LNG at its required low temperature. The tanks rely on insulation to maintain the temperature, rather than on power refrigeration. Most tanks are made of specially alloyed metal; others are constructed with pre-stressed concrete. Some tanks hold as much as 50,000 cubic meters of LNG. A few hold more than 100,000 cubic meters. Tanks are large because of economies of scale, because they take up less space in urban areas, and because there is less loss from boiling-off LNG reverting to gas and dispersing.[49]

Tank trucks deliver LNG to the satellite stations and also supply liquified gas for industrial applications. About 75 trucks have an average capacity of 10,200-12,500 gallons of LNG (38-47 cubic meters); they travel up to 1,500 miles (2,414 km) for deliveries.[50]

Domestic supplies of natural gas are transported primarily by pipeline. The United States maintains a system of natural gas pipelines which carry large amounts of gas within producing regions and to major consuming regions. These pipelines extend to every continental state except Vermont. Long distance transportation of natural gas became possible with the introduction of welded gas pipelines in 1925.[51]

In 1979, the United States consumed 19.5 trillion cubic feet (.4 trillion cubic meters) of natural gas.[52] Fifty billion cubic feet (1.3 billion cubic meters) of it moved around the U.S. in pipelines owned by 34 interstate natural gas pipeline companies. As of 1979, there were 341,247 (549,066 km) miles of natural gas transmission pipelines, field and gathering lines, and an additional 688,480 (1,107,764 km) miles of distribution mains.[53] The U.S. natural gas pipeline network is shown in Figure 2.2-2.

The typical natural gas pipeline is 30 inches (.76 meters) in diameter and about 1,000 miles (1,609.3 km) in length. Some are as wide as 48 inches (1.2 meters). Pipelines are buried and are invisible above ground except for right-of-way markers and occasional compressor stations.

The natural gas "grid" consists of the lines and interconnections between cross-country pipelines. It is formalized among companies by proprietary agreements and fraught with institutional barriers. The nation's natural gas supplies are managed by many small, independent gas companies who would have to forfeit some control of their operations if a grid were to exist, and they are reluctant to do this. The interconnections that exist now are meant to be used for only a short time for instance, in emergencies or for sales or exchanges between companies.

Underground storage facilities which are the preferred method of storage, are usually natural formations such as salt mines, aquifers, or fully depleted oil and gas wells. The average capacity of underground storage pools is about nineteen billion cubic feet. In 1978, there were 388 such storage facilities in the U.S. There are also 53 underground storage aquifiers, with an average capacity of 30 billion cubic feet (.8 billion cubic meters). Approximately half of the states in the U.S. use underground pools, and about ten states use aquifiers. States in the East North Central, West South Central, and Middle Atlantic regions make the most use of underground natural gas storage.[54]

Gas companies try to store their peak-shaving supplies near the areas where they will be consumed. Most storage areas are a few miles away from the towns that use them. Companies use the smaller distribution main pipelines to transport natural gas from storage areas into the homes and businesses of their customers.

Twenty percent of the energy the U.S consumed in 1979 was in the form of natural gas. Per capita consumption of natural gas began to decline in 1972, but increased slightly in 1978 by 1.7 percent. Small increases in the residential and commercial sectors were offset by a larger decrease in the industrial sector.[55]

States rely on natural gas to varying degrees. In some states gas is used principally for heating homes and domestic water, and for cooking; in others it is used for electrical generation or high-temperature industrial processes.

Industry is by far the biggest overall consumer of natural gas. In 1979, 8,636 trillion Btus were used. Almost half of the energy that industry uses is natural gas. Residential and commercial uses of natural gas amounted to 7,770 trillion Btus in 1979, and utilities used 3,610 trillion Btus to generate electricity.[56]

Coal (2.2-3)

Commercial coal mining in the U.S. began about 1750 near Richmond, Virginia. The first expansion of coal mining began with the rise in iron and steel production during the Civil War. By 1885, railroads were the greatest consumers of coal. When the railroads converted to diesel electric locomotives, the electric power generating companies stepped in as the major consumers of coal. Decline in the use of anthracite coal for space heating and cooking was offset by an increased use of bituminous coal by the iron and steel industries. However, overall coal use has dwindled rapidly since 1910 from about 70 percent of U.S. energy use to about 18 percent in 1979, having been displaced for most uses by oil and gas.[58]

Pressures to reduce dependence on foreign oil and uncertainties about nuclear power's ability to provide a fraction of U.S. electric demand are again bringing coal to national attention.

Utilities and energy planners (principally the U.S. Department of Energy) are looking to the nation's tremendous domestic reserves of coal to be the primary source of energy for the nation's electric power plants--for new plants, and replacing oil in some oil plants. This increased use of coal will not be without a number of attendant environmental problems.

Nevertheless, the U.S. government, through several important pieces of legislation, is encouraging utilities and private industry to convert from the use of oil and gas to coal. The Power Plant and Industrial Fuel Use Act requires utilities to use fuels other than oil or gas in new utility boilers after 1990.[59]

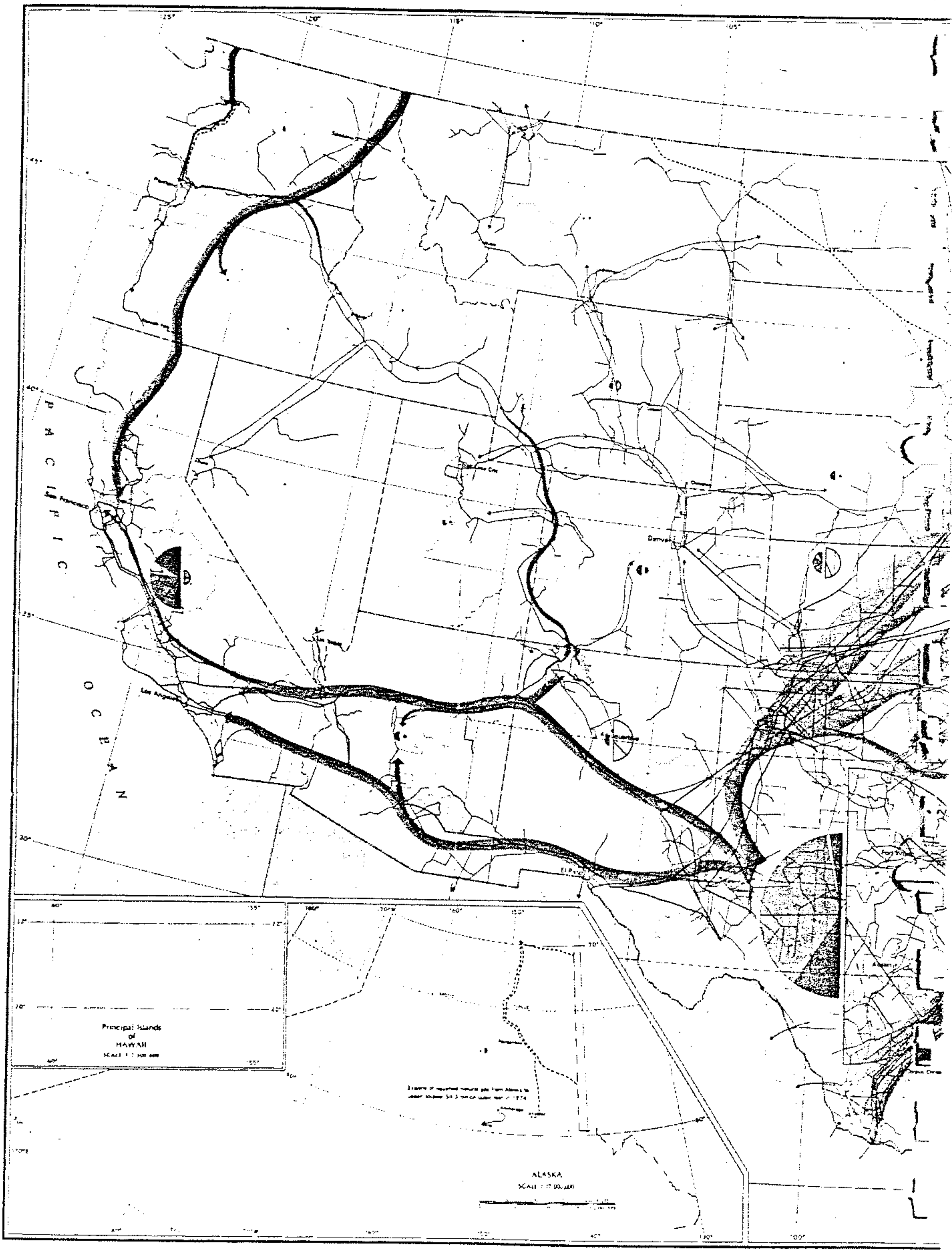
The U.S. Geological Survey and the U.S. Bureau of Mines estimate that the U.S. holds 1.5 trillion tons (1,360.8 trillion kg) of coal at depths to 3,000 feet (914.4 meters) and in seams at least fourteen inches thick. The Bureau of Mines consideres 136.7 billion tons (124,012 billion kg) economically recoverabele with current mining technology. The remainder could only be mined using sophisticated deep-mining techniques, since the deposits are either too deep for surface mining or the seams too thin to be effectively surface-minded.

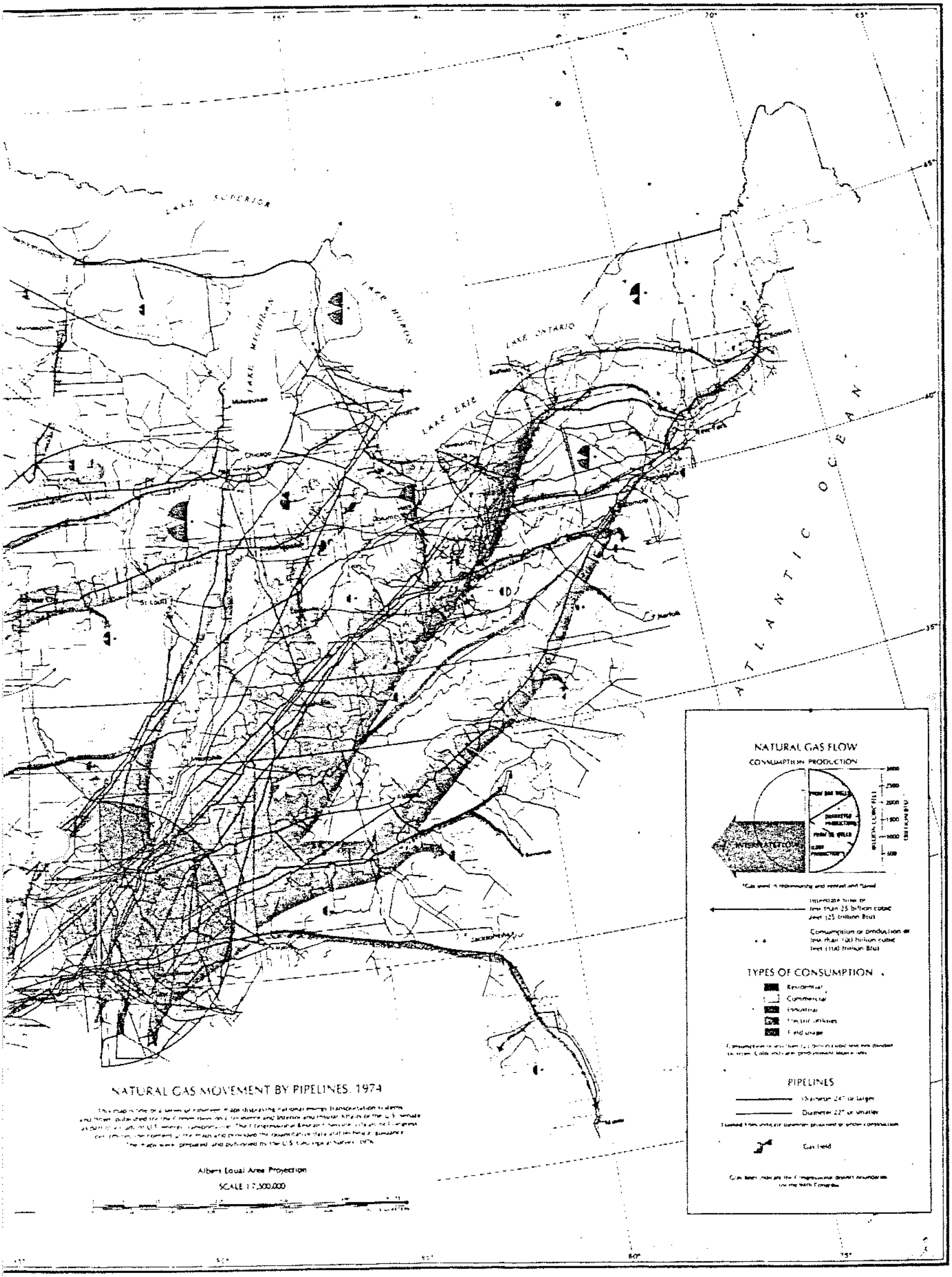
Coal is the most plentiful fossil fuel in the United States. It represents about 88 percent of the proven reserves of all U.S. fuels. Extensive deposits of coal are found in the eastern, central and western United States, including high-grade coal resources in Alaska. The states with the greatest known resources of minable coal are Montana, Illinois, West Virginia, Pennsylvania, and Kentucky. Thirty states in all have been identified by the Department of the Interior as having minable coal resources.

About 70 percent of the coal in the U.S. is located west of the Mississippi. However, much of the western coal is low in energy value, high in sulfur content, and must be strip-mined. Anthracite coal has an average moisture content of five percent and a sulfur content of 0.7 percent or less. Subbituminous coal has an average 25 percent moisture content and sulfur ranging from two percent to 0.7 percent (and less.)

Figure 2.2-2[57]

NATURAL GAS MOVEMENT MAP





NATURAL GAS MOVEMENT BY PIPELINES, 1974

This map is one of a series of [illegible] maps displaying national energy transportation systems and flows published for the Committee on Commerce and Interior and Insular Affairs of the U.S. Senate as part of a study of U.S. energy transportation. The Congressional Research Service, Library of Congress, [illegible] the content of the maps and provided the quantitative data and technical guidance. The maps were prepared and published by the U.S. Geological Survey, 1976.

Of the various types of coal, anthracite is of the highest energy quality, followed by bituminous, subbituminous, and lignite. Anthracite is found largely in Pennsylvania (although there are substantial Alaskan deposits) and has an energy value of 14,000 Btus per pound. Subbituminous coal contains an energy value of 9,500 Btus per pound and lignite yields 6,100 Btus per pound.

Ownership of coal reserves is split among three interests: energy companies; the railroad industry; and coal consuming industries which include electric, steel, other metals, and chemical industries.[60] The locations of most coal beds is known. Factors such as rank, ash content, continuity, thickness, and depth remain to be discovered.

The major questions surrounding coal reserves are where and how coal will be extracted and used. A 1973 study by the Library of Congress indicated that 30 billion tons (27,215.5 billion kg) of low-sulfur (one percent or less) strippable reserves exist in the West, compared to only 1.8 billion tons (1,632.9 billion kg) in the East. However, there are an additional 82 billion tons (74,389.1 billion kg) of low-sulfur reserves in the East, half of which are recoverable with current deep mine techniques.[61] Coal in the West is primarily recoverable by stripmining techniques. Energy planners are looking with interest at western coal, and several conversion technologies have been proposed for exploiting these deposits. Development plans for using western coal involve stripmining and transporting coal by unit-trains (specially designed long freights, carrying only coal) to consuming areas, or mixing pulverized coal with water and transporting the resulting "slurry" via pipeline to consuming areas.

Strip mining is the least expensive and most efficient means of mining coal. It is done by stripping overlying material away from a minable coal seam with large electric shovels, and blasting the coal into chunks with explosives. Most strip mines are less than two hundred feet deep. Strip mines produce as much as 15,000 tons (13,607,771.1 kg) of coal a day and employ as many as 700 men in a single mine.[62]

Underground mining is the traditional method of mining coal. Historically mine shafts were dug to intersect coal seams, and miners would drill or blast into the coal seam and then load carts full of broken coal and push them to the surface. Now much of this operation has been mechanized. Continuous mining machines cut rather than blast the coal, break it and move it continuously into waiting cars. Most underground coal mines are less than 3,000 feet deep. produce from two to three tons to 10,000 tons, and employ one to two thousand men per mine.[63]

More than half of the coal mined in the U.S. in the mid-1970s came from surface mines. However, coal that can be mined using surface methods comprises only 30 percent of U.S. coal reserves and ten percent of the estimated coal resources. About a quarter of U.S. coal comes from underground mines; the remainder is mined with augers which bore into coal seams exposed on hillsides.[64]

Improvements in deep mining technologies such as the development of the continuous mining machine, have helped reduce the labor-intensity of deep mining. Other advanced deep mine technologies, called "longwall" and "shortwall" systems. have eliminated the older "roof and pillar" methods, enabling recovery of up to 90 percent of the coal in a seam with current techniques.[65]

Coal is still a plentiful domestic resource; in 1979, the U.S. exported 59,874 million kg of coal and imported only 1,814 million kg.[66] Australia and South Africa provided 72 percent of total U.S. coal imports in 1978. Other suppliers are Canada, Poland, West Germany, and the Netherlands.[67]

Most use of coal involves significant transportation, which affects its delivered price more than other fuels. This, in turn affects the need for different varieties of coal, the working of the spot and long-term delivery markets, private ownership of some production and transportation capacity, and perhaps seasonal fluctuations of supply in demand.[68]

Coal is transported mainly by railroads, water carriers, and trucks. Coal slurry pipelines (carrying coal suspended in water) are becoming an important alternative. Several slurry pipelines are planned and one is now operating. About half of U.S. coal production moves by rail, a quarter by water, and about ten percent by truck. The rest is consumed at the mine-mouth.[69] Figure 2.2-3 shows total coal movement in the U.S.

It is significant that all of these transportation modes, with the exception of the pipelines, depend on diesel fuel. According to the Congressional Research Service, "...our dependence on overseas sources for half of the oil we use may threaten our supply lines for coal as well."[70]

The single largest movement of coal in the U.S. is transport of metallurgical coal by rail from the Appalachian region to Virginia for export, followed by transport of steam coal from that region to North Carolina. Large amounts also move from Appalachia to Ohio and Michigan, and to New York and New England from Pennsylvania, and interstate in Pennsylvania, Illinois, Indiana, Kentucky, Ohio, and West Virginia. Long shipments come from Wyoming and Montana to the Midwest.

Trucks move coal in smaller amounts and over shorter distances. Trucks are used similarly for interstate transportation in such states as Pennsylvania and Ohio. The principal route for barge traffic is the Ohio river, and the Atlantic coast is the shipping point for exports.

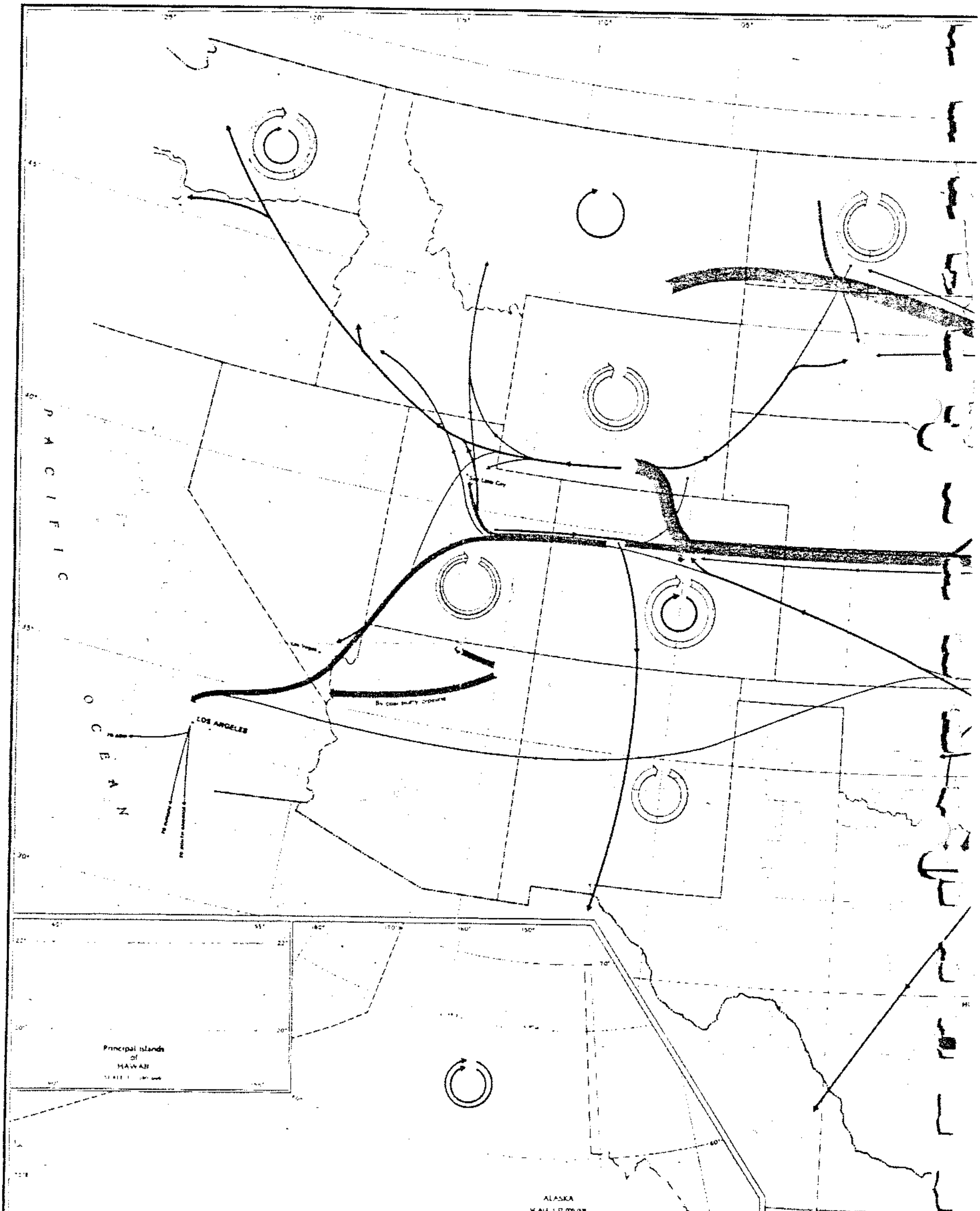
Coal is not actually refined, but more than half of the coal used in the U.S. is cleaned before it is burned or processed in order to remove ash and inorganic sulfur. Sulfur oxides are a serious pollutant, and clean coal is best for gasification.

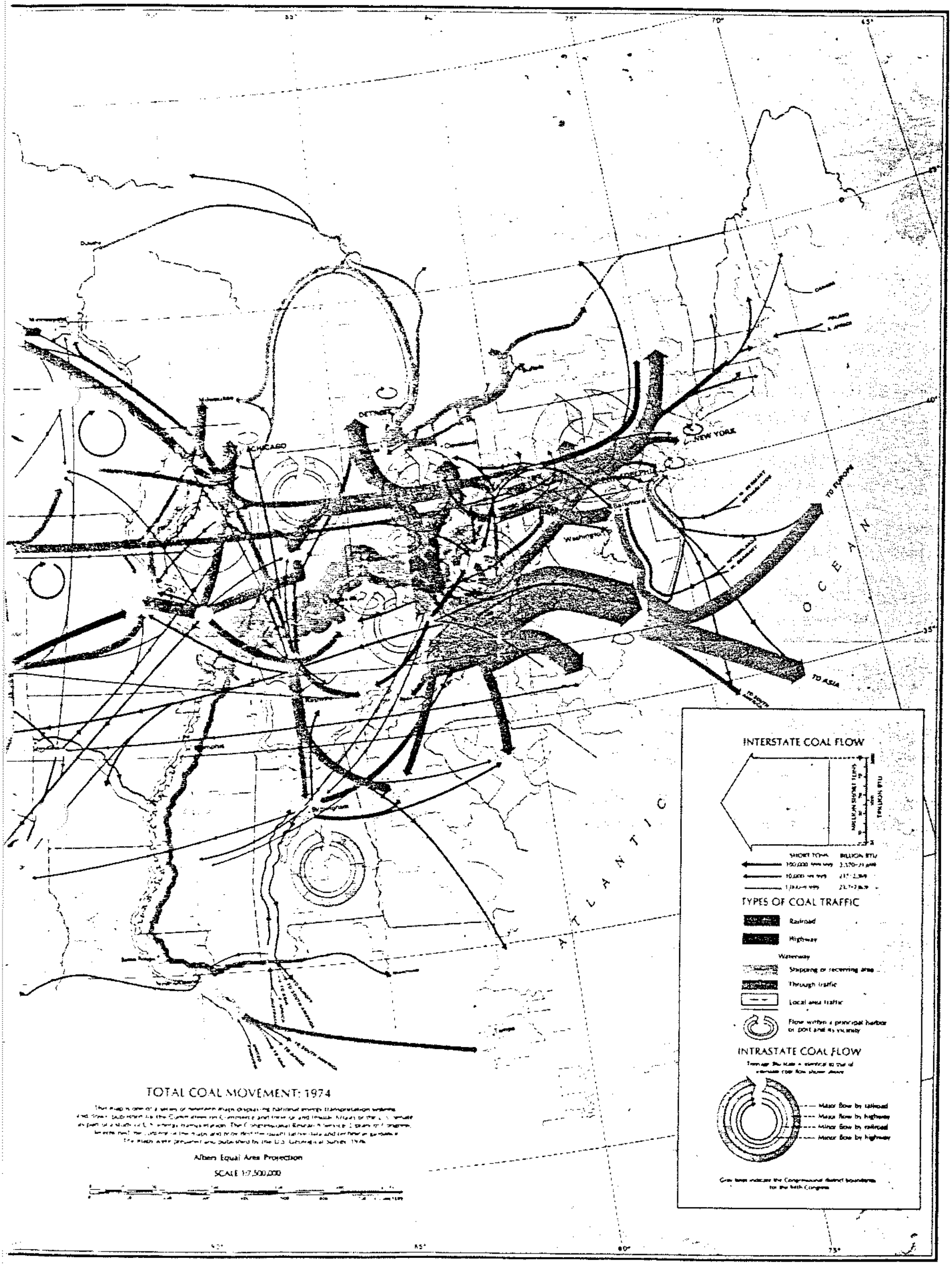
Coal technology is changing as its place in the U.S. energy picture changes. In the last centruy, when oil replaced coal as an industrial fuel, coal was relegated to use by power plants, which burned it directly. Now recently devised technologies such as fluidized-bed burning have improved the efficiency of coal use, and techniques such as coal gasification make coal available as gaseous as well as solid fuel.

The availability of water may be the major limiting factor in future coal exploitation. A study by the National Academy of Sciences (NAS) found that, even by using watersaving technologies such as dry cooling towers in a coal-fired power plant and other conversion facilities, the water supplies for these uses "are not normally available at coal mine sites in the western United States. In most coal-rich areas the local supply of ground or surface water is insufficient to meet the consumptive use requirements in conventional energy conversion processes."[71]

Figure 2.2-3[72]

COAL MOVEMENT MAP





TOTAL COAL MOVEMENT: 1974

[illegible]

Water is needed not only to provide cooling for conversion and power processes, but also to rehabilitiate stripmined areas. The NAS study points out: "At any distributed site in the desert West, the reestablished vegetation should not be expected to be greater than the original cover, because the native plants have developed through the processes of natural ecological succession. Experience has shown that the process requires from twenty to fifty years or more even when a seed source is close by and the distrubed areas are not extensive. Consequently, the probability for successfully rehabilitating such areas is extremely low."[73] The report suggests that many western areas might have to be classified "national sacrifice areas," since they could be rejuvenated only partially once strip mined.[74]

Nuclear Power (2.2-4)

Tremendous power from atomic energy was theorized as early as 1905 when Albert Einstein mathematically demonstrated that the nuclear energy content of a substance depends on its mass ($E = mc^2$). It was not until 1942, when a group of scientists led by Dr. Enrico Fermi built the first atomic reactor at the University of Chicago that the nuclear reaction was harnessed.

Commercial nuclear reactors operating in the U.S. today produce electricity by using the energy of the fission reaction to heat water to generate steam for turning turbines. Fission is an energy conversion process in which neutrons subatomic particles bombard and split the heavy atomic nuclei of elements such as uranium. The neutrons which split uranium atoms must be released at a controlled rate to sustain a chain reaction. The thin rods of uranium fuel within the reactor are surrounded by control rods made of materials which absorb neutrons. Water is circulated through the reactor core to remove and use the generated heat.

Nuclear steam generation is the newest type of electric generating technology. Nuclear power now supplies about eleven percent of all U.S. electricity. As of July, 1980 there are 74 nuclear power plants in the U.S. in operation or start-up testing, with construction permits granted for 85 more. Construction permits are pending for fourteen nuclear power plants.[75]

Some states rely more heavily on nuclear-generated electricity than others. Illinois, New york, Connecticut, Pennsylvania, South Carolina, Virginia, Florida, and Alabama all received substantial portions of their electricity from nuclear plants in 1975.[76]

Nuclear plants are sited close to where their power will be used, instead of near their fuel sources, like coal plants. The main considerations in siting nuclear plants are safety and environmental effects, as well as the availability of cooling water. Because of the transmission costs of electricity, plants are built as close to consumers as the above factors will allow. Sites for related facilities depend on other resource considerations. For example, enrichment plants require large amounts of electricity and uranium mills require a great deal of water and are sited along streams.[77]

Further centralization of nuclear facilities--reactors, reprocessing and fuel fabrication facilities—into nuclear energy "parks" has been suggested as a means of eliminating long transportation hauls of nuclear materials and thus their exposure to hijackers, terrorists, and inadvertant accidents.[78]

Reliance on nuclear fission power plants as a source of United States electricity will be limited by several factors. Two important issues are the availability of uranium and other fuels, and the safe and efficient operation of various reactor types.

The major limiting factor in nuclear power growth is the natural limit of the availability or uranium fuel. According to new estimates by th U.S. Geological Survey, the domestic reserves of uranium that the U.S. now has could supply only fifteen percent of the uranium that the U.S plans to use between now and 2000. According to U.S.G.S. Frank C. Armstrong, the U.S. will need between 1.6 and two million tons (1,451.5 and 1,814.4 million kg) of uranium ore over the next 25 years, but U.S. production could only supply 315,000 tons (285.8 million kg). Current U.S. uranium reserves total about 600,000 tons (544.3 million kg), with another one million tons (907.2 million kg) in the "undiscovered but probable" category. Another two million tons (1,814.4 million kg) are considered "speculative" and "possible" by the U.S.G.S.[79]

According to Warren Finch, Chief of the U.S.G.S. Branch of Uranium and Thorium Resources, "The uranium found thus far was easy. It was at or near the surface. The new ore for the future will have to be found in deeper horizons and be of lower grade."[80] He points out that no new uranium mining districts have been found in the U.S. in the last eighteen years, but three to five times the uranium found in the last quarter century will have to be located before 2000. Uranium procession and mining operations have used some new technologies such as solution mining to expand the available resource. Atlantic Richfield Company has drilled wells in Texas and pumped alkaline leachants into them to release liquid containing uranium oxide. The liquid is filtered, dried, and shipped to processing plants. However promising this technology, experts in the nuclear industry predict that solution mining will be capable of supplying only 7,000 tons (6.4 million kg) of raw material to the industry in 1985.[81]

An additional limit to the nuclear industry is the nuclear fuel cycle's tremendous demand for materials and energy. Various estimates of the energy required to produce electricity from the atom indicate that it will take from 25 months to thirteen years to "pay back" the costs of energy to build and operate the plant.[82] Other procedures, including the decommissioning of nuclear plants, require additional energy expenditures not included in the conventional analysis of net energy from nuclear-generated electricity. At the end of a nuclear power plant's lifetime (approximately 30 years), the whole installation must be dismantled and buried, since the components are highly radioactive.

The Department of Energy, in its 1976 energy study, National Energy Outlook, predicted that nuclear power generation would supply 26 percent of the nation's electricity, compared to 8.6 percent in 1975, but the continuing problems in the nuclear industry, stemming from resource limits, financial limits, and technological difficulties, may significantly reduce the future supply of power from this source.[83]

Figure 2.2-4 is a diagram of the various steps in the nuclear fuel cycle, not all of which have been activated as of this writing.

There are seven basic steps to the nuclear fuel cycle:

1. Uranium ore is shipped from the mine to a milling facility where it is refined to uranium oxide, or yellowcake. Uranium presents problems similar to those encountered in coal mining; that is, there are conflicts in water and land use and physical dangers to miners in the form of radioactive dust and mine hazards. One kilogram of uranium ore yields the same thermal energy as about 50 kilograms of bituminous coal.[84] New Mexico, Wyoming, and Utah are the major domestic sources of uranium ore. Canada, Australia, South Africa, Zaire and Gabon are major foreign sources. There are now 32 separate facilities in the U.S either operating or planning to produce yellowcake. These mills are capable of processing about 800,000 tons (725.7 million kg) of uranium ore each month, yielding about 1,320 tons (1.2 million kg) of yellowcake monthly.[85]

2. Trucks carry an average of 44,000 pounds (39.9 million kg) of uranium concentrate to a conversion facility, where uranium hexafluoride (UF_6) is produced. There are two uranium hexafluoride conversion plants in the U.S. One plant is located in Metropolis, Illinois, and one is Sallisaw, Oklahoma. Between them they can produce about 1,380 metric tons of UF_6 per month.

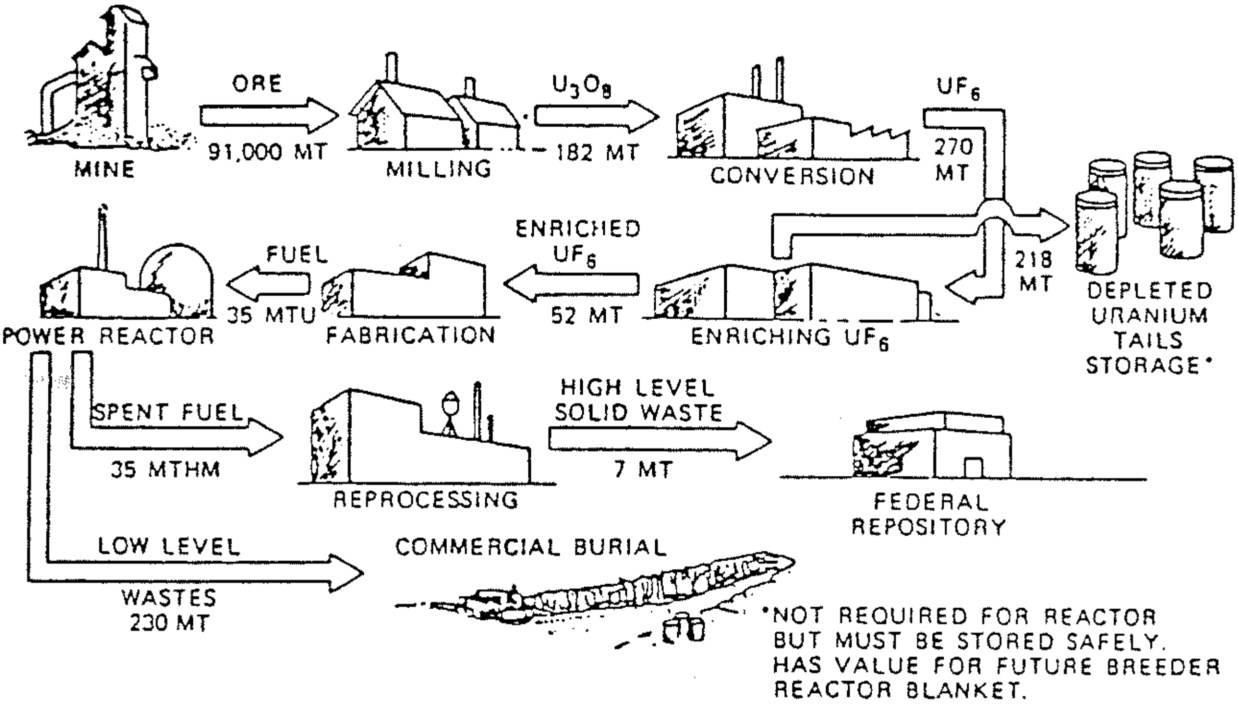
3. Uranium hexafluoride is shipped to an enrichment plant, which produces two different types of uranium hexafluroide. In one, the preperation of fissionable Uranium-235 is increased; in the other, it is depleted. Lightwater reactors (LWRs), the type now used in the U.S., require uranium fuel that is about three percent U-235 and more than 99 percent U-238, which does not fission easily. The depleted uranium left with between 1.2 percent and 1.4 percent of the originally present U-235, is stored at the enrichment site as a potential fuel for the advanced breeder reactors, which are still in development.

Uranium enrichment facilities, called "gaseous diffusion plants," use about one-third of the energy that goes into producing refined uranium fuel. There are three such facilities, all owned by the federal government, at Portsmouth, Ohio; Oak Ridge, Tennessee; and Paducah, Kentucky. The plant in Kentucky performs only an initial step in light enrichment and ships all material to one of the other two plants. The Tennessee plant now produces the bulk of the low enriched UF_6 used in commercial reactor fuel.[86]

An alternative to the nuclear fuel problem would be to develop the breeder reactor. The breeder reactor can convert U-238 to fissionable plutonium (Pu-239). Plutonium is an extremely long-lived and highly toxic radioactive element with a half-life of 24,000 years. This and its chemical reactivity pose a number of safety as well as technological problems.

Figure 2.2-4 [87]

DIAGRAM OF NUCLEAR FUEL CYCLE



Average Annual Fuel Materials Requirements for a Typical 1000 Mwe Light Water Reactor

The U.S. is planning a prototype facility for the Liquid Metal Fast Breeder Reactor (LMFBR) near Oak Ridge, Tennessee. However, the original production schedules have fallen far behind and the first test is not expected before the mid-1980s. It will take at least a decade to build and operate the first commercial breeder plants in the U.S., placing the energy contribution from this technology into the next century.

4. Enriched UF_6 is shipped to a fuel assembly fabricator, where it is made into pellets that are inserted into fuel tubes, or fuel rods. The first step to produce fuel pellets is converting the UF_6 to uranium dioxide, or UO_2. Sometimes this process must be done at a separate facility, but often this work is performed in the same plant or an adjacent one.

There are now seven companies in the U.S. making powdered UO_2 and pressing it into pellets: some also fabricate fuel assemblies. Fabrication facilities are located in Columbia, South Carolina; Windsor, Connecticut; Wilmington, North Carolina; Lynchburg, Virginia; and Richland, Washington. Fabricators usually ship nuclear fuel assemblies by truck to the reactors where they will be used.[88]

5. Nuclear fuel assemblies are gradually spent in the production of heat to make steam for electrical generation. The Uranium-235 and plutonium contained in the fuel assemblies in the core of the nuclear reactor disintegrate to produce high-velocity particles with a great deal of kinetic energy. These energetic particles collide with one another and the structural elements of the core, and so convert much of their kinetic energy into heat. This heat transfers to a fluid coolant that circulates through the reactor core.[89]

Types of fission reactors are designated by the type of coolant they use. In the boiling-water reactor, water is the coolant. When the steam produced by the heat has done its job of turning one or more steam turbines, it is condensed and returns to the reactor core as hot water.

Other types of nuclear power plants use special coolants rather than water. For example, heavy water, an organic liquid, a liquid metal, or a gas such as air, carbon dioxide, or helium may be used as the cooling medium. In these plants, the heat from the coolant is transferred by means of a heat exchanger to a water-steam-turbine-generator system. Waste heat from the plant is recycled to the coolant water.

The nuclear reaction which consumes the fuel is a chain reaction, which requires a large inventory of fuel. However, only a small fraction of the fuel is expended or burned in a day. To produce 1,000 megawatss (MW), a reactor need only fission one kilogram of Uranium-235 a day, or about 800 pounds (362.9 kg) a year.[90]

6. Spent fuel is either stored at the reactor site or shipped to a fuel repository. Two of these repositories are at sites intended for fuel reprocessing facilities, although no fuel reprocessing is now being done.

Three commercial nuclear fuel reprocessing plants have been built in the U.S. These three plants, Nuclear Fuel Services, located in West Valley, New York; General Electric at Morris, Illinois; and Allied General Nuclear Services at Barnwell, South Carolina are not currently in operation.[91]

Spent fuel must be removed from the reactor core at a rate of about one-third of the fuel per year. The spent fuel waste is first stored at the reactor site so that intense, short-lived radioactivity can decay. With few repositories available, wastes are now being stored at temporary facilities and the overflow has become a serious disposal problem.[92]

7. Other wastes contaminated with low-level radiation are transported from the reactor to one of six commercial burial sites. Low-level wastes such as contaminated gloves, radiation suits, and tools, are produced at all stages of nuclear power production and must be buried.

In 1975, all movements of nuclear materials were by trucks on highways except for enriched UF_6 which is transported directly by the government owned-enrichment plants. Despite the higher costs incurred by using this form of transport for long distances, trucks offer numerous advantages over other transport modes. They are relatively inexpensive to purchase, operate on public roads, do not require their own right-of-ways, and they are capable of carrying solid commodities from point to point with greater ease and speed than any other ground transport mode.

The general pattern of nuclear fuel transportation in the U.S. is predominantly from west to east. Uranium yellowcake shipments travel from Colorado, Wyoming, and New Mexico to eastern Oklahoma and Illinois. From here, the uranium hexafluoride moves further east to the three enrichment centers in Puducah, Kentucky, Portsmouth, Ohio; and Oak Ridge, Tennessee. Some of the enriched material returns west to the powder-pellet facility at Oklahoma City or the fabrication plant at Richland, Washington. However, the major part of the enriched uranium flows further east primarily to fuel fabricators in South Carolina and North Carolina. The concentrated, and crucial intermediary steps of the fuel cycle center on the lower mid-Atlantic and Appalachian regions. The major nuclear fuel consuming states are Illinois, New York, Connecticut, Pennsylvania, South Carolina, Virginia, Florida, and Alabama. Fig. 2.2-5 shows total nuclear fuel movements.

This flow pattern is in contrast to all other energy transportation flows which follow the traditional path of east to west. With development of western coal and the eastern movement of Alaskan oil and gas, however, the west to east flow could reserve the traditional pattern.

Relative to other commodities, truck transport of nuclear materials is light. The heaviest recorded flow between two points of the nuclear cycle amounted to little more than an average of one truck per day in 1975. One of the busiest crossroads in nuclear traffic occurs along interstate highway 40 from Nashville to Knoxville, Tennessee. By way of comparison, almost all of the uranium yellowcake transported in 1975 to hexafluoride converters could have been loaded in a single unit (coal) train of 10,000 tons.

When one measures the energy content per truckload, it takes over 3,000 unit (coal) trains to match the energy carried by one unit nuclear train.

Hydroelectric Power (2.2-5)

One of the most efficient of generating electricity is by powering turbines and generators with the force of falling water. This conversion of kinetic to electric energy is about 95 percent efficient.

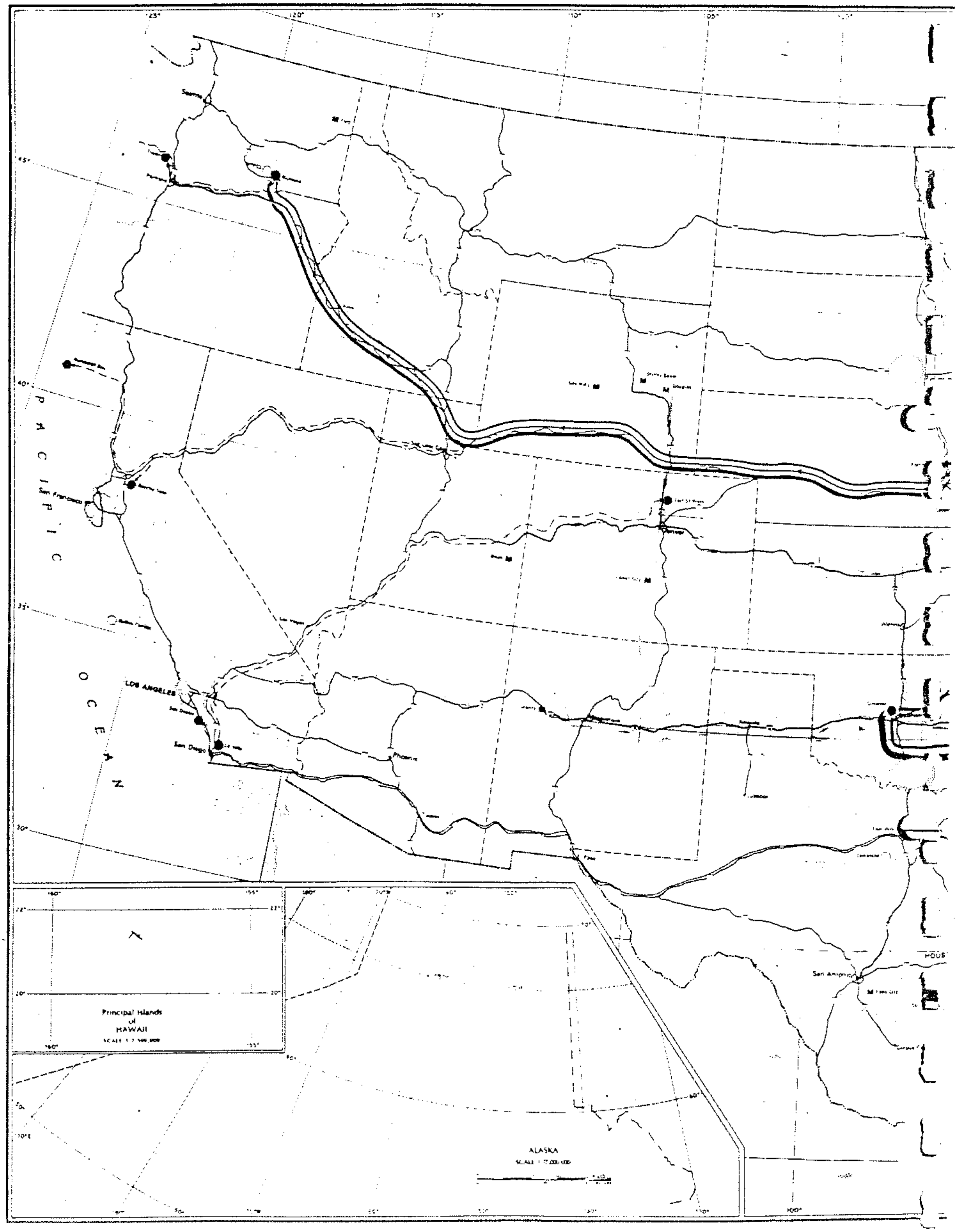
Flowing or dammed water was one of the first power sources tapped to produce electricity. The water wheel, invented for ginding grain and pumping water, was converted to a system to drive electrical generators. Within a month of th opening of the first central electric generating station in 1892, water-wheels on the Fox River in Appleton, Wisconsin began generating the nation's first hydroelectricty.[94]

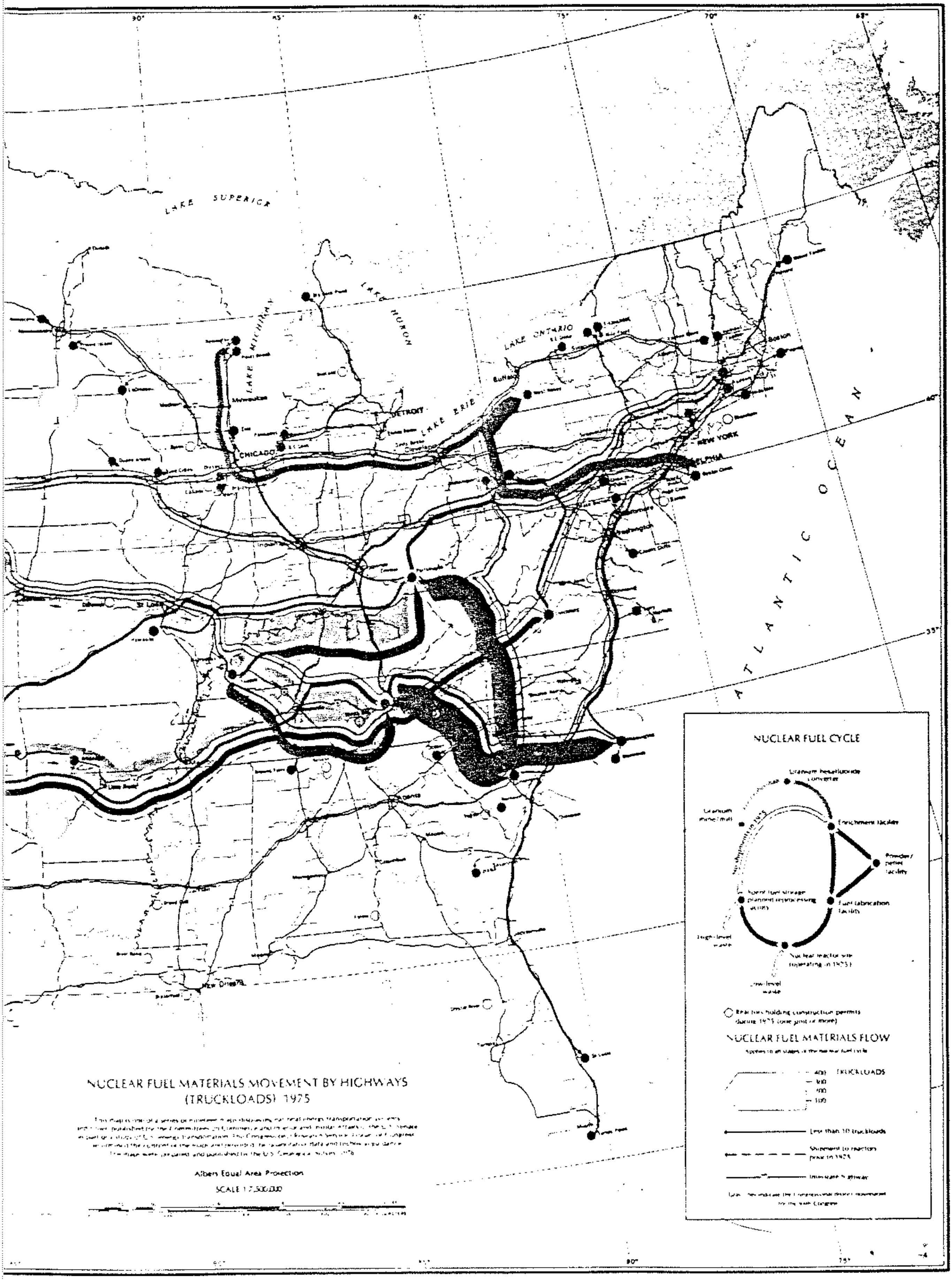
The water wheel proved to be inefficient, and was replaced by modern turbo-generators which could withstand high water pressure. Large dams were built to supply the pressure. Installed conventional hydroelectric capacity in the U.S. tripled between 1921 and 1940, and nearly tripled again from 1940 to 1960, and will have doubled again by the end of 1980.[95]

In 1940, hydroelectric turbines supplied 30 percent of the nation's electricity. By 1971, this had fallen to fifteen percent of installed generating capacity. Hydroelectricity now supplies about twelve percent of U.S. electricity.[96]

Figure 2.2-5[93]

NUCLEAR FUEL MOVEMENTS MAP




NUCLEAR FUEL MATERIALS MOVEMENT BY HIGHWAYS (TRUCKLOADS) 1975
Albers Equal Area Projection
SCALE 1:7,500,000
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
ATLANTIC OCEAN
CHICAGO
Milwaukee
DETROIT
Cleveland
Buffalo
Boston
NEW YORK
PHILADELPHIA
St Louis
New Orleans
NUCLEAR FUEL CYCLE
Uranium hexafluoride converter
Uranium mine/mill
Enrichment facility
Powder/pellet facility
Fuel fabrication facility
Spent fuel storage (planned reprocessing sites)
High-level waste
Nuclear reactor site (operating in 1975)
Low-level waste
No shipments in 1975
Reactors holding construction permits during 1975 (one unit or more)
NUCLEAR FUEL MATERIALS FLOW
400 TRUCKLOADS
300
200
100
Less than 10 truckloads
Shipment to reactors prior to 1975
Interstate highway
90°
85°
80°
75°
70°
65°
40°
35°

The electrical generating facilities in many old dams were retired when replaced by cheaper, centrally generated electricity, and much of the recent increase in hydroelectric capacity is actually in storage facilities at existing large hydroelectric plants. During times of off-peak electrical demand, the water is released to supply energy.

Hydroelectric capacity in the U.S. can be divided between "small" or "low-head" hydro facilities and big faciltities. "Small" hydro has been defined by the U.S. Department of Energy as a dam generating less than fifteen megawatts, and "low-head" dams (the head being the distance between the surface of the water behind the dam and the foot of the dam) as being less than sixteen feet high.

In 1973, the U.S. produced 271,634 billion kilowatt-hours (271.6 billion MW) of hydroelectricity, or about 3.4 quads. In 1977, the U.S. used 2.4 quads of hydroelectricity or about four percent of total U.S. energy consumption.[97] The U.S. has a total installed hydro-generating capacity of 63,648 megawatts. According to a report by the Army Corps of Engineers, "Including the expected output of facilities currently under construction, the annual average electricity production from conventional hydropower plants is 287.8 billion kwh, compared to a total U.S. electricity production of about 2,000 billion kwh in 1976."[98]

The state of Washington is the largest producer of hydroelectricity with 71,429,000,000 kwh (71.4 million MW) in 1971, 26.8 percent of the nation's total hydroelectric production. California, the next largest, produces about half that amount, and Oregon about the same as California. New York also has a substantial amount of hydroelectric production.[99]

The potential for expanding hydroelectric generation is limited by the fact that environmental and resource-conservation priorities stand in the way of further damming of the nation's wild and scenic rivers. The most productive sites for hydroelectric dams are already in use today, and federal energy studies do not indicate that increased large-scale hydrolectric power will be a major contributor to the nation's energy future.

In 1977, President Carter asked the U.S. Army Corps of Engineers to study the potential for additional hydropower from existing dams. In a report released in July of that year, the Corps reported that an additional 54.6 megawatts could be achieved by "upgrading and expanding existing hydropower facilities to all existing large and small dams in the U.S." The Corps estimated that the rate of production at the level of development would be an additional 159.3 billion kwh (159.3 million MW) per year.[100]

If this projected capacity were completely developed, the Corps estimates that it "could defer 15.3 percent and 8.65 percent of the projected growth in steam-electric capacity and generation during the period 1975 - 1985." In terms of oil consumption, the Corps estimates that complete development could save the equivalent of 727,000 barrels per day. The Corps' report cautions, however, that such figures represent an "upper bound on the physical potential" of existing dams in the U.S., and "does not include detailed consideration of engineering, economic, financial, or environmental feasibility," competition for water, or institutional and legal barriers.[101]

Hydropower is, in the long run, a relatively inexpensive way to produce electricity, but high initial capital investments are required to construct dams, turbines, generators, and other equipment. The electricity produced by hydro grows cheaper as the capital investment is paid off, with low maintenance costs and zero outlay for fuels.

Energy Distribution Systems (2.3)

Because electricity moves by wire and cannot be stored in large quantities, it must move directly from the generating plant to the customer, through electrical transmission and distribution systems. Transmission has been defined as electrical movement through power lines of capacity greater than 69 kilovolts (kv), and distribution usually over shorter distances, has been defined as movement through lines of less than 69 kv capacity. "Bulk power supply" moves electricity through lines carrying more than 230 kv.[102]

Transmission (2.3-1)

Energy from generating plants is fed into the transmission system at full voltage, then transformed at substations into lower voltages for residential, commercial, and industrial uses, usually 110 and 220 volts. Utilities use sophisticated equipment such as switching gear, transformers, and lightening arrestors to handle high voltage electric arcs and power surges.[103]

As of 1978, the electrical transmission system for privately owned utilities in the U.S consisted of 331,807 structure-miles (533,991.6 km) of transmission lines, including lines of all voltages from 0 to 765 kv.[104] In addition to transmission within the U.S., inter-ties with Canada and Mexico move a great deal of electricity into the U.S. electrical system. Four new interconnections between the U.S. and Canada are expected to be completed by 1984.[105] One of these interconnections between James Bay and New York City will be the highest voltage international transmission line in the world, using 765 kv lines.

Efficiencies in electrical transmission improved along with efficiencies in generation. Between 1900 and 1960, the maximum alternating current voltages increased from less than 50 kv to almost 500 kv. Increased loading of lines incurred increased losses of electricity, but these were offset by greater capacity with the net result that utilities were able to transmit electricity longer distances at lower costs. Line capacity has more than doubled since the 1950s, from 345 to 765 kv.[106]

Table 2.3-1 shows the transmission volt mileages of various kilovolt levels in the United States at ten-year intervals since 1940. It illustrates the increasing use of high voltage wires.[107]

In 1975, the Federal Power Commission reported that it expected the U.S. to add 61,000 miles to the present major supply transmission network by 1984, with two-thirds of this addition at 230 and 345 kv levels. It reported proposals of 1,500 additional miles of the highest operating alternating current transmission, 765 kv, and anticipated another 1,844 miles of direct current line in service by 1984.[108]

Electrical transmission has been concentrated into lines of increasingly higher voltage because of economies of scale similar to those of pipelines. The Congressional Research Service's Report, <u>National Energy Transportation</u>, states "...electricity can be transmitted as effectively 300 miles (482.8 km) over a 765 kv line as it can be transmitted ten miles (16.09 km) over a 138 kilovolt line. A single 765 kv line can carry more than 2,000 megawatts over a long distance; this would require five 345 kv lines."[109]

Overhead transmission is the most economical and efficient method of moving electricity. Because it requires fifteen to twenty acres of land per mile of transmission line, overhead transmission becomes another factor in centralization of transmission. Utilities use higher voltage lines to minimize their use of land.

Table 2.3-1[110]

MILES OF TRANSMISSION IN USE AT 230 KV OR ABOVE
(THOUSANDS OF MILES)

	230kv	287kv	345kv	500kv	765kv	Total
1940	2.3	.6	--	--	--	2.9
1950	7.4	.8	--	--	--	8.2
1960	18.7	1.0	2.6	.1	--	22.4
1970	40.6	1.0	15.1	7.2	.5	64.6

High voltage lines of up to 230 kv are found in almost every state. Concentrations of 345 kv lines (up to four per route) move large quantities of electricity to population centers in the eastern states, and from Washington down the length of Oregon to California.[111] To further cut transmission costs, the utility industry has inter-tied regions larger than single company franchise areas, and created power pools. These organizations regulate the generation and dispatching of electricity to all pool members so as to achieve the lowest cost for the pool as a whole.[112]

Distribution (2.3-2)

Once the electricity has been transmitted to the local service area, the high voltages must be reduced by line transformers. These transformers and secondary line transformers reduce the voltage to the 120-240 volts used in homes or increase the voltage to 2,400 volts used in industry. This final stage of the electricity delivery process is called the "distribution system". At present, there are over four million pole miles (6,437.3 million km) of lower voltage distribution lines that service residential, commercial and industrial customers.

Factors Influencing Centralization (2.4)

Overview (2.4-1)

With the advent of the electrical generating plant, it was logical to locate as close as possible to the prospective customers. The optimum sites for power plants were therefore initially in or near the industrial sector. Proximity to end-use requirements saved on transmission costs and access to water and fuel transportation facilities was already established. Once the prime sites were taken, however, it was necessary to locate electrical power plants in the suburbs, away from the industrial centers.

As the electrical industry expanded, it became a trend for the smaller companies to merge in order to enjoy greater economies of scale. A larger plant could produce more electricity and deliver it further distances at a reduced unit cost. At the same time, technological advances in design, engineering and industrial construction sustained rapid growth in electricity demand and improvements in thermal efficiencies of central station power generation and electric transmission made such economies feasible.[113]

World War I greatly accelerated the trend toward interconnections between utilities because of the dramatic increase in electrical demand. As a matter of national security, electricity supplies had to meet critical war industry demands. The benefits of increased efficiencies due to consolidation were recognized and implemented which solidified the trend toward centralized electricity systems.

Rapid progress in the development of higher maximum voltage transmission lines, larger generating capabilities and improved distribution facilities required greater capital investment and provided another reason for ownership consolidation of the numerous small scale power plants. Private ownership by individuals was impractical and soon gave way to the investor-owned utilities that dominated the market.

The need for larger amounts of capital required different financial and institutional arrangements. Thus, "standard mortgages were replaced by open-ended mortgages, gradually creating an incentive for transfer of investor-owned systems to larger holding companies."[114] These public utility holding companies acquired control over many regional companies by purchasing sufficient stock in each to direct its operation. By 1932, eight holding companies produced 75 percent of the electricity consumed in the U.S. The trend toward consolidation within the electric power industry continued, eventually resulting in a relatively smaller number of producers generating a larger percentage of the nation's electricity.

In order to further expand the availability of electricity, the federal government initiated another method of financing. In 1935, President Roosevelt introduced the Rural Electrification Administration (REA) which provided low-interest loans for cooperatives and non-profit organizations to overcome the high costs of central-station electricity in the rural sector. The Rural Electrification Act of 1936 successfully encouraged the extension of electricity to the country's less populated rural areas. "As of June 30, 1968, 19.4 percent of all the farms in the United States had central-station electric service available."[115]

Over half of the farms were served by the rural electric cooperatives at that time and the remainder were supplied by investor-owned companies, public utility districts and municipal plants.[116]

The electric utility industry continued its trend toward centralization for the next three decades by means of technological advances, improved economies of scale with larger power plants and consistent growth rates for demand. During the 1930s and 1940s, much larger power plants were built as a result of the use of hydrogen-cooled generators. By the early 1950s, higher steam pressures and temperatures became possible due to technological advances, although scientists discovered that lower steam pressures of around 2400 psi were more desirable for the efficiency of the overall operation of a power plant.[117]

When it was not feasible to make a single power plant larger, there were incentives to build additional units upon a previously existing power plant site. Multiple units per site resulted in lower costs of production due to the exclsuion of costs of land acquisition, transporation facilities, and licensing obstacles. Thermal efficiencies were also improved but plateaued by the 1960s due to inherent thermodynamic limitations.

In addition to improvments in generating capabilities, progress was made in transmission facilities. As lines were devised to carry higher voltages, the maximum voltage capacity increased from 50 kilovolts in 1900 to current capacities of 765 kv.

In every case, the costs of research and development, production and installation were offset by the ability to produce and distribute electricity at overall lower costs. For example.

> Other things equal, the per unit costs of transmitting large amounts of electric energy over significant distances are greatly reduced by utilizing the highest voltage line available. Power transmission lines are generally categorized as "high-voltage", 69 to 300 kolovolts; "extra-high-voltage," (EHV), 300 to 1000 kilovolts; and "ultra-high-voltage (UHV), 1000 kilovolts and above.[118]

As more efficient means of production were developed, the utilities enjoyed continued economies of scale. Electricity was consistently delivered to the consumer at lower marginal costs of power production.

Today the electric utilities in America are divided into investor-owned utilities, municipal utilities, cooperatives, and federal agency utilities. Private, investor-owned utilities produce the majority of the nation's electricity and thus form the base of the electric power industry. By 1920 there were almost 6,500 investor-owned utilities, accounting for 94 percent of the generating market. Today, only 250 privately-owned utilities contribute about 90 percent of our electricity power supply.[119,120]

Municipal and public utilities have also participated in the trend toward centralization. Messing argues that:

> ...public power systems--which theoretically provide an approriate mechanism for the design and implementation of decentralized energy systems--have in the past provided an extensive market and an institutional incentive for the development of centralized power. Although they give the appearance of heterogeneity, diversity, and public ownership to the electric utility industry, from the standpoint of system development they have served to support increased centralization through the provision of an extensive distribution and marketing network, and the absence of a competitive interest either in owning and operating generating systems, or in providing integrated energy planning in local planning decisions.[121]

The Bonneville Power Administration established in 1936, is a major broker of power resources rather than a major producer of electric power. The Southwestern Power Administration established in 1944, the Southeastern Power Administration established in 1950, the Alaska Power Administration established in 1956 and the Western Area Power Administration established in 1977 produce hydroelectric power for federal water projects and function as marketing agents. The Tennessee Valley Authority (TVA) established in 1935, is the only federally-owned power corporation. It is the only one of the six federal energy agencies to own and operate thermal electric generating facilities. In 1970, the TVA had become the single largest electric utility in the country, producing five percent of the nation's total generating capacity. Altogether, the six federal agency utilities account for about twelve percent of the total U.S. generating capacity.[122]

Utility Regulation (2.4-2)

In exchange for government granting of protected service areas to single utilities, a complex system of federal, state, and local regulation developed. The electric power industry is one of the most highly regulated industries in the country. Rates, plant siting, environmental considerations, pooling, transmisson and distribution lines, fuels, utility structure and financing are all regulated in some measure by at least one of a number of regulating bodies.

The initial shift from local and municipal to state control developed as utility service areas spread from limited urban areas. Federal regulation developed because some electricity systems crossed state borders which made them subject to th Commerce Clause of the Constitution. Other electricity systems blocked rivers, thereby triggering federal constitutional authority to regulate the nation's navigable waters.

The Federal Power Commission became the Federal Energy Regulatory Commission (FERC) which is responsible for regulating interstate transmisson, interstate rates, and wholesale marketing of electric power. The Economic Regulatory Administration, like FERC, is housed within the Department of Energy and regulates emergency programs and other interstate actions intended to insure the reliability of the bulk power supply system.

Numerous other laws and agencies which have been established to protect the quality of our environment also affect utilities. The National Environmental Policy Act requires submission of an Environmental Impact Statement whenever various activities affect the environment and the Environmental Protection Agency requires utilities to conform to pollution abatement regulations. The federal Public Utility Regulatory Policy Act of 1978 (PURPA), requires state utility regulatory commissions to scrutinize investor-owned utilities' activities in a number of areas. The three objectives of PURPA are to see that utilities: (1) increase electricity conservation; (2) increase the efficiency of electric generating facilities and resources; and (3) set equitable retail rates for electric consumers.

There are six rate possibilities provided by PURPA to establish equitable rate structures. These rates include: (1) cost-of-service (set according to actual costs); (2) the exclusion of block (declining) rates; (3) time-of-day; (4) seasonal; (5) interruptible; and (6) load management techniques. The states are not forced to implement the various rates if they can prove the rates are inappropriate.[123]

The amount of regulatory control the federal government exercises is very controversial. The debate stems form one view which supports maximum centralized control by government regulation versus another view which supports decentralized utility management. Typifying the former viewpoint was the proposed National Electrical Energy Reliability and Conversation Act of 1977. If passed, S. 1991 would have provided:

> ...a national bulk power system consisting of power generating facilities and a system of very-high-voltage transmission lines owned and operated by a federal corporation, the National Power Grid Corporation. The Naitonal Power Grid Corporation would also establish one federal regional bulk power supply corporation in each of the nation's power supply regions, to blanket the country. The regional corporations would have authority to acquire and operate transmission (but not generating) facilities. The national corporation would take over all federal electric power generating ad transmission facilities ...except for the Tennessee Valley Authority which would be able, if it wished, to transfer federal transmission facilities to the regional corporations.[124]

The probability of legislation such as S. 1991 passing is unknown. Considering the uncertainties inherent in the electricity business, it is difficult to predict the course regulation of the utility industry will follow.

Utility Rates (2.4-3)

The price of electricity is set by "rate-or-return" or "rate-base" regulations, which are established for the most part by state public utility commissions., The rate base is computed by combining the value of the utility's depreciated plant and equipment, and an allowance for the cost of capital. The prices will theoretically provide a predetermined fair rate of return on the rate base, after allowances for operating and maintenance costs, depreciation and taxes have been made.

Originally, the more electricity customers used, the less it cost the utility to produce electricity per unit. Thus a "sliding scale rate" or "block rate" evolved that accounted for an automatic rate decrease as a customer's electricity consumption increased. After nearly a century of stable rates using the above guidelines, the shock of the Arab oil embargo and resultant quadrupling of oil prices in 1973-74 caused an eventual reversal in the electric industry's rate structure.

Additional factors contributing to this reversal in declining real rates for electricity are the high inflation rates of the last decade, strict environmental requirements, increases in other fuel prices, high maintenance and operating costs, rising costs of capital and the peaking of most economies of scale. Phillip Hill predicted in 1979 that the costs of electrical power generation will increase by a factor of four or five between 1970 and 1985.[125]