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REGIONAL REFERENCE ENERGY SYSTEMS: ELECTRIC UTILITY APPLICATIONS*

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ABSTRACT

Reference Energy Systems have been developed for the region serviced by the Tennessee Valley Authority for the base year 1975 and projections developed for the years 1980, 1985 and 2000. This systems formulation has traditionally been applied to the assessment of energy technologies and policies on a national level. This paper presents a reformulation of the projection methodology in order to apply the Reference Energy Systems format to an electric utility region (e.g., the Tennessee Valley Authority). The Reference Energy System is a network representation of the technical activities required to supply various forms of energy to end-use activities. Technologies are defined for all operations involving specific fuels including resource extraction, refinement, conversion, transportation, distribution, and utilization. Each of these activities is represented by a link in the network for a given year with the levels of energy demand and supply specified.

A unique advantage of using the system presented here for utility planning is its integrative view of the entire energy system as opposed to an analysis limited exclusively to the electric sector. This systems approach incorporating all resources, technologies and uses of energy allows a utility to assess the impact of alternate technologies and policies across the entire energy system. Demand patterns for twenty-five end-use demand categories within the residential, commercial, industrial, and transportation sectors are developed for a base case scenario representing reasonable energy use patterns derived in a consistent manner by applying engineering techniques to the best available information. The impact of a new technology in terms of resource consumption may be evaluated by modifying the energy flow paths to incorporate the new technology. Alternate paths through the network reflect the substitutability of resources and technologies for one another.

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INTRODUCTION

The United States has traditionally been an energy independent country relying upon its own plentiful supply of resources to meet its energy needs. Over the past decade this situation has reversed itself due to the nation's increasing reliance on imported oil. In 1970 the U.S. imported 3.4 million barrels of oil per day to meet about 25% of its demand for petroleum products. Since 1970 oil imports have more than doubled reaching 8.7 million barrels of oil per day in 1977 to meet nearly 50% of the nation's demand for petroleum. This rising level of imported energy coupled with the dramatic price increases following the Arab oil embargo of 1973 have led to a reexamination of the nation's energy priorities in terms of the production and demand for energy. Alternative energy sources such as coal synthetics, solar, and nuclear power have been receiving increased attention. Conservation strategies such as end-use device efficiency improvements, improvements in building construction practices, and specific lifestyle changes are being pursued as a result of both government regulation and price inducement. To assess the impact of these alternative sources of energy, technologies, and policies on the nation's energy system requires an analytical framework which incorporates the entire energy system. The systems formulation presented in this paper is based on the Reference Energy Systems approach and incorporates all resources, technologies and uses of energy in a uniform manner.

The Reference Energy System is a network representation of the technical activities required to supply various forms of energy to end-use activities and has wide application in the assessment of energy technologies and policies. Technologies are defined for all operations involving specific fuels including resource extraction, refinement, conversion, transportation, distribution, and utilization. Each of these activities is represented by a link in the network for which an efficiency is specified. The network is quantified for a given year with the level of energy demands and the energy flows through the supply activities that are required to serve these demands.

The Reference Energy System has traditionally been applied to the assessment of energy technologies and policies on a national level. The diversity of energy consumption across the United States is such that regional analysis of energy resources and consumption is essential for any meaningful analysis of policy issues. Both energy resources and end uses have such widely varying characteristics on a national level that analysis of such issues as conservation strategy, utility load forecasting, new technology implementation, and environmental policy require an in-depth knowledge of energy requirements on a regional level.

This paper presents a reformulation of the projection methodology developed on a national level and applies it to an electric utility region—the Tennessee Valley Authority. Reference Energy Systems have been developed for the region serviced by TVA for the base year 1975 (Figure I) and projections were developed for the years 1980, 1985 and 2000 (Figure II). Brookhaven National Laboratory and the Tennessee Valley Authority have entered into a cooperative agreement to model the energy system for the area serviced by TVA. This region, typical of many utilities, cuts across both state and county political boundaries. Thus energy supply and demand data available for political entities from published government statistics can not be utilized directly in this study. The Tennessee Valley Authority has agreed to supply Brookhaven with the necessary energy and economic data that is available to them for the region. Brookhaven has responsibility in the project for developing the energy model and deriving regional estimates of energy supply and demand not provided by TVA. This cooperative arrangement has proven mutually beneficial to both TVA and Brookhaven. As a result of this study the Tennessee Valley Authority currently has access to energy consumption data for all fuels consumed in the region. This was not available previously. In addition TVA is planning to run the Brookhaven Energy System Optimization Model using the Reference Energy Systems developed in this study as input. Brookhaven has had an opportunity to successfully demonstrate the applicability of its modeling capabilities to a utility region. The general methodology demonstrated in this study is also directly transferrable to other utility regions.

The Tennessee Valley Authority is a wholly owned corporate agency of the United States government established by Act of Congress in 1933 to develop the Tennessee Valley. The production and sale of electric power are part of TVA's resource development program. TVA supplies power at wholesale to 160 municipal and cooperative distributors which in turn distribute power to about 2.5 million residential, commercial and industrial customers. These customers are located in seven states including the entire state of Tennessee and parts of Alabama, Georgia, Kentucky, Mississippi, North Carolina and Virginia. TVA also serves directly 49 industrial customers with large or unusual power requirements and several Federal installations including uranium enrichment plants located at Oak Ridge, Tennessee and Paducah, Kentucky.

A unique advantage of using the system presented here for utility planning is its overall view of the entire energy system as opposed to an analysis limited exclusively to the electric sector. This systems approach allows a utility to assess the impact of alternative technologies and policies across the entire energy system. Recent electric utility forecasts of future energy requirements have been reduced from what they were in the 1972 to 1973 time period. Higher energy prices, depressed economic conditions and conservation have all been contributing factors to the low energy growth recently experienced. These factors have added a considerable degree of uncertainty to future projections. Traditionally, utilities have depended upon historical trends in forecasting future loads, but this method is rapidly being replaced by more sophisticated techniques using econometrics and detailed engineering analyses of demands. A systems approach using the latter technique is being applied in this study to project requirements for fuel and electric power. Demand patterns for twenty-five end-use demand categories within the residential, commercial, industrial and transportation sectors are developed for a base case scenario representing reasonable energy use patterns derived in a consistent manner by applying engineering techniques to the best available information. Demand for electric power is then obtained from the summation of electric demands over all other demand categories.

Fundamental to the proper use of information contained in this report is recognition that data presented here are base-line projections and must <u>not</u> be construed as predictions of the future. These projections are not forecasts of what "will be", but are intended to be used for technology assessments. They are reference projections in the sense that new technologies are not included in the projections. This does not imply that new technologies such as the electric car will not be prevalent by the year 2000, but it allows these new technologies to enter the system in some predetermined fashion. The impact of a new technology in terms of resource consumption may be evaluated by modifying the energy flow paths to incorporate the new technology.(1) Alternate paths through the network reflect the substitutability of resources and technologies for one another.

ENERGY DEMAND IN THE TVA REGION - METHODOLOGY

Residential Sector

Demand for energy in the residential sector is disaggregated into space heating, water heating, air conditioning, cooking, appliances and lighting. Energy requirements for space heating in the TVA region consumed 59% of the energy in the residential sector in 1975. The delivered energy to space heating appearing in the Reference Energy System between the column headings DECENTRALIZED CONVERSION and UTILIZING DEVICE is computed from the energy demand per household (42×10^6 Btu/Households), the number of households, (2025×10^3 Households), and the market penetration for space heating in the TVA region (100%). The basic energy demand for space heating, appearing in the RES under the column heading DEMAND CATEGORY, is computed as the product of the delivered energy and the end-use device efficiency. The basic energy demand represents the net energy required to provide a given level of services, for example, to maintain room temperature at 72°F.

The residential housing stock is classified into five distinct building types: mobile homes, single-family detached, single-family attached, multi-family low rise and multi-family high rise. Energy requirements for space heating vary from 9.9×10^6 Btu/household for multi-family high rise units to 45.8×10^6 Btu/household for single-family detached units. This variation in heating requirements is due to such factors as outside wall exposure and construction practices. The population in the TVA region is projected to increase from 6,290,000 in 1975 to 7,919,000 in the year 2000. The number of households is projected to increase from 2,025,000 in 1975 to 3,168,000 in the year 2000. These projections of population and households imply a continuation of the decrease in the number of persons per household that has been occurring historically.

The proportion of households in the region using electricity to meet their space heating requirements is projected to increase from 43% in 1975 to 62% in 2000. This includes 435,000 households projected to have electric heat pumps in 2000 versus 60,000 in 1975. The proportion of households using natural gas, oil, coal, wood and LPG to meet their energy requirements for space heating is projected to decrease as these fuels are replaced by electricity. The low cost of electricity and the relatively moderate climate in the region explains the continued reliance on electricity for space heating. The average residential customer paid 2.26 cents per kilowatt-hour for electricity in 1976 compared to a national average of 3.3 cents per kilowatt-hour.

Energy requirements for air conditioning vary regionally with temperature, humidity and cloud cover. Equivalent full load operating hours is a measure of air conditioning energy requirements that reflects these meteorological variables. Average annual unit energy requirements for air conditioners in the U.S. are 1390 kWh for room units and 3560 kWh for central units. Increasing these unit energy demands by the ratio of operating hours in the TVA region (1200 hours) to operating hours in the U.S. (1000 hours) results in an annual electric demand in the region of 1668 kWh per unit for room air conditioners and 4272 kWh per unit for central air conditioners. The basic energy demands derived for 1975 are escalated in proportion to the market saturation and the number of households projected in the reference years. Virtually all homes are projected to have air conditioning by the year 2000, with central air conditioning dominating the market.

Energy requirements for domestic hot water heating are computed from the energy demand per household (19.2×10^6 Btu/household), the market penetration of water heaters (90%), and the number of households in the region. Sixty-two percent of the households in 1975 used electricity to meet their energy requirements for domestic hot water. Electric hot water heating is projected to continue dominating the market such that over three-quarters of the households use electricity to meet their domestic hot water energy requirements by 2000. Energy requirements for cooking in the residential sector are computed from the energy demand per household (3.9×10^6 Btu/household) and the number of households in the TVA region. Seventy-seven percent of the households in the TVA region had electric ranges in 1975. Electric ranges are projected to continue dominating the market such that the year 2000 virtually all households have electric ranges. The residential lighting and appliance category accounts for energy consumed by refrigerators, dishwashers, electric dryers, gas dryers, televisions, food freezers, clothes washers, lighting and miscellaneous small appliances. To allow for the introduction of new electrical devices not yet in use, it is assumed that these devices will consume as much energy in 2000 as small appliances per household did in 1970, 1.6×10^6 Btu per household.

Commercial Sector

The commercial sector incorporates a wide range of activities which for the purposes of this study are disaggregated into two broad categories: 1) buildings and 2) agriculture and mining. A methodology analogous to the one followed in the residential sector is used to compute energy consumption in commercial buildings. Energy is consumed in commercial buildings for space conditioning, water heating, cooking, lighting, refrigeration, computers and other electrical appliances. Commercial buildings serve a broad range of functions which include: retail stores, warehouses, offices, service stations, educational buildings, hospitals, government buildings, churches, passenger and freight terminals, hotels, and other miscellaneous buildings. These buildings have widely varying energy requirements, but in order to develop unit energy requirements for the commercial inventory in a consistent fashion the following building definitions were established: office buildings, retail buildings, schools, hospitals, and other.

The commercial inventory in the TVA region was 680 million square feet in 1975 and is projected to 1980, 1985 and 2000 in proportion to output in the services sector from the Brookhaven National Laboratory input-output model, adjusted by regional earnings. The following methodology is used to project the commercial inventory in the region. First, exogenously specified fuel prices, capital costs and GNP are input into the Data Resources Incorporated (DRI) 10 sector general equilibrium macroeconomic model. Then, using aggregate economic and energy estimates from the DRI model, the BNL input-output model solves for energy service levels and output in each of the 110 sectors.(2) The commercial inventory in the TVA region is then calculated from U.S. output in the services sector from the I/O model, adjusted by regional earnings as follows:

$$\frac{(\text{OUTPUT})_t}{(\text{OUTPUT})_{1975}} \times [\text{EARNINGS RATIO}]_t \times \left[\begin{matrix}\text{TVA COMMERCIAL}\\ \text{INVENTORY}\end{matrix}\right]_{1975}$$

where, OUTPUT = Dollars of output in the services sector from the I/O model for the U.S.

t = Projection year -- 1980, 1985, 2000

The regional adjustment or "Earnings Ratio" is computed as the ratio of projected regional earnings in the commercial sector to projected U.S. earnings in the commercial sector, normalized to 1970 as follows:

$$[\text{EARNINGS RATIO}]_t = \left[\left(\frac{E_{TVA}}{E_{U.S.}}\right)_t \bigg/ \left(\frac{E_{TVA}}{E_{U.S.}}\right)_{1970}\right]$$

where, E = Earnings in the commercial sector.

t = Projection year — 1980, 1985, 2000.

Earnings projections for the U.S. and by state are from the 1972 OBERS Projections of Regional Economic Activity in the U.S.(6) developed by the Bureau of Economic Analysis for the Water Resources Council. These projections are based on the 1972 Series E population projections from the Bureau of the Census. Earnings in the TVA region are derived from earnings in each of the states by assuming earnings is proportional to population.

Energy requirements for space heating in commercial buildings is proportional to population weighted heating degree days in the region and is derived from unit energy demands for the five building categories. The average unit energy requirement for space heating in the commercial sector is 23,000 Btu/sq ft. The mix of fuels satisfying this demand was estimated relative to the mix of fuels for residential space heating. Over one-half of the energy requirements for space heating in commercial buildings is projected to be met by electricity by 2000 compared to an estimated 25% in 1975. Electric heat pumps are projected to meet the demand for space conditioning in an estimated 200 million square feet of commercial buildings by the year 2000, reducing the demand for electricity in those buildings by a factor of over one-third relative to conventional heating. The fraction of the commercial inventory heated by natural gas, fuel oil, LPG, coal and wood is projected to decrease over the reference years.

The energy requirement for air conditioning in commercial buildings is proportional to equivalent full load operating hours in the TVA region and is computed from a unit energy demand of 53,500 Btu per square foot for air conditioning in commercial buildings. This unit demand is in terms of basic energy demand and must be divided by the coefficient of performance to obtain delivered electricity. The energy requirement for water heating in commercial buildings is a function of the unit energy demand for water heating and the commercial inventory. The mix of fuels satisfying this demand is estimated relative to residential water heating, with electricity projected to dominate the market over the next twenty-five years. Energy demand for commercial cooking is a function of the number of meals served and the energy required to cook a meal. The energy required to cook a meal is assumed to be 75% of the energy demand in the residential sector. The number of meals served is proportional to the population and the fraction of all meals eaten in commercial establishments. In 1975 an estimated 20% of all meals were eaten in commercial establishments and this is projected to increase to 25% by the year 2000.

The energy demand in commercial buildings for lighting, refrigeration, HVA/C auxiliary equipment, and miscellaneous electrical appliances including computers is computed as a function of the unit energy demands in these categories. The consumption of electricity by refrigeration equipment and miscellaneous electrical appliances including computers is projected to increase by a factor of two by the year 2000.

Agricultural uses of energy associated with growing crops and raising livestock are currently estimated to be 2014 trillion Btu's in the U.S. Energy consumption associated with the marketing, distribution and processing of foods as well as energy consumed by farmers for residential uses is not accounted for in this estimate. Included in this estimate are the contributions to energy consumption by such activities as plowing, planting, irrigation, harvesting and crop drying in addition to such indirect energy uses as fertilizer and pesticide production. The basic energy demand derived for agriculture is escalated in proportion to projected output in the agriculture sector of the BNL input-output model for the U.S., adjusted by regional earnings.

Mineral industries in the TVA region are primaily engaged in the mining of bituminous coal and lignite, the non-ferrous metal ores bauxite and zinc, and the mining and quarrying of the nonmetallic minerals stone, clay and phosphate rock. Consumption of energy in the TVA region is derived from value added for these mineral industries and is escalated in proportion to projected output in the mining sector of the BNL input-output model, adjusted by regional earnings.

Industrial Sector

The industrial sector has been disaggregated into several major energy intensive industries including aluminium, steel, petrochemicals and uranium enrichment; remaining industrial energy requirements (excluding petroleum refining) are included in the demand categories industrial process heat and industrial electric drive. Consumption of fuels in these demand categories is initially projected in proportion to industrial activity in the U.S.,and then regionalized based on earnings in manufacturing. This methodology is analogous to that followed in the commercial sector.

Electric power is the major form of energy used to produce primary aluminum and is required in the electrolysis of alumina. The electrolytic efficiency of this process is based on a minimum theoretical requirement of 27.3 million Btu per ton. Oxidation of carbon at the anode is accounted for in the losses to coal. Secondary recovery from scrap is less energy intensive than primary production and is projected to represent a growing share of the market. This is expected to increase from 20% of total production in 1975 to 33% by the year 2000, thus decreasing energy consumption per pound of aluminum produced. It is estimated that 1144 million pounds of primary aluminum was produced in 1975 at the four major plants located in the region. In addition to primary production, 289 million pounds of aluminum were produced from scrap.

From an ad hoc survey of the major steel producers in the TVA region and plant capacity data pubished by the American Iron and Steel Institute, it has been estimated that 383,400 tons of steel were produced in 1975 using the electric furnace. Considering the low cost of electricity, the lack of blast furnaces to produce pig iron, and the minor role of the steel industry in the region, the electric furnace is projected to continue dominating the steelmaking process in the TVA area. Scrap metal is the primary raw material used in the electric furnace with essentially no pig iron required. Requirements for electric power in the electric furnace are 675 kilowatt-hours per ton of steel produced.

Hydrocarbons derived from natural gas and crude oil, including natural gas itself, natural gas liquids, naphtha and refinery gas serve as the raw material basis for production of most organic chemicals. Coal and coal tar are still used as a raw material in the production of certain aromatic compounds. Historically, the mix of raw materials supplying the chemical industry has shifted from coal to oil and gas. This trend is not expected to continue as coal becomes more readily available relative to oil and gas. Regional demand for hydrocarbons as a petrochemical feedstock in 1975 are assumed to be proportional to value added in the chemicals and allied products industry (SIC-28). The mix of resources supplying the petrochemical industry is assumed to be proportional to the mix of resources in the east south central census region.[(9)] Demand for petrochemical feedstocks is escalated in proportion to projected output in the chemicals and allied products sector of the BNL input-output model for the U.S., adjusted by regional earnings in SIC-28.

The Tennessee Valley Authority supplied almost 22 billion kilowatt-hours of electricity in 1975 to the two federally operated gaseous diffusion uranium enrichment plants located in Paducah, Kentucky and Oak Ridge, Tennessee. Sales to these federal agencies are projected to increase by almost a factor of two, to 40 billion kilowatt-hours by 1980, and then level off at that demand through the year 2000.[(12)] Electricity sales to industry by TVA include sales to muncipalities, cooperatives, and sales directly served to industry. Electricity sales to industry are escalated to the year 2000 from data provided by TVA.

All energy used for fuel in the industrial sector which is not consumed in the aluminum, steel, petrochemical, uranium enrichment or petroleum refining industries is accounted for in the category industrial process heat. To estimate demand for energy in this category overall energy requirements by industry are initially estimated. Industrial process heat then represents the balance of unaccounted fuels in the industrial sector after all other end uses are accounted for. Total energy requirements in the industrial sector are assumed to be proportional to regional value added in manufacturing. Thus,

$$(\text{ENERGY})_{\text{TVA}} = \left(\frac{\text{ENERGY}}{\text{VA}}\right)_{\text{ESC}} \times (\text{VA})_{\text{TVA}}$$

$$\text{and, } (\text{VA})_{\text{TVA}} = \sum_i (\text{VA}_i \times \text{POP}_i^{\text{TVA}}/\text{POP}_i)$$

where, ENERGY = Industrial energy consumption
VA = Dollars of value added in manufacturing
POP_i = Population in county i
i = Counties in the TVA region.

POP_i^{TVA} equals the population in county i that is serviced by TVA and is estimated from Bureau of the Census data. The ratio of industrial energy consumption per dollar of value added in manufacturing in the east south central census region, $(ENERGY/VA)_{ESC}$, is assumed to approximate energy consumption per dollar of value added in the TVA region.

Energy consumed in the industrial process heat category is escalated at an annual growth rate of 4.8% from 1975 to 1980, 3.4% from 1980 to 1985 and 3.2% thereafter. This growth rate is derived from (1) the historical ratio of U.S. energy consumption in the industrial sector to gross national product (GNP) and (2) the ratio of TVA to U.S. earnings in manufacturing in the projected year divided by the ratio of TVA to U.S. earnings in 1970. Energy consumed in the industrial sector in the U.S. between 1960 and 1972 grew at 2.0% per year, whereas GNP grew at 3.4% per year over the same period (see Figure III). The ratio of industrial energy consumption to GNP (in constant dollars) has been declining over time and is projected to continue declining through 2000. A least squares fit to Energy-GNP data over the period 1960-1972 results in the following equation:

$$(\text{ENERGY/GNP})_t = (\text{ENERGY/GNP})_{1960} + M(t - 1960)$$

where, $(ENERGY/GNP)_{1960}$ = 32,453 Btu/\$GNP
M = -241 Btu/\$GNP per year
t = 1960,...,1972

Thus, if it is assumed that the ratio of industrial energy consumption to GNP continues to decline as it has since 1960, at the rate of 241 Btu per dollar of GNP per year, then the following equation can be used to project the ENERGY/GNP ratio in 1980, 1985 and 2000:

$$(\text{ENERGY/GNP})_t = 32{,}453 \text{ Btu/\$GNP} - \frac{241 \text{ Btu/\$GNP}}{\text{Year}}(t-1960)$$

where, t = 1980,...,2000

Since GNP is projected to increase at an annual rate of 3.2% over the 1975 to 2000 time period, the level of energy consumption by industry in the U.S. can be projected to time period "t" using the following equation:

$$(\text{ENERGY})_t = (\text{ENERGY/GNP})_t \times (\text{GNP})_t$$

Values of energy, GNP, and the energy/GNP ratio are listed in Table I for the years 1975, 1980, 1985, and 2000.

Projections of energy consumption for industrial process heat in the TVA region are derived from national projections, adjusted by regional earnings in manufacturing. Demand for energy by industry in the U.S. is projected to increase at an annual rate of 2.6% over the reference years compared to 3.6% in the TVA region. This regional variation in the demand for energy reflects the increasing proportion of earnings projected to orginate in the region by the year 2000. Earnings in manufacturing is projected to increase at an annual rate of 3.1% in the U.S. compared to 3.9% in the TVA region.

Transportation Sector

In 1975 the automobile consumed 52% of the energy in the transportation sector compared to 31% projected for 2000, reflecting improved automobile fuel economy and market saturation. The total number of automobiles in the region is computed as a function of the number of vehicles per driving age population in each state and the state population serviced by TVA. The number of vehicles per driving age population is derived from the total number of registrations in each state and the state's population 16 years of age and older. The number of vehicles per driving age population in the region was .61 in 1975, the same as the national average. The number of registered vehicles has historically been an increasing proportion of the driving age population. This trend is not expected to continue as the market becomes saturated. It is projected that by the year 2000 85% of the population over 16 years of age will own automobiles. A constant value of 10,800 miles per vehicle is multiplied by the number of vehicles in calculating annual vehicle-miles traveled (VMT). This is a national average from the FHWA, adjusted by R. L. Polk data. Automobile gasoline consumption is computed as a function of VMT's and the fleet average fuel economy. The fleet average fuel economy is derived for each reference year on the basis of the mix of model years on the road, the distribution of vehicle-miles with age of auto, and the fuel efficiency per model year as follows:

$$\text{COMPOSITE FUEL EFFICIENCY IN YEAR } t = [\text{TOTAL VEHICLE-MILES/TOTAL FUEL REQUIREMENTS}]_t$$

where, $[\text{TOTAL FUEL REQUIREMENTS}]_t =$

$$\sum_{m=t-10}^{t} \left[\frac{\left(\frac{\text{miles}}{\text{vehicle}}\right)_m \times (\text{Fraction of Total Vehicles})_m}{(\text{Fuel Economy})_m} \right] \times (\text{Total vehicles})$$

m = Model year
t = Projection year -- 1980, 1985, 2000

Fuel economy per model year is assumed to be 10% lower than specified in the Energy Policy and Conservation Act because of typically observed nonoptimum engine performance in older model vehicles. The fleet average fuel economy projected for 1980, 1985 and 2000 is 14.9 mpg, 19.3 mpg, and 25 mpg, respectively.

The truck and bus category includes all gasoline and diesel fuel not consumed by automobiles; marine and aviation consumption of gasoline is included in ship and air transport, respectively. Thus gasoline and diesel fuel consumed by agricultural, construction, and miscellaneous equipment is included in the truck and bus category. Trucks are by far the largest energy consumer in this category, with buses using less than 5% of the fuel consumed. Trucking activity is subdivided into two classes--freight trucking includes all trucks over 10,000 lbs gross vehicle weight (GVW) and non- freight trucking includes all trucks under 10,000 lbs GVW. Freight trucking activity is measured in terms of ton-miles and the fuel economy of these vehicles is measured in terms of Btu's per ton-mile. Non-freight trucking activity is measured in terms of truck-miles and their fuel economy is measured in terms of Btu's per truck-mile. The number of trucks in the TVA region is estimated from the total number of trucks in each state and the fraction of the population in that state which is serviced by TVA. Gasoline and diesel fuel consumption is then computed as a function of regional trucking activity and the energy intensiveness of the trucks (see Tables II and III). Passenger-miles for local, intercity and school buses are estimated in proportion to the population.

Historicaly, freight trucking activity in the U.S. has increased in proportion to GNP, and this trend is projected to continue through the year 2000 with GNP growing at an annual rate of 3.2%. Regional freight trucking activity in 1980, 1985 and 2000 is derived from U.S. projections based on regional earnings. Freight trucking activity in the TVA region is projected to increase at an annual rate of 4.2%, from 16 billion ton-miles in 1975 to 45 billion ton-miles in the year 2000. Nonfreight trucking activity in the TVA region is projected to increase at an annual rate of 5.1%, from 9 billion truck-miles in 1975 to 31 billion truck-miles in the year 2000. Projections of demand for gasoline and diesel fuel are based on a 25% improvement in the fuel economy of all trucks. This efficiency improvement includes the fuel savings derived from the projected changeover to diesel engines. In 1975 23% of the motor fuel consumed by trucks and buses was in the form of diesel fuel compared to 69% projected for the year 2000.

Consumption of jet fuel and aviation gasoline by both commercial air carriers and general aviation is accounted for in this demand category. Demand for jet fuel and aviation gasoline in 1975 was determined for the state of Tennessee from published data. Consumption of jet fuel and aviation gasoline in the TVA region, excluding Tennessee, was estimated from a survey of the commercial airports serving the area. Air passenger-miles were then derived from the estimated fuel consumed in the region in 1975, given an average energy intensity for air transportation in the U.S. of 8698 Btu's per passenger-mile. Projected energy consumption is computed from Air Transportation Association of America projections of U.S. domestic and international air passenger-miles adjusted by regional earnings. Air passenger miles in the TVA region are projected to increase from 2200 million passenger-miles in 1975 to 10,700 million passenger-miles in the year 2000, at an annual rate of 6.5%.

Consumption of diesel fuel by railroads is computed as a function of rail transport activity, measured in terms of ton-miles, and the energy intensiveness of the railroads, measured in terms of Btu's per ton-mile. Demand for fuel oil by commercial shipping in 1975 is computed from the demand for fuel oil by ships in the state of

Tennessee, inflated by the population in the TVA region relative to the population in Tennessee. Regional energy demands for commercial shipping are derived from Tennessee data only rather than from the energy usage in each state because of the disproportionate share of port facilities in the states of Alabama and Mississippi.

ENERGY SUPPLIES

Nuclear power and coal are projected to play a major role in satisfying the nation's demand for electric power over the remainder of this century. The U.S. Bureau of Mines estimates that 219 billion tons of coal are economically recoverable from a demonstrated coal reserve of twice that amount. Demand for coal is expected to reach one billion tons in 1985 and two billion tons by 2000 compared to a demand in the U.S. of 640 million tons in 1975. In developing a projection of coal mining in the TVA region the results of the National Coal Assessment study were applied in estimating production levels for 1980, 1985 and 2000. It is assumed that coal production in the TVA region will increase at the same rate as forecast for the Interior Appalachia region from the "Recent Trends" scenario in the National Coal Assessment. This results in a 3.5% growth rate from 1975 to 1985 and a 1.8% growth rate thereafter and compares favorably with the projections for Appalachia contained in the National Energy Outlook. Coal production within the region was 27 million tons in 1975 and was computed from data for individual counties within the TVA region.

The Tennessee Valley Authority has traditionally depended upon hydroelectric power and coal to meet its power requirements. Electricity generated from nuclear plants is playing an increasing role in meeting the systems demand for base load electric power with gas turbines and pumped storage being used to meet the systems demand for peak power. Electricity generated from coal-steam plants met 72% of the demand for electric power in 1975, hydroelectric power satisfied 20% of the demand, and electricity generated from nuclear power and gas turbine peaking units met the remainder of the load. The generation mix shown in Table IV assumes interchange deliveries and receipts net to zero and that all of the power sold by TVA is generated within the system. Electricity sales totaled 381 trillion Btu's or 112 billion kilowatt-hours in 1975, remaining approximately constant since 1973. This trend is similar to that experienced by many other utilities across the nation since the Arab oil embargo. Recent electric utility forecasts of future energy requirements have been reduced from what they were in the 1972 to 1973 time period. Higher energy prices, depressed economic conditions, and the "conservation ethic" have all been contributing factors to the low energy growth recently experienced. These factors have added a considerable degree of uncertainty to future projections. Traditionally, utilities have depended upon historical trends in forecasting future loads, but this method is rapidly being replaced by more sophisticated techniques using econometrics and detailed engineering analyses of demands. A systems approach using the latter technique is being applied in this study to project requirements for electric power. More specifically, demand for electric power is obtained from the summation of electric demands in 1980, 1985, and 2000 over all other demand categories, adjusted to include transmission, distribution and pumped storage losses.

System generating capacity in service, under construction or planned as of June 30, 1976 is shown in Table V for the Tennessee Valley Authority. The mix of capacity additions projected for 1985 results in a generation mix of 34% coal-steam and 56% nuclear-steam with the remainder of the load being met by hydro, pumped storage and and gas turbine peaking units. No capacity additions to hydropower are planned after 1980 and the electricity generated from hydro is projected to remain constant at the 1980 level over the reference years. Pumped storage is projected to play an increasing role in meeting the systems demand for peak power with four units totaling 1530 Mw expected to be operational within one year and 5430Mw projected to be on line by the year 2000. No additional gas turbine peaking units are planned after 1980. Coal continues to be an important fuel in meeting TVA's energy requirements, although nuclear power dominates the schedule of planned additions over the next ten years.

ACKNOWLEDGEMENT

The author wishes to express his appreciation to the many people at the Tennessee Valley Authority who have provided data for this study. Special thanks are owed to Ms. Joanne Swanson and Dr. Philip Kazemersky of TVA's Energy Research Group for successfully coordinating the TVA data gathering effort. Dr. Lynn Maxwell of the Division of Power Utilization has been invaluably helpful in providing electric power demand projections for the region. The Division of Power Resource Planning ably provided power supply projections for the TVA service area.

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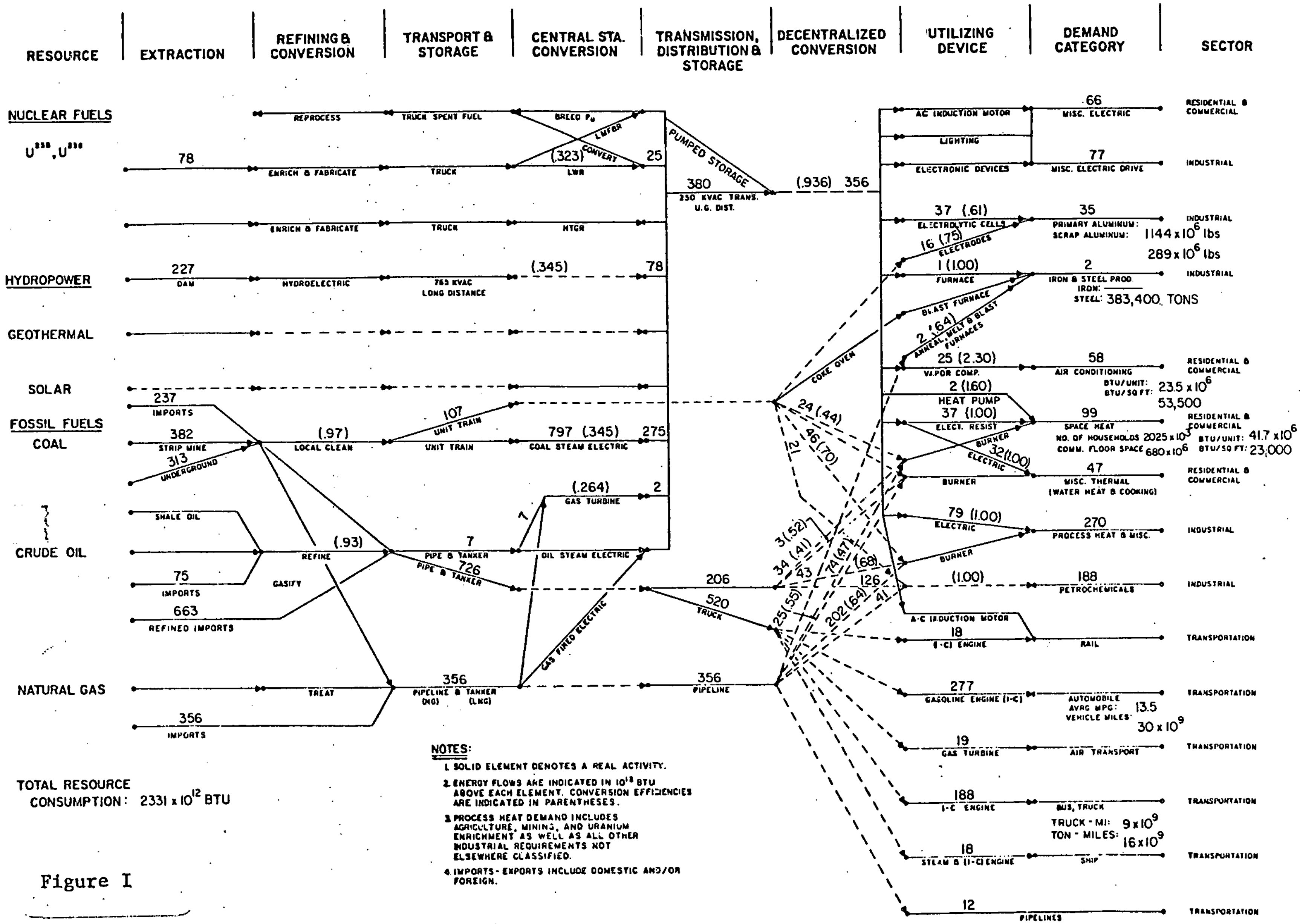
TENNESSEE VALLEY AUTHORITY REFERENCE ENERGY SYSTEM, YEAR 1975



TOTAL RESOURCE CONSUMPTION: 2331×10^{12} BTU

NOTES:

1. SOLID ELEMENT DENOTES A REAL ACTIVITY.
2. ENERGY FLOWS ARE INDICATED IN 10^{12} BTU ABOVE EACH ELEMENT. CONVERSION EFFICIENCIES ARE INDICATED IN PARENTHESES.
3. PROCESS HEAT DEMAND INCLUDES AGRICULTURE, MINING, AND URANIUM ENRICHMENT AS WELL AS ALL OTHER INDUSTRIAL REQUIREMENTS NOT ELSEWHERE CLASSIFIED.
4. IMPORTS - EXPORTS INCLUDE DOMESTIC AND/OR FOREIGN.

Figure I

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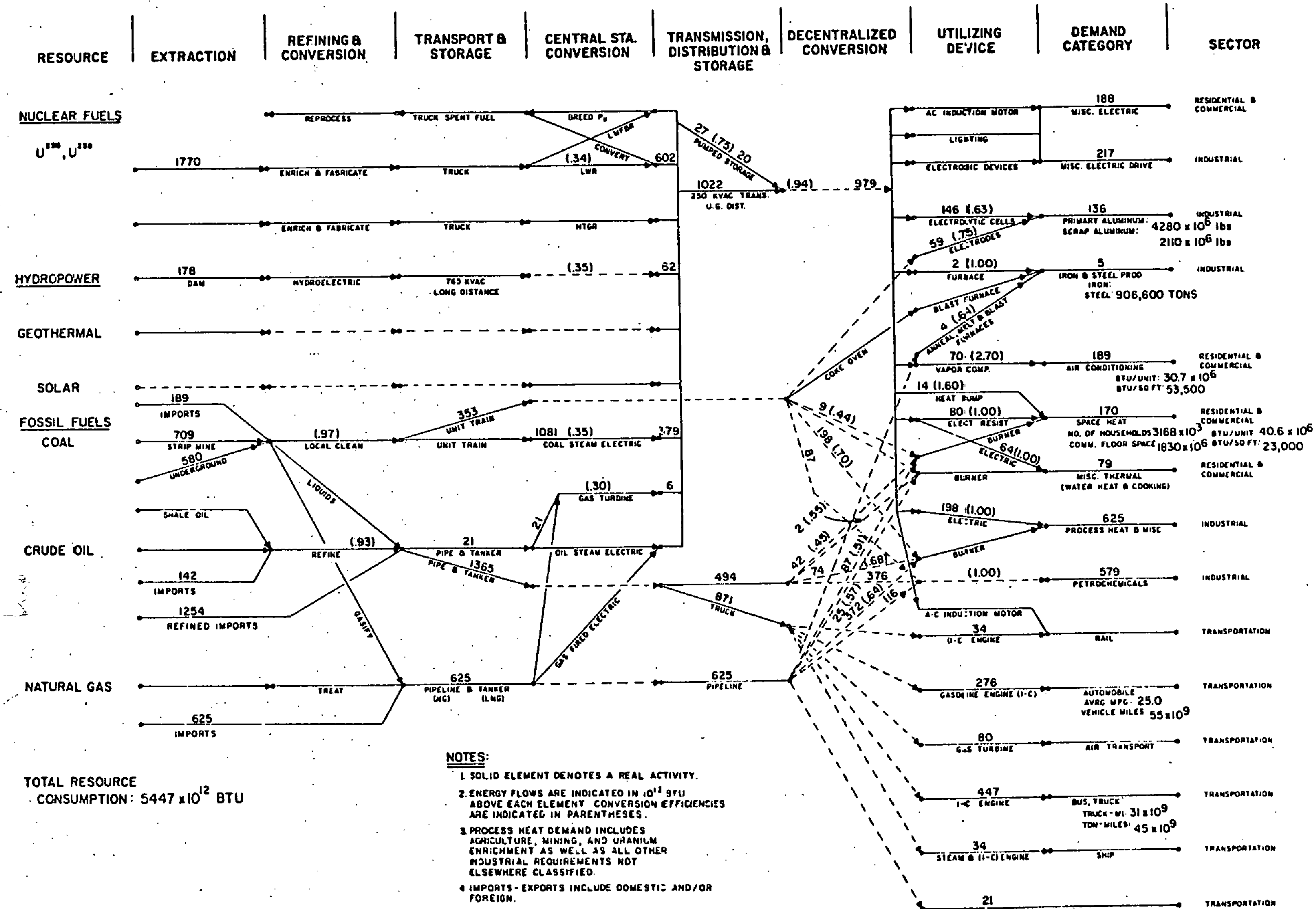
TENNESSEE VALLEY AUTHORITY REFERENCE ENERGY SYSTEM, YEAR 2000



NOTES:

1. SOLID ELEMENT DENOTES A REAL ACTIVITY.
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3. PROCESS HEAT DEMAND INCLUDES AGRICULTURE, MINING, AND URANIUM ENRICHMENT AS WELL AS ALL OTHER INDUSTRIAL REQUIREMENTS NOT ELSEWHERE CLASSIFIED.
4. IMPORTS-EXPORTS INCLUDE DOMESTIC AND/OR FOREIGN.

Figure II

4-869-78

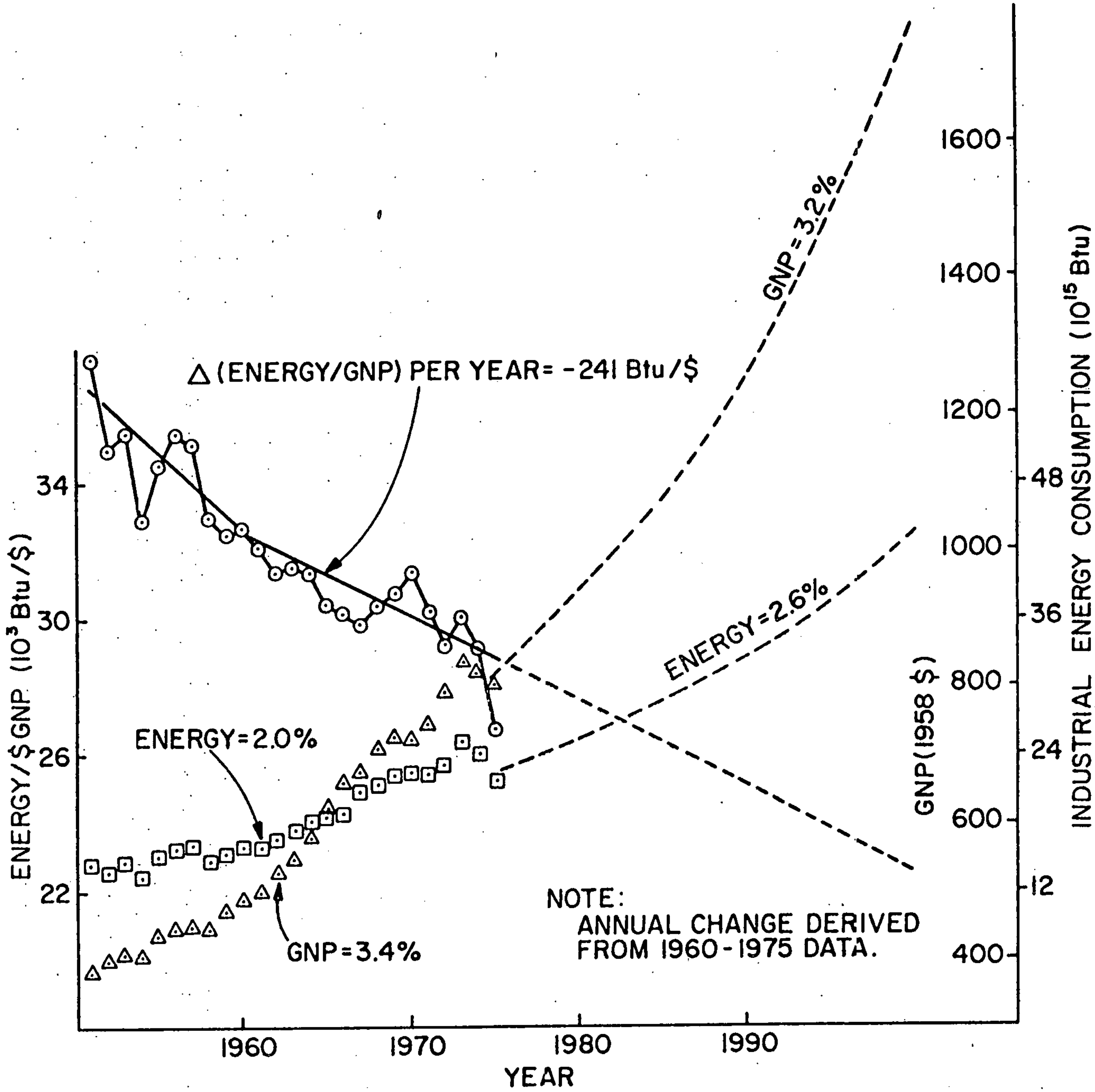

Figure III INDUSTRIAL ENERGY CONSUMPTION RELATIVE TO GNP, 1951-2000

6-193-78

TABLE I

INDUSTRIAL ENERGY CONSUMPTION VERSUS GNP IN THE UNITED STATES

Year	Industrial Use of Energy (10^{15} Btu)	GNP (Billions of 1958$)	Energy/GNP (10^3 Btu/$)
1975	21.5	816	26.3
1980	26.4	955	27.6
1985	29.5	1118	26.4
2000	40.9	1793	22.8
Rate of Change Per Year	2.6%	3.2%	-241

TABLE II

TVA MODAL TRANSPORTATION PROJECTIONS

(BILLIONS)

	1975	1980	1985	2000
Passenger-Miles				
Air	2.2	3.4	4.7	10.7
Local & Intercity Bus	1.4	1.9	2.2	3.9
School Bus	1.2	1.3	1.3	1.4
Ton-Miles				
Air	-	-	-	-
Truck (GVW over (10,000 lbs.)	16	20	25	45
Ship	25	29	33	47
Rail	26	30	34	48
Truck-Miles				
Non-Freight Trucking	9	12	16	31

TABLE III

ENERGY INTENSIVENESS BY TRANSPORT MODE

Btu/Passenger-Mile				
Air	8698	7918	7431	7431
Local & Intercity Bus	1490	1490	1490	1490
School Bus	1704	1704	1704	1704
Btu/Ton-Mile				
Air	-	-	-	-
Truck (GVW over (10,000 lbs.)	4678	4444	4210	3509
Ship	567	567	567	567
Rail	709	709	709	709
Btu/Truck-Mile				
Non-Freight Trucking	12061 (10.4mpg)	11458 (10.9mpg)	10855 (11.5mpg)	9045 (13.8mpg)

TABLE IV

TVA ELECTRIC GENERATION - BY CENTRAL STATION POWER PLANT

	Heat Rate	Millions of KwH (Percent)			
	1975		1980	1985	2000
Coal-Steam	9,880 Btu/kWh	80,602 (72%)	94,679 (58%)	66,429 (34%)	110,827 (35%)
Nuclear-Steam	10,570 Btu/kWh	7,429 (7%)	46,962 (29%)	107,891 (56%)	176,360 (56 1/2%)
Hydroelectric	9,880 Btu/kWh	22,950 (20%)	18,276 (11%)	18,276 (9%)	18,276 (6%)
Oil-fired Gas Turbine	12,950 Btu/kWh	551 (1%)	2,393 (1%)	1,195 (1/2%)	1,846 (1/2%)
Pumped Storage	-	-	1,347 (1%)	1,209 (1/2%)	5,948 (2%)
Total	-	111,532	163,657	195,000	313,257

Table V

GENERATING CAPACITY ON JUNE 30, 1976

In Service

TVA Hydro Plants	*No. Units*	*Installed Capacity - kW*
Apalachia	2	78,900
Blue Ridge	1	20,000
Boone	3	75,000
Chatuge	1	10,000
Cherokee	4	129,300
Chickamauga	4	111,000
Douglas	4	115,000
Fontana	3	238,500
Fort Loudoun	4	135,590
Fort Patrick Henry	2	36,000
Great Falls	2	31,860
Guntersville	4	101,700
Hiwassee	2	117,100
Kentucky	5	175,000
Melton Hill	2	72,000
Nickajack	4	100,350
Norris	2	100,800
Nottely	1	15,000
Ocoee #1	5	18,000
Ocoee #2	2	21,000
Ocoee #3	1	28,800
Pickwick	6	220,040
South Holston	1	35,000
Tims Ford	1	45,000
Watauga	2	50,000
Watts Bar	5	153,300
Wheeler	11	356,400
Wilbur	4	10,700
Wilson	21	629,840
Total	109	3,231,180

TVA Coal-Fired Plants	*No. Units*	*Installed Capacity - kW*
Allen	3	990,000
Bull Run	1	950,000
Colbert	5	1,396,500
Cumberland	2	2,600,000
Gallatin	4	1,255,200
John Sevier	4	846,500
Johnsonville	10	1,485,200
Kingston	9	1,700,000
Paradise	3	2,558,200
Shawnee	10	1,750,000
Watts Bar	4	240,000
Widows Creek	8	1,977,985
Total	63	17,749,585

TVA Nuclear Plants	*No. Units*	*Installed Capacity - kW*
Browns Ferry	2	2,304,000

TVA Combustion Turbine Plants	*No. Units*	*Installed Capacity - kW*
Allen	20	620,800
Colbert	8	476,000
Gallatin	4	325,200
Johnsonville	16	1,088,000
Total	48	2,510,000
Alcoa Dams (12)		423,715
Corps of Engineers Dams (8)		853,000
Total System in Service		27,071,480

Under Construction or Planned

	No. Units	Installed Capacity - kW
Browns Ferry Nuclear Unit 3 Scheduled Commerical Operation—1977	1	1,152,000
Sequoyah Nuclear Scheduled Commercial Operation—1978-1979	2	2,441,160
Raccoon Mountain Pumped Storage Scheduled Commercial Operation—1978	4	1,530,000
Watts Bar Nuclear Scheduled Commercial Operation—1979-1980	2	2,539,800
Bellefonte Nuclear Scheduled Commercial Operation—1980-1981	2	2,664,000
Proposed Hartsville Nuclear Scheduled Commercial Operation—1983-1984	4	5,148,000
Proposed Phipps Bend Nuclear Scheduled Commercial Operation—1984-1985	2	2,574,000
Proposed Yellow Creek Nuclear Scheduled Commercial Operation—1985-1986	2	2,678,000
	19	20,726,960

Source: 1976 Power Annual Report, Tennessee Valley Authority.