Potential Growth of Nuclear and Coal Electricity Generation in the U.S.

August 1989

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

DISCLAIMER

This program was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor Battelle Memorial Institute, nor any of their employees, makes **any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.** Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government of any agency thereof, or Battelle Memorial Institute. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE MEMORIAL INSTITUTE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831;
prices available from (615) 576-8401. FTS 626-8401.

Available to the public from the National Technical Information Service,
U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.

NTIS Price Codes, Microfiche A01

Printed Copy

<u>Pages</u>	<u>Price Codes</u>
001-025	A02
026-050	A03
051-075	A04
076-100	A05
101-125	A06
126-150	A07
151-175	A08
176-200	A09
201-225	A10
226-250	A11
251-275	A12
276-300	A13

POTENTIAL GROWTH OF NUCLEAR
AND COAL ELECTRICITY
GENERATION IN THE U.S.

C. H. Bloomster
E. T. Merrill

August 1989

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RL0 1830

Pacific Northwest Laboratory
Richland, Washington 99352

ABSTRACT

Electricity demand should continue to grow at about the same rate as GNP, creating a need for large amounts of new generating capacity over the next fifty years. Only coal and nuclear at this time have the abundant domestic resources and assured technology to meet this need. However, large increase in both coal and nuclear usage will require solutions to many of the problems that now deter their increased usage. For coal, the problems center around the safety and environmental impacts of increased coal mining and coal combustion. For nuclear, the problems center around reactor safety, radioactive waste disposal, financial risk, and nuclear materials safeguards.

This report assesses the impacts associated with a range of projected growth rates in electricity demand over the next 50 years. The resource requirements and waste generation resulting from pursuing the coal and nuclear fuel options to meet the projected growth rates are estimated. The fuel requirements and waste generation for coal plants are orders of magnitude greater than for nuclear. Improvements in technology and waste management practices must be pursued to mitigate environmental and safety concerns about electricity generation from both options.

EXECUTIVE SUMMARY

The growing demand for electricity in the United States will create a huge need for new generating capacity (Figure S.1). The long-term growth rate in electricity demand nationwide is projected by many sources to be between 1.5% and 3.5% per year. A growth rate near 2.5% appears to be the consensus. This study explores the long term implications of these growth rates. For instance, the 2.5% growth rate generates a cumulative need for nearly 2000 GW of new capacity (about three times existing capacity) over the next 50 years. Of this, about 1200 GW is needed to meet baseload.

For perspective, 1200 GW is equivalent to about 1000 large nuclear power plants or 2000 large coal-fired powerplants. That averages to 20-40 new large power plants per year. Only the coal and nuclear options have the abundant domestic resources and assured technology at this time to meet this large a need for baseload capacity. Oil and natural gas probably have sufficient resources, but oil imports are already large and gas is

FIGURE S.1. Growth in Electricity Demand will Create a Huge Need for New Generating Capacity

expected to be more costly and more valuable for uses other than baseload generation. Other electricity generation technologies either do not have sufficient resources or require technological breakthroughs to become competitive on a large scale.

The need for new baseload capacity at the 2.5% growth rate could be entirely met by either coal or nuclear. However, if all of this new baseload capacity is supplied by coal, today's environmental concerns about acid rain, the greenhouse effect, and other impacts from coal combustion would be increased about five-fold. Thus, the need for clean coal technologies is obvious and questions concerning the greenhouse effect need to be resolved soon. On the other hand, if all of the new baseload capacity is supplied by nuclear, then ten times as much new nuclear capacity must be built as exists today.

If the higher (3.5%) growth rate were to occur, the fuel and waste disposal requirements would be about twice that for the 2.5% growth rate. The all-coal and all-nuclear option for this growth rate might encounter supply problems because of the depletion of resources. For instance, the all-nuclear option would consume uranium equivalent to our entire domestic resources estimated to be recoverable at less than \$500 per pound U_3O_8 . This would undoubtedly lead to uranium conservation measures, such as the introduction of breeder reactors and Pu and U recycle, well before the end of the study period. The all-coal option would consume about half of the domestic coal reserves at the 3.5% growth rate.

Given these consequences, it is unlikely that baseload demand at a 2.5% or higher growth rate would be supplied by either all coal or all nuclear, but rather that the need would be jointly filled by both fuel types. In addition, other technologies, e.g. renewables and fusion, would be used to help meet demand, as they became competitive.

If the lower (1.5%) growth rate were to occur, the fuel and waste disposal requirements would be about half that for the 2.5% growth rate. However, even at this low growth rate, large amounts of new capacity are

required. An average of 18 GW/year of new capacity must be added between 2005 and 2015. This would increase to about 40 GW/year at the end of 50 years.

Besides growth, the need for new generating capacity is increased by the need to replace obsolete capacity. In 1988, there were 658 GW of installed capacity; most of this will need to be replaced over the next 50 years. The need to replace obsolete capacity is only about 1 GW/year today but should increase to over 20 GW/year by 2010.

As the demand for electricity continues to grow, the need for new power plants will become more evident than it is today. Coal and nuclear, which provide nearly three-fourths of current electricity generation, will be called on to meet most of the need for new capacity. However, large increases in both coal and nuclear usage will not be acceptable to society without solutions to many safety, environmental, and economic concerns. For coal, notable issues are acid rain, the greenhouse effect, acceptable emission limits, occupational health and safety, and mine reclamation. For nuclear, notable issues include reactor safety, radioactive waste disposal, financial risk, and liability limits. Resolution of these issues will require both technological improvements and institutional innovations. Given the long lead time for research and technology development, planning decisions must be undertaken now to assure that acceptable technology will be available to meet the future needs. Solving these problems should be approached with a sense of urgency. Today's surplus generating capacity will soon disappear.

World-wide use of nuclear power is increasing as other nations seek independence from imported fossil energy, increased cost competitiveness, and reduced environmental pollution. Many of the 31 nations that now have nuclear power plants in operation or under construction plan to increase their nuclear capacity. World nuclear capacity increased 4% in 1988 to 310 GW produced by 428 reactors. Nuclear energy now provides 20% of the world's electricity generation and over 50% of the electricity supply in some nations.

Most nations plan to build light water reactors, particularly the large PWR. The trend is toward larger units of standardized design; for instance, in France new plants will be 1400 MW PWRs with plans for 2000 MW later. Most foreign nations plan to reprocess spent fuel and recycle the U and Pu in light water reactors. Development of the breeder reactor is continuing in several nations, but widespread deployment appears to be at least 30 years away.

Increasing foreign nuclear usage should impact the domestic nuclear industry in several ways. First, increased resource depletion could lead to increased fuel costs and greater incentives for uranium and plutonium recycle and breeding. Second, greater activity and international competition should spur technological advances. Third, increased operating experience should lead to improved designs and operating procedures. Fourth, more widespread usage should lessen opposition and lead to acceptable solutions to current political and institutional issues. Fifth, an active global market should sustain modern, competitive production capabilities and supporting infrastructure.

The fuel consumption in a coal-fired power plant is roughly 100,000 times greater by weight than in a nuclear plant to generate the same amount of electricity. Nearly all of the coal converts into gaseous products of combustion, predominately CO_2 . Although CO_2 emissions are not presently regulated, atmospheric warming (the greenhouse effect) is a potential concern in the long-term. About 3 tons of CO_2 are produced for every ton of coal burned. Coal combustion also produces SO_2 and NO_x . SO_2 and NO_x emissions which contribute to acid rain are regulated now, and more stringent regulations may be imposed. In contrast, nuclear fission produces no CO_2 , no SO_2 , no NO_x , and a negligible quantity of gaseous emissions.

ACKNOWLEDGMENT

The authors gratefully acknowledge the study guidance and constructive reviews provided by Edward Mastal, Department of Energy, and Laurin Dodd, John Burnham, William Richmond, and Richard Nightingale of the Pacific Northwest Laboratory.

CONTENTS

ABSTRACT	iii
EXECUTIVE SUMMARY	v
ACKNOWLEDGMENT	ix
INTRODUCTION	1
FORECASTS OF ELECTRICITY DEMAND	3
SUMMARY	3
NATIONAL FORECASTS	3
FACTORS AFFECTING ELECTRICITY DEMAND	4
NERC FORECASTS TO 1996	7
REGIONAL FORECASTS	9
PROJECTIONS OF THE NEED FOR NEW GENERATING CAPACITY	11
SUMMARY	11
CAPACITY PLANNING	11
Peak Demand	11
Reserve Margin	12
Retirement of Obsolete Capacity	14
SCENARIOS FOR ESTIMATING LONG-TERM CAPACITY NEEDS	16
PEAK DEMAND PROJECTIONS TO 2037	16
TOTAL CAPACITY REQUIREMENTS	17
ANNUAL REQUIREMENTS FOR NEW CAPACITY	21
Planning Uncertainties	24
IMPORTANCE OF LONG-TERM AND NEAR-TERM PROJECTIONS	25
SUPPLY OPTIONS	27
GENERATION PATTERNS	27

CAPACITY	29
FUTURE SUPPLY OPTIONS	29
RESOURCE CONSUMPTION AND WASTE PRODUCT GENERATION	33
SUMMARY	33
INTRODUCTION	34
Nuclear and Coal Supply Scenarios	35
Comparison with EIA Projections.	36
CRITICAL RESOURCE REQUIREMENTS	36
Coal	37
U ₃ O ₈	38
Uranium Enrichment	39
Spent Fuel Disposal	40
Reprocessing	41
Potential Growth in Annual Fuel and Waste Disposal Requirements	41
FOREIGN NUCLEAR TRENDS	45
DISCUSSION AND CONCLUSIONS	49
REFERENCES	55
GLOSSARY	59
APPENDIX A - PROJECTIONS OF ELECTRICITY DEMAND	A.1
APPENDIX B - PROJECTIONS OF THE RATIO OF ELECTRICITY DEMAND GROWTH TO GNP GROWTH	B.1
APPENDIX C - NERC REGIONS	C.1
APPENDIX D - LOAD DURATION CURVES	D.1
APPENDIX E - CAPACITY PROJECTIONS	E.1
APPENDIX F - TABULATION OF RESOURCE CONSUMPTION AND WASTE GENERATION FOR THREE GROWTH SCENARIOS	F.1

APPENDIX G - FUEL CYCLE ASSUMPTIONS	G.1
APPENDIX H - NUCLEAR CONTRIBUTION BY NERC REGION IN 1986	H.1

FIGURES

1	Forecasts of Electricity Demand	4
2	Historic Growth in Electricity Consumption and Real GNP	5
3	Growth Rates of United States Electricity Use and GNP	6
4	Historic Residential Electricity Prices in Constant 1987 Dollars	7
5	Historic Growth of Electricity Demand and Generating Capacity	12
6	Variations in Annual National Peak Load and Energy Demand	13
7	Effect of Availability on Margins	15
8	Projected Peak Demand for Three Growth Rates	17
9	Capacity Requirements for Three Growth Scenarios	18
10	Incremental Capacity Requirement for Three Growth Scenarios	19
11	Cumulative Retirements of Obsolete Capacity for Selected Service Life Assumptions	20
12	Cumulative Need for New Baseload Capacity for Three Growth Scenarios	21
13	Annual Additions to U.S. Generating Capacity	22
14	Annual New Capacity Requirements in Selected Years for Three Scenarios	23
15	Annual Need for New Baseload Capacity in Selected Years for Three Scenarios	24
16	Electricity Generation by Fuel Type	27
17	Electricity Production by Fuel Type	28
18	Generating Capacity by Fuel Type	29

TABLES

1	NERC 1988 Forecasts for Selected Years	8
2	Projected Regional Growth Rates in Electricity Demand and Peak Load	10
3	Scenarios for Determining Capacity Requirements	16
4	Cumulative Incremental Need for New Capacity for Both Load Growth and Replacement of Obsolete Capacity for Selected Years	21
5	Coal Consumption Assuming all Future Additions to Base Load Capacity are Coal-Fired	33
6	Consumption of U ₃ O ₈ Assuming Nuclear Energy is used to Meet all Future Additions to Base Load Capacity	34
7	Cumulative Capacity in New Baseload Plants Required over Fifty Years for Alternative Growth Scenarios	35
8	Alternative Coal and Nuclear Supply Scenarios and Options	36
9	Consumption of U.S. Recoverable Coal Reserves Over the Next 50 Years	37
10	Consumption of U ₃ O ₈ Over the Next 50 Years	38
11	Year in which Existing Enrichment Capacity is Reached under Alternate Scenarios	40
12	Estimated Fuel Requirements and Waste Generation for Coal-Generated Electricity in 1987 and 2037	42
13	Estimated Fuel Cycle Requirements and Waste Generation for Nuclear-Generated Electricity in 1987 and 2037	43
14	Foreign Reprocessing Capacity	46

INTRODUCTION

The purposes of this report are: 1) to assess the potential range of future electricity demand in the United States by evaluating forecasts of electricity demand, 2) to derive estimates of the long-term need for new generating capacity, and 3) to evaluate the implications of meeting this need through alternative nuclear and coal supply scenarios.

We examine the potential demand for electricity over the next 50 years. A 50-year period was selected for several reasons: first, because of the long time required to deploy new generating technology; second, to provide a sufficient time span in which to consider the impacts of retiring most of the current capacity; and third, because nearly all power plants completed in the future will still be in operation. At least 20 years are required before new generating technology can be developed, demonstrated and deployed on a large scale. Most of the new power plants that will be brought on-line within the next ten years are now under construction. Decisions on large capacity additions for the following ten years must be made in the next ten years and must be based largely on proven or evolutionary technology. Therefore, the potential market for new generating technology is determined primarily by the need for new capacity after the next twenty years.

Assumptions about the future are necessary for today's business decisions and provide a basis for strategic planning. Long-term projections are important, but not in an absolute sense, since plans can be periodically revised. Long-range planning is required to efficiently and reliably meet projected demands at the lowest economic and social cost, particularly taking into consideration the long lead times required for technology development, siting, power plant construction, and licensing.

In this study our primary concern is with the aggregate need for new capacity in the U.S. over the long term. Historically, the national electricity demand is strongly related to the gross national product, which is used as a predictor in most forecasts. Although utilities plan and add capacity on a regional basis, there is much commonality between regions in the supply options and in the overall economic factors that determine demand.

The differences between regions in the supply options are primarily related to the transportation costs of fuel and the availability of indigenous economically-recoverable energy resources. A potential drawback to focusing on the aggregate need is that regional shortages may be masked in the short term, but since our perspective is on meeting long-term needs, temporary regional imbalances are not significant to our objectives.

The primary focus in this study is the need for baseload generating capacity. Baseload plants produce about 80% of the energy generated. Baseload capacity operates over extended periods of time without interruption. The remaining energy is generated by load-following plants which operate intermittently, usually cycling on a daily basis and by peaking plants which operate for short periods of time, hours or minutes, during the peak loads.

This report is organized in six sections. The first section, Forecasts of Electricity Demand, analyzes recent long-range forecasts and discusses the factors that affect electricity demand. The second section, Projections of the Need for New Generating Capacity, estimates the long-term needs for new capacity under three scenarios. The third section, Supply Options, discusses the current electricity supply and summarizes future options. The fourth section, Resource Consumption and Waste Generation, compares coal and nuclear fuel cycles currently and under the three long-term scenarios. A fifth section, Foreign Nuclear Trends summarizes nuclear trends abroad. In the sixth section, Discussion and Conclusions, the implications of the data and the various supply and demand scenarios are presented.

This report updates and expands upon a previous report on the long-term need for new generating capacity (BL 87). In the two years since the previous report, electricity demand, in response to the strong economy, has risen much more sharply than most forecasters had predicted.

FORECASTS OF ELECTRICITY DEMAND

SUMMARY

Nearly all sources forecast electricity demand to grow at an annual rate between 1.5% and 3.5%. Growth in electricity demand is closely tied to growth in the GNP. Forecasts of the ratio of growth in electricity demand to growth in the GNP range from 0.6 to 1.4 with an average of about unity. Long-range forecasts of GNP annual growth rates range from 2 to 3%.

Current 10-year utility planning is based on an average annual growth in summer peak demand of 1.9% and an average annual growth in generating capacity of 1.2%. This will reduce the reserve margin, on a nationwide basis, from a current value of 30% to 22% in 1997. Utility forecasts predict summer peak demand of 594 GW in 1997 and planned capacity of 728 GW. Most of this new capacity is currently under construction. Of the 85 GW of planned net capacity additions from 1988 through 1997, 15 GW will be supplied by coal units, 22 GW will be supplied by nuclear units, and 20 GW will be supplied by non-utility generators.

NATIONAL FORECASTS

Numerous forecasts of electricity demand are made each year (Appendix A). Most of the forecasts fall within a range of growth rates varying from 1.5% to 3.5% per year (Figure 1). The most recent forecasts range from 2.0 to 3.2% growth rates. These forecasts provide estimates of the probable bounds for electricity demand to year 2015. For comparison, these growth rates are projected to the year 2037 to illustrate the long term effect of a continuation of these growth rates.

Most of the forecasts are derived from imputed relationships between electricity demand and economic activity, primarily gross national product (GNP). Recent forecasts of the ratio of electricity demand growth to GNP growth (Appendix B, Table B.1) range from 0.58 to 1.35 with the mean and median being slightly less than 1.00. Recent forecasts of annual GNP growth rates to year 2000 range from 2.3 to 2.9% with the mean at 2.6% (Appendix B, Table B.2).

FIGURE 1. Forecasts of Electricity Demand

FACTORS AFFECTING ELECTRICITY DEMAND

Econometric studies link electricity demand to economic activity. Electricity demand and real GNP have grown consistently over time (Figure 2). The growth rate in electricity demand exceeds GNP growth rate by about a factor of two through 1973. Since 1973, electricity growth generally matches GNP growth (Figure 3) and electricity consumption has remained nearly constant at 0.55 kwh per dollar (1987) of real GNP.

One reason for the decline in growth rate since 1973 was the increase in real (constant dollar) electricity prices (Figure 4). Prior to 1972 real electricity prices steadily declined (DOE 85a, pp. 60-61). Steep

FIGURE 2. Historic Growth in Electricity Consumption and Real GNP

increases in real electricity prices followed the large increases in petroleum prices in 1973 and 1979. Real electricity prices, however, have remained nearly constant since 1982 and are projected to remain nearly constant through 2000 (EW 88, p. 69).

We think real electricity prices will decline over the long term, but much more slowly than they did in the past, in response to technology improvements and because the industry is less vulnerable to imported oil and many of the other factors that led to the severe energy price increases. Declining real prices should lead to a general increase in consumption.

Revenues from electricity sales are currently about 4% of GNP. However, 4% in no sense represents an upper limit since electricity is substitutable

FIGURE 3. Growth Rates of United States Electricity Use and GNP

Source: NRC 86, p. 25, updated by authors to include data through 1988.

both for other forms of energy and for other factors of production; e.g., labor and materials. Although at some point market saturation must occur, that point may be substantially above the current level. Currently, total energy sales alone, for example, comprise about 10% of GNP.

Therefore, over the long-term, we expect electricity demand to track the economy. The economy, as measured by real GNP, has typically grown at the rate of 2 to 4% per year with the long-term average near 3%. Real GNP should continue to grow in response to increased population and productivity. The average growth rate for GNP in recent forecasts is 2.6% per year to year 2000 (see Table B.2, Appendix B).

Although weather strongly affects electricity demand (DOE 85b, pp. 18-20), yearly weather variations are not predictable and tend to balance out over time. An allowance for abnormal weather must be included in the reserve margin, however.

FIGURE 4. Historic Residential Electricity Prices in Constant 1987 Dollars

NERC FORECASTS TO 1996

The North American Electric Reliability Council (NERC) annually forecasts annual demand, peak demand, and capacity for the next 10 years. The forecast is an aggregation of individual utility system forecasts representing virtually all of the power systems in the United States and Canada.

The 1988 NERC forecast (NERC 88) is for average annual growth rates in the summer peak demand of 1.9%, in net energy for load of 2.0%, and in installed generating capacity of 1.3%. The uncertainty ranges in the NERC forecasts to 1997 are estimated to be 1.0-2.6% per year for peak load and 0.9-2.8% per year for net energy for load. The uncertainty ranges cover an 80% probability band; there is a 10% probability that the upper bound

will be exceeded and a 10% probability that the lower bound will be exceeded. Table 1 presents NERC forecasts for 1990 and 1997 and preliminary data for 1988 from their 1988 report (NERC 88).

The reserve margin at the summer peak demand was 30% in 1988, and is projected to decrease to 22% in 1997. However, much of the excess capacity is oil-fired. If we exclude oil-fired capacity, the reserve margin is only 21% in 1988. By 1997 the reserve margin drops to 14% with oil-fired capacity excluded.

After 1997, when the reserve margin has been reduced to about 20%, new generating capacity will be needed at a rate to keep pace with the growth in peak demand. NERC projects the U.S. peak demand to be 594 GW in 1997. The U.S. capacity resources at the peak, including imports, is projected to be 725 GW in 1997.

In the ten-year period from 1988 through 1997, 92 GW of new capacity and 7 GW in retirements are planned for a net addition of 85 GW. Most of the new capacity installed will be nuclear, followed by non-utility generating capacity followed by coal. Coal capacity is scheduled to increase 15 GW from 286 GW in 1987 to 301 GW in 1997. Nuclear capacity is scheduled to increase 22 GW, from 85 to 107 GW. Hydro capacity is scheduled to

TABLE 1. NERC 1988 Forecasts for Selected Years

	1988 Preliminary	Forecasts		Average Annual Increase 1988-1997, %
		1992	1997	
Peak demand, GW	500	541	594	1.9
Net energy for load (TWh)	2,690	2,916	3,210	2.0
Installed capacity, GW	658	695	725	1.0
Planned Capacity Resources, Summer, GW	650	696	728	1.2
Reserve Margin, %	30	29*	22*	(2.7)

TWh = Tera watt hours = billions of kWh.

* Based on planned resources.

decrease 1 GW to 70 GW. Natural gas capacity is scheduled to increase 9 GW to 63 GW. Oil capacity is scheduled to increase 3 GW to 61 GW. Dual (oil/gas) fuel capacity is scheduled to increase 4 GW to 72 GW. Pumped storage is scheduled to increase 2 GW to 18 GW. Other utility generating capacity (geothermal, wind, solar, cogeneration, and biomass) is scheduled to increase from 3 to 6 GW. Non-utility generating capacity is scheduled to increase 20 GW to 28 GW. The above capacities are rounded to the nearest GW and refer to the summer capability.

Planned retirements by utilities through 1997 are 156 units with a total capacity of 7 GW. These are primarily small petroleum and natural gas units (NERC 87). The average unit size of the capacity to be retired is 47 MW. The largest power plant to be retired is the 840 MW Hanford nuclear plant. The planned capacity retirements are fueled by oil (2 GW) and natural gas (2 GW), coal (2 GW), and nuclear (1 GW).

The rate of retirements over the next 10 years corresponds to the installation rate of new capacity 50 to 60 years ago. Thus, the planned retirement schedule reflects overall aging and is consistent with plant life extension programs. The average age of installed capacity would reach about 23 years in 1995, up from 15 years in 1985.

REGIONAL FORECASTS

Different parts of the nation are expected to grow at different rates. Recent forecasts to 1997 (NERC 88) of peak loads and electricity demand by NERC region are shown in Table 2. Note: 1) the range of peak load growth rates varies from a low of 1.0% in the South Central Illinois subregion to a high of 2.9% in the Florida subregion, and 2) the range of net energy for load growth rates varies from a low of 1.1% in the NW Pool to a high of 3.4% in the Arizona-New Mexico subregion.

TABLE 2. Projected Regional Growth Rates in Electricity Demand and Peak Load

NERC Regions(a)	Summer Peak Load			Net Energy for Load		
	GW		Annual Growth Rate, %	Billions of kWh		Annual Growth Rate, %
	1987	1997		1987	1997	
ECAR	72.6	83.0	1.6	409	473	1.5
ERCOT	39.3	50.3	2.4	195	257	2.9
MAAC	40.5	44.5	1.3	207	244	1.8
MAIN	37.5	42.6	1.5	182	215	1.7
MAPP-US	23.2	26.2	1.5	113	136	1.7
NPCC-US	42.7	50.9	1.9	239	288	1.8
SERC	109.8	137.3	2.4	574	721	2.4
SPP	47.7	57.4	1.9	228	273	1.9
WSCC	83.0	101.4	1.9	496	602	1.8
NERC-US Total	496.2	593.7	1.9	2644	3210	2.0
<u>Selected Subregions</u>						
S. Central Illinois ^(b)	6.8	7.4	1.0	34	39	1.4
Florida ^(c)	25.7	33.1	2.9	125	174	3.3
Arizona-New Mexico ^(d)	10.6	14.2	2.6	55	76	3.4
NW Pool ^(d)	25.7	29.3	1.2	186	215	1.1

Source: NERC 87, pp. 11 and 16.

(a) NERC Regions are shown in Appendix C.

(b) Subregion of MAIN.

(c) Subregion of SERC.

(d) Subregion of WSCC.

PROJECTIONS OF THE NEED FOR NEW GENERATING CAPACITY

SUMMARY

In this section, we project the long-term need for new generating capacity. Three scenarios were selected to represent the projected "most likely" situation and the high and low extremes. The most likely scenario is that national electricity demand will grow with the economy at an average rate of 2.5%/year and that the plant service life will average 50 years. The high growth scenario combines a growth rate of 3.5% with a 40-year plant life. The low growth scenario combines a growth rate of 1.5%/year with a 60-year plant life. Taking into account currently scheduled capacity additions, additional (currently unscheduled) capacity is required by 1992 under the high scenario, by 1995 under the middle scenario, and by 2000 for the low scenario. In all scenarios, once reserve margins, which are currently high, reach our assumed value of 20%, annual requirements for new capacity additions increase to meet the combined growth rate and replacement rate requirements.

CAPACITY PLANNING

The need for new generating capacity comes from three sources: 1) the growth in peak demand, 2) the replacement of obsolete capacity, and 3) the need for reserve capacity. Generating capacity is added, as needed, to meet the projected peak demand; a reserve margin is added to ensure reliability. The determination of peak demand, reserve margin, and the replacement of obsolete capacity are described below.

Peak Demand

Although the growth in peak demand is the important variable for capacity planning, it is more difficult to forecast, because of its greater sensitivity to weather and end-use patterns, than the growth in annual electricity demand. However, over the long run the national peak demand and annual demand track each other rather closely (Figure 5). Over the period from 1960 through 1987 total growth in the peak load is only two percent more than the total growth in the annual electricity demand

FIGURE 5. Historic Growth of Electricity Demand and Generating Capacity

(Figure 6). Thus, the forecasted growth in electricity demand, 1.5 to 3.5%/year, should be a good predictor of peak load growth and adequate for purposes of long range projection. Although the peak demand determines the amount of capacity needed, the shape of the annual demand, as reflected by the load duration curve, determines the type of capacity needed to meet reliability standards and achieve the lowest cost (see Appendix D). In this study we assume the shape of the load duration curves remains constant and thus the proportions of base, intermediate, and peak capacity remains constant.

Reserve Margin

The reserve margin is the installed capacity above that required to meet the peak load, expressed in percent, as $(\text{Capacity} - \text{Peak})/\text{Peak}$. The margin allows for scheduled outages, forced outages, deratings, and higher than projected peak demands. To meet reliability criteria, a reserve margin

FIGURE 6. Variations in Annual National Peak Load and Energy Demand

of 20% has been the rule-of-thumb.^(a) Although reserve margins have been much above this value in recent years, current utility planning is headed towards 20%. Some suggest a reserve of about 25% margin (EW 85, p. 56). One study (EPRI 78, pp. S8-S11) indicates that the optimum reserve margin for some individual utilities may be about 30%. On the other hand, advances in load management, time-of-day pricing, increases in plant reliability, and expanded regional interties may enable utilities to operate with lower

(a) The 20% rule-of-thumb for the reserve margin derives from a report by the Federal Power Commission (FPC), titled "The 1970 National Power Survey." The FPC concluded that a 20% reserve margin industry wide, might be advisable (Senate 85, pp. 1243-1244).

reserve margins. The lowest and highest reserve margins, nationwide, since 1953 were 16.6% in 1969 (Hy 85, pp. 85, 103) and 39.9% in 1982.

The term "reserve margin" can be misleading. A large fraction of the capacity included in the reserve margin is typically unavailable (out-of-service) at the peak load. The "available" reserve capacity is the critical measure of reliability at the peak load. A recent article on reliability (EPRI 86, p.10) showed that 15 to 18% of capacity was unavailable at the peak load (Figure 7). In 1983, for example, the capacity margin^(a) was 25%. However, at the peak 6% of the capacity was down for maintenance, 6% was down for forced outages, and 3% was not available because of partial outages and derating. Thus, 15% of the capacity was unavailable at the peak, leaving an operating margin (available reserve capacity) of 10%. This is illustrated in Figure 7. Note that the percentages shown in Figure 7 refer to the capacity margin and not to the reserve margin.^(b)

Retirement of Obsolete Capacity

The need for new capacity additions also depends on the retirement of obsolete capacity. Although the average service life of plants retired since 1970 is 36 years, utilities are currently undertaking plant life extension and upgrading programs that could extend plant life to 50 to 60 years at a fraction of the cost for new capacity. As indicated earlier, the planned rate of retirements through 1996 is consistent with the rate of plant additions 50 to 60 years earlier. Therefore, an average service life ranging from 40 to 60 years reflects recent experience and current trends. The need for new capacity to replace obsolete capacity can readily be determined for future years for various service life assumptions.

The rate of peak load growth and the average service life combine to determine the need for annual capacity additions. In the past, when electricity demand was growing at 7% per year and the average service life was 36 years, the replacement rate for obsolete plants was only 9% of the annual capacity addition. However, in the future with demand growing at

(a) The capacity margin is expressed in percent as $(\text{capacity} - \text{peak})/\text{capacity}$.

(b) The reserve margin (%) is equal to $\text{capacity margin} (\%) / (1 - \text{capacity margin} (\%)/100)$.

FIGURE 7. Effect of Availability on Margins (a)

Note: Providing reliable electric service requires having reserve capacity actually available when needed. A distinction must therefore be made between the theoretical capacity margin usually quoted and the operating margin provided by readily available plants. During 1983, for example, demand for electricity reached only 75% of utilities demonstrated capacity, but 15% of capacity was sometimes unavailable because of preventive maintenance, forced outages, and other causes leaving an actual operating margin as low as 10% during the summer demand peak.

(a) EPRI 86, p. 10.

only 2.5% per year and the average service life at 50 years, the equilibrium replacement rate for obsolete capacity increases to 29% of the annual capacity addition. However, with the transition from the 7% to 2.5% growth rate, which occurred in 1973, the replacement rate should gradually increase

to over 40% of the annual capacity addition (assuming a 50-year service life) before the equilibrium rate of 29% is established.

SCENARIOS FOR ESTIMATING LONG-TERM CAPACITY NEEDS

Three scenarios were developed to study the range of probable needs for new capacity over the next 50 years. The scenarios (Table 3) vary the peak demand growth rate and the average service life over their expected ranges of uncertainty. A reserve margin of 20% is assumed for each scenario. The middle scenario reflects our view of the most likely scenario. The high and low scenarios, which combine the extreme values in each direction, reflect our view of the most likely boundary conditions.

These scenarios are used to calculate the new capacity requirements for each year through 2037. The process is to 1) calculate the peak demand in each year, 2) add on the reserve margin to determine the capacity required to meet the peak demand, 3) determine the need for new capacity to replace obsolete capacity based on the service life, and 4) determine the need for new baseload capacity as a fraction of the total new capacity.

PEAK DEMAND PROJECTIONS TO 2037

We projected the peak demand to the year 2037, assuming growth rates of 1.5, 2.5, and 3.5% (Figure 8). Even at these historically low growth rates the difference between the high and low peak demands increases rapidly—reaching 100 GW by 1996 and growing to 1700 GW by 2037. This provides a startling measure of the magnitude of the uncertainties in future electricity demand, considering the fact that total capacity in 1988 is 658 GW.

TABLE 3. Scenarios for Determining Capacity Requirements

<u>Scenario</u>	<u>Peak Demand Growth Rate (%/Year)</u>	<u>Average Service Life of Power Plants (Years)</u>	<u>Reserve Margin (%)</u>
High-Demand	3.5	40	20
Middle-Demand	2.5	50	20
Low-Demand	1.5	60	20

FIGURE 8. Projected Peak Demand for Three Growth Rates

TOTAL CAPACITY REQUIREMENTS

The capacity requirements (Figure 9) for each of these scenarios are obtained by adding a 20% reserve margin to the peak demand (see Appendix E for tabular data for selected years from which Figures 8 to 12, 14, and 15 were derived and for the complete year-by-year tabulation of capacity projections when both NERC plans and our scenarios are considered). By 1996, the difference in capacity requirements between the high and low scenarios grows to 130 GW; this increases to 2100 GW in 2037.

The planned capacity in 1996 by NERC is 716 GW (NERC 87). This capacity is required in 1993 for the high scenario, in 1995 for the middle, and not until 2000 for the low scenario. Under the high scenario, construction would need to be accelerated for plants now under construction or new

FIGURE 9. Capacity Requirements for Three Growth Scenarios

capacity commitments would need to be made soon.^(a) The middle scenario corresponds closely to current capacity expansion plans. Under the low scenario, current capacity expansion plans would need to be stretched out about 5 years.

The incremental capacity requirements to meet projected load growth for each scenario over the 716 GW currently planned for 1996 are shown in Figure 10. The requirements under the high scenario exceed 2500 GW in 2037. Because of the scale needed to show the high scenario, the large requirements for new capacity in the earlier years may appear deceptively small. For perspective, keep in mind that each GW represents one large modern plant. For example, the middle scenario required an additional

-
- (a) Since new baseload capacity requires a lead time of eight to ten years, additional capacity requirements prior to 1996 would have to be smaller units, such as gas turbines, that could be installed more quickly. Other possibilities for the near term are upgrades of existing plants, power purchases, and phase-ins of combined cycle plants. The recent growth rate has been about in line with the middle scenario, indicating that a pick up in the orders for new baseload capacity should occur within a few years.

FIGURE 10. Incremental Capacity Requirement for Three Growth Scenarios

209 GW by 2005, the high scenario required an additional 385 GW by 2005, and the low scenario required 59 GW more by 2005.

The total new capacity requirements to meet both load growth and the need to replace plants are obtained by adding the retired capacity to the incremental capacity requirements shown in Figure 10. The cumulative retirements of obsolete capacity for each service life assumption are shown in Figure 11. Retirements are based upon the capacity additions that were made one service life earlier. The additions through 1984 were derived from the historical capacities given by EIA scaled by the ratio of the NERC capacity to the EIA capacity in 1984 (604/672). After 1984 the additions were calculated from the planned capacity increases reported by NERC or required by our scenario, if that was larger, plus the retirements. Figure 11 illustrates the substantial impact of the service life assumption on the need for new capacity; that is, 143 GW more capacity is required by 2005 to replace obsolete plants assuming a 40 year service life than for a

FIGURE 11. Cumulative Retirements of Obsolete Capacity for Selected Service Life Assumptions

60 year service life. The planned retirements to 1996 by NERC (NERC 87) are 11 GW; this corresponds most closely to the 60 year service life assumption. Also, note the knee in the curves reflecting the transition from the higher to the lower growth rate in capacity additions that occurred in 1973.

The total new capacity requirements (Table 4) are obtained by adding Figures 10 and 11 and subtracting 11 GW for the planned retirements that are already included in the 716 GW planned by NERC for 1996.

The need for new baseload capacity (Figure 12) is estimated to be about 60% of the total new capacity requirements. The need for new baseload capacity determines the potential need for new nuclear or coal plants. The cumulative need for new baseload capacity to year 2037, over and above the 716 GW capacity already included in NERC plans through 1996, ranges from 601 GW in the low scenario to 1156 GW in the middle scenario to 2067 GW in the high scenario. Note that the difference between the high and low scenarios exceeds 200 GW by 2000.

TABLE 4. Cumulative Incremental Need for New Capacity^(a)
(GW) for Both Load Growth and Replacement of
Obsolete Capacity for Selected Years

Scenario	1996	2005	2037
High Demand	143	534	3445
Middle Demand	26	269	1928
Low Demand	(40)	70	1002

(a) Above the currently planned capacity of 716 GW in 1996.

FIGURE 12. Cumulative Need for New Baseload Capacity
for Three Growth Scenarios

ANNUAL REQUIREMENTS FOR NEW CAPACITY

Turn now to the annual requirements for new capacity to meet load growth, retirements, and reserve margins. For perspective, consider the steep decline in the annual additions to capacity and the prospects for recovery (Figure 13). The largest additions to capacity, 44 GW, occurred

FIGURE 13. Annual Additions to U.S. Generating Capacity

in 1973. Since then there has been a general decline. The decline, using NERC 1987 projections, is forecast to bottom out in 1995 at 5 GW, a pickup to 9 GW in 1996 is projected. Under the middle demand scenario (Figure 13), the annual additions to capacity, above those projected by NERC, would increase rapidly to 25 GW in 1998. However, the retirements under the 50-year service life assumed in the middle demand scenario are higher than the retirements planned for the 10 preceding years. Thus, if a longer service life does prevail (e.g., 60 years), the annual capacity additions would be about 5 GW smaller than shown. Nonetheless, annual capacity additions would increase to over 20 GW by the year 2000. The high scenario requires a few additional plants in 1992, and over 35 GW per year from 1993 onward. The low scenario does not require additional plants until 2000. NERC plans, as shown in Figure 13, are intermediate between the low

and middle scenarios; NERC 1987 projections were for a 2.1% growth which was revised to 2.0% growth in 1988.

The annual requirements for the three scenarios are summarized for selected years in Figure 14. For example, 44 GW of new capacity are required in the year 2005 under the high demand scenario. Keep in mind that approximately 44 GW are also required in 2006, 2007, etc., since these are annual requirements. The annual requirements are somewhat erratic in that the retirements in a given year reflect historical plant additions. For instance, the high requirements in 2025 for the middle scenario is caused by replacing plants that began service in 1975 according to the assumed 50-year retirement schedule for this scenario. Plant additions in 1975 were unusually high compared to the succeeding years.

The total new capacity requirements include the need for peaking capacity, load-following capacity, and baseload capacity. We estimate the annual need for new baseload capacity (Figure 15) to be approximately 60% of the total new capacity requirements previously shown in Figure 14.

FIGURE 14. Annual New Capacity Requirements in Selected Years for Three Scenarios

FIGURE 15. Annual Need for New Baseload Capacity in Selected Years for Three Scenarios

Planning Uncertainties

The differences in capacity requirements between the high and low scenarios are enormous. Translated into dollars, the differences reach into the hundreds of billions. The high and low scenarios, we believe, bound the range of future capacity demands and illustrate the magnitude of the uncertainties facing capacity planners. Fortunately, planning horizons are shorter and plans can be adjusted as events unfold. But, as we have seen, adjustments to abrupt changes, such as occurred in 1973, can take a long time.

Planning uncertainties deal with demand and supply projections and what drives them. Apparent drivers are GNP, price elasticity, and inter-fuel competition. Underneath lies a web of complex relationships, constantly changing with economic and social activity.

One of the obvious factors that affects uncertainty is the length of the lead time between the capacity addition decisions and plant startup. The rate of divergence (2% per year) between the low and high projections provides a measure of the relationship of uncertainty to lead time. For instance, for each year the lead time is shortened or lengthened, the uncertainty in the capacity requirements for a future target year is reduced or increased, respectively, about two percent, or about 14 GW currently.

IMPORTANCE OF LONG-TERM AND NEAR-TERM PROJECTIONS

Near-term and long-term projections serve different purposes. Near-term projections are essential to power plant construction and conservation decisions. Long-term projections are essential for strategic planning purposes in order to foster the timely development of suitable technologies, to ensure the availability of sufficient and secure energy supplies, and to develop policies that protect against severe economic disruptions.

Accurate near-term projections are essential in order to avoid the economic and social costs that can be caused by either shortages of efficient generating capacity or by an excess capacity of capital-intensive plants. New baseload capacity, using existing coal or nuclear technology, now requires a lead time of 8 years or more for licensing and construction. Inaccurate near-term projections on the low side could result in suppliers having to utilize inefficient high cost power sources or in consumers experiencing power shortages. Inaccurate projections on the high side could result in over-building, and subsequent underutilization, of capital-intensive plants. As demonstrated in the recent past, over-building can threaten the financial viability of the utilities involved and can have a dramatic impact on rates charged to the consumers.

The absolute accuracy of long-term projections is not as important as for near-term projections, assuming that projections are frequently updated and that energy supply strategies and associated R&D programs are appropriately re-evaluated to reflect changes in projections. However, it must be recognized that if there is a large mismatch between long-term projections and realizations, then strategies developed for meeting long-term needs

may not be appropriate. For example, over-prediction of electricity demand growth rates in the early 1970s led to supply strategies directed toward an early introduction of both nuclear breeder reactors and recycling of uranium in light-water reactors (LWR). Similarly, under-prediction of future demand could result in non-optimum supply strategies and the unavailability of sufficient resources and new technology to meet future needs.

SUPPLY OPTIONS

GENERATION PATTERNS

The electricity generated in 1987 came from coal (55%), nuclear (17%), hydro (9%), natural gas (10%), petroleum (4%) and other sources (5%) (Figure 16). Other sources include non-utility generation, net imports, geothermal, solar, refuse, and wood.

The trends in electricity production by fuel type show substantial variations over time although year to year changes are slight. The actual and forecast trends in fuel mix as a percent of total generation is illustrated in Figure 17. From 1960 to 1971 the coal contribution declines from 55% to 44%, being displaced by oil. Coal generation then remains relatively constant until 1978 and then increases back to 53-55% through 1996. Oil generation grows substantially from 6% in 1960 to 16% in 1973, in response to the low oil prices during this period. The oil share remains on a plateau until 1978, from which it declines steadily to 4% today and remains at 3-4% through 1996. Hydroelectric generation has steadily declined

FIGURE 16. Electricity Generation by Fuel Type (1987)

FIGURE 17. Electricity Production by Fuel Type

from 19% in 1960 to 9% today and is forecasted to decline to 8% in 1996, in response to the lack of available large-scale hydro sites. Natural gas generation remains relatively constant at 21-24% from 1960 through 1972, following which generation gradually declines to 10% today and to 9% in 1996. Nuclear generation increases from 0.1% in 1960 to 17% today and is forecasted to increase to 21% in 1996. Other generation is projected to increase from 3% today to 4.5% in 1996. Note that electricity generation increases about four-fold from 1960 to 1996 so that, although a fuel share may drop, actual generation may increase. Net imports (not shown in Figure 17) are projected to increase from less than 2% today to 4% of the domestic electricity supply in 1996.

CAPACITY

In 1987 (NERC 87), coal-fired units had the largest capacity (286 GW), followed by nuclear (85 GW), conventional hydro (70 GW), dual (oil/gas) (68 GW), oil (58 GW), gas (54 GW), and other (27 GW) (Figure 18). The capacity data represents the summer capability.

From 1987 through 1996, 85 GW of new capacity is scheduled to be added and 11 GW is scheduled to be retired for a net addition of 74 GW. Most of this new capacity is comprised of coal (26 GW), nuclear (28 GW) and other (13 GW). Should additional capacity be required, smaller blocks of peaking capacity, such as gas turbines, would be brought in quickly, perhaps as part of a staged-construction, combined-cycle plant (ED 86, p. 1).

FUTURE SUPPLY OPTIONS

The future electricity supply is expected to come from many sources, but only coal and nuclear currently have the extensive domestic reserves and proven technology to reliably provide large blocks of economic power.

FIGURE 18. Generating Capacity by Fuel Type (1987)

Note: Dual uses either natural gas or petroleum.

However, since new developments frequently alter the competitive situation, pursuing diverse energy options is advantageous and avoids dependency on a single option.

Many improvements in both coal and nuclear technology are on the horizon that address concerns over expanded use of these fuels. For example, 1) new developments in clean coal technology and recent experience in coal gasification offer promise to alleviate some of the environmental drawbacks to expanded coal usage and 2) improvements in LWR designs and new developments in liquid metal reactors and HTGRs offer promise to sharply reduce safety and risk concerns over nuclear power plants. Therefore, under foreseeable conditions, including the potential for improved technology, the future electricity supply is expected to be generated primarily by coal and nuclear baseload plants.

In addition, the existing large hydroelectric plants have an indefinite life and should continue to generate electricity at or above their current levels. Since few new large scale sites are available, the percentage of hydro's contribution should drop as electrical usage expands. However, small scale hydro has the potential to make a significant contribution if it becomes competitive, and environmental concerns are satisfied.

Advancements in gas turbine technology, such as the steam-injected gas turbine and the combined cycle, promise to lead to large efficiency improvements and expanded applications for natural gas. This should enable natural gas to maintain or increase its share of the generation until the low cost reserves are depleted. Domestic gas resources are large and gas reserves recoverable at current prices are estimated at nineteen years.

Renewable energy resources are also large and could provide a significantly increased fraction of the electricity supply if breakthroughs in their competitiveness are realized.

With domestic oil reserves at low levels and imports running high, oil generation should decline further and its share of electricity production should continue to drop.

Fusion energy, although a potentially inexhaustible source of electricity, appears to be at least 30 years away from significant commercial use.

Canadian imports are expected to increase and become a more important source of supply, particularly in the Northeast. However, for reliability reasons imports are unlikely to become a dominant percentage of a system's load.

Conservation is also a potential supply option. The sharp decrease in the electricity growth rate beginning in 1973 is attributable to conservation. Conservation has not played as important a role in electricity usage as in overall energy usage. A crude measure of conservation is the productivity of electricity as measured by the ratio of real GNP to electricity generation. There has been only a slight increase (3%) in this ratio over the last decade. In contrast, the ratio of real GNP to overall energy consumption has increased about 30% over the same period (Hy 85, p. 101). The slight increase in electricity productivity was probably caused by shifts in the economy away from electricity consuming industries. A potentially larger improvement in productivity was partially offset by substitution of electricity for primary energy in some industries. Decreases in electricity consumption per unit of output did occur in the top four electricity intensive industries, chemicals, paper, primary metals, and food processing.

RESOURCE CONSUMPTION AND WASTE PRODUCT GENERATION

SUMMARY

This section estimates the coal and nuclear fuel consumption and resulting waste generation for the three growth scenarios studied in the preceeding section. For each scenario we examine the consequences of pursuing two extreme fuel supply options. One extreme assumes the phasing out of nuclear and its replacement with coal. The opposite assumes the phasing out of coal and its replacement with nuclear.

Exclusive use of domestic coal reserves in the all coal options would result in a significant depletion over fifty years (Table 5). Under the high growth scenario, the depletion of coal reserves would reach 37% and the annual consumption of coal would increase about 500% over the 1987 consumption of 700 million tons. The annual generation of solid waste and gaseous emissions would tend to increase proportionally to coal consumption.

TABLE 5. Coal Consumption Assuming all Future Additions to Base Load Capacity are Coal-Fired

<u>Electricity Growth Scenario</u>	<u>Cumulative Consumption to 2037 (billions of tons)</u>	<u>Depletion of Coal Reserves(a)</u>	<u>Annual Coal Consumption in 2037 (billions of tons)</u>	<u>Increase over 1987 Consumption (%)</u>
High, 3.5%/year	90	37%	4.1	490
Medium, 2.5%/year	62	25%	2.5	260
Low, 1.5%/year	43	18%	1.4	100

-
- (a) Based on estimated recoverable coal reserves of 245 billion tons. Reserves are economically recoverable with current technology.

In the all nuclear scenarios the consumption of uranium over the next fifty years would represent a significant fraction of the domestic resource (Table 6). In the high growth scenario, the consumption would be equivalent to 86% of these resources. However, since a large fraction of the uranium supply would be imported, the actual depletion of domestic resources would be much lower. The annual consumption of U_3O_8 in 2037 would increase 1650% in the high growth scenario over the 1987 consumption of 0.02 million tons.

INTRODUCTION

Previous sections of this report clearly identify the long-term need for new baseload electricity generation plants. Based on current experience, coal and nuclear technologies are unique 1) in their proven ability to provide low cost electricity using domestic fuels and 2) in their potential for significantly increased utilization. Both technologies will play a role in the future; however, the relative roles of the two technologies is subject to questions.

Aside from meeting the pure demand requirements, other factors influence decisions on the relative roles of nuclear and coal technologies. These factors include economics, reliability of the fuel supply, waste product generation and disposal, environmental and health concerns, and public acceptability.

TABLE 6. Consumption of U_3O_8 Assuming Nuclear Energy is used to Meet all Future Additions to Base Load Capacity

Growth Scenario	Cumulative Consumption to 2037 (millions of tons)	Equivalent Percentage of Domestic Resource(a)	Annual Consumption of U_3O_8 in 2037 (million tons)	Increase over 1987 Consumption (%)
High	6.1	86%	0.35	1650
Medium	3.9	55%	0.21	950
Low	2.2	31%	0.11	450

(a) Based on estimated U_3O_8 resources of 7.07 million tons recoverable at less than \$500 per pound: resources include identified, inferred, and undiscovered resources. Assumes no introduction of breeders, and no U and Pu recycle.

The purpose of this section is to assess the resource requirements and estimate the quantities of wastes generated for future supply scenarios involving various mixes of coal and nuclear plants. Projections of resource requirements and waste generation provide a perspective for formulating long range research and development plans to improve technology, mitigate adverse impacts, assure the availability of critical resources, and increase the utilization of potential by-products.

Nuclear and Coal Supply Scenarios

The three electricity growth scenarios, 1.5, 2.5, and 3.5%/year, described in the previous section, cover the prospective boundary and intermediate conditions for baseload capacity requirements. The cumulative capacity of new baseload plants required for each scenario over the next 50 years is shown in Table 7.

We analyzed three fuel supply options, 100% coal, 50% coal/50% nuclear, and 100% nuclear, for each growth scenario (Table 8). The all coal and all nuclear options have a degree of credibility. There have been calls for the phasing out of nuclear power, both here and abroad, and problems related to acid rain, the greenhouse effect, and the impacts of coal mining could conceivably severely restrict coal usage. These extreme options bracket the ranges of coal and nuclear usage expected over the long-term. An intermediate fuel supply option appears more realistic; the 50/50 option corresponds closely with recent experience in new plant additions.

TABLE 7. Cumulative Capacity (GW) in New Baseload Plants Required over Fifty Years for Alternative Growth Scenarios

<u>Growth Rate Scenario</u>	<u>New Baseload Capacity, GW</u>
High	2067
Middle	1156
Low	601

TABLE 8. Alternative Coal and Nuclear Supply Scenarios and Options

<u>Electricity Growth Rate Scenario</u>	<u>Fuel Supply Options</u>		
High	all coal	50% coal/50% nuclear	all nuclear
Middle	all coal	50% coal/50% nuclear	all nuclear
Low	all coal	50% coal/50% nuclear	all nuclear

Comparison with EIA Projections

A recent EIA report (DOE 87, Table 8) provided four projections of U.S. operable nuclear capacity. Our scenarios and fuel supply options encompass the EIA projections as noted below.

The EIA projections were based upon 40 year operating lifetimes whereas we assumed 40, 50, and 60 year lifetimes, depending on the growth rate, for our scenarios. If we had also used 40 year lifetimes the following similarities are noted. Our all coal options were equivalent to the EIA no new nuclear orders case except that our nuclear capacity peaks at 107 GW whereas EIA peaks at 103 GW. Our low growth scenario with the 50% nuclear option was similar to the EIA lower reference case. The EIA upper reference case was about midway between our low and middle growth scenarios each with the 50% nuclear option. The EIA optimistic case was about midway between our middle and high growth scenarios each with the 50% nuclear option.

CRITICAL RESOURCE REQUIREMENTS

The following section examines the consumption of critical resources for each of the supply scenarios. The upper boundary scenarios explore the extreme trends to see what difficulties they lead to. From a strategic point of view, this helps to identify the actions and their timing that might be undertaken to mitigate the difficulties.

Coal

The consumption of coal for each of the scenarios and fuel supply options is summarized in Table 9. The extreme case is the all-coal option in the high growth scenario; this option would consume 90 billion tons, 37% of the coal reserves, by 2037 and, if this growth rate continued, 100% would be reached in 2061. Under the middle growth (2.5%/year) scenario, 62 billion tons of coal, cumulative, would be required through 2037 for the all-coal option; this is 25% of the United States recoverable coal reserves. And, if this rate of growth continued, 100% of the recoverable coal reserves would be consumed by 2079.

Under the extreme case, annual coal consumption would increase to 4.1 billion tons, about six times current usage. Under the middle scenario all-coal option, annual coal consumption would reach 2.5 billion tons in

TABLE 9. Consumption of U.S. Recoverable Coal Reserves
Over the Next 50 Years

<u>Scenarios</u>	<u>New Coal Plants</u>		
	<u>0%</u>	<u>50%</u>	<u>100%</u>
Low	26 ^(a) 11%	34 14%	43 18%
Mid	22 9%	42 17%	62 25%
High	19 8%	55 22%	90 37%

(a) Billion of tons consumed; lower figure is the % of U.S. recoverable reserves of 245 billion tons (NCA 85). Reserves are economically recoverable with current technology. More abundant coal resources are recoverable at higher prices.

2037, over three times current consumption.(a) However, this amount of increased coal combustion could exacerbate concerns over the environmental impacts of coal plants and lead to more stringent environmental control standards. More stringent standards, in turn, could result in lower fuel efficiency and the need for increased fuel consumption.

U₃O₈

The cumulative consumption of U₃O₈ for each of the scenarios and fuel supply options is summarized in Table 10; in the extreme case (high growth-all nuclear) the U₃O₈ consumption would reach 6.1 million tons, which is equivalent to 86% of the U.S. resources. Under the all-nuclear option for

TABLE 10. Consumption of U₃O₈ Over the Next 50 Years

<u>Scenario</u>	<u>New Nuclear Plants</u>		
	<u>0%</u>	<u>50%</u>	<u>100%</u>
Low	0.9 ^(a) 13%	1.5 22%	2.2 31%
Middle	0.8 12%	2.3 33%	3.9 55%
High	0.6 9%	3.4 48%	6.1 86%

(a) Million of tons consumed; lower figure is the equivalent % of the mean estimate for domestic U₃O₈ resources of 7.07 million tons recoverable at less than \$500 per pound (Pi 81, p. ii).

(a) Although coal could be phased-in to replace existing nuclear capacity over a number of years, an immediate shutdown in nuclear capacity and replacement with coal could cause severe economic disruptions in at least five of the nine NERC regions (Appendix H). The reserve margins in these five regions would fall below 20%. Nuclear generated between 20 and 44% of the electricity in these regions in 1988.

the middle scenario, 3.9 million tons, cumulative, of U_3O_8 would be required through 2037; this is 55% of the total United States U_3O_8 resource recoverable at less than \$500 per pound.

For perspective, 3.9 million tons of U_3O_8 could be recovered at production costs under \$100 per pound U_3O_8 and 6.1 million tons could be recovered at less than \$150 per pound (Pi 81, p. 3.4). However, since imports should continue to provide a substantial fraction of the U_3O_8 supply, the depletion of domestic resources should be much lower. The actual price increases, therefore, should be much lower. In addition, an increase in demand of this magnitude should provide sufficient incentive for Pu and U recycle and the introduction of breeder or advanced converter reactors well before the end of the period in order to avoid significant resource depletion, over-dependence on imports, and much higher uranium prices.

Under the middle scenario all-nuclear option, annual U_3O_8 requirements would increase to 208,000 tons in 2037, about ten times current consumption. Consequently, the number of fuel assemblies required would increase about ten-fold to 45,000. Similarly, U_3O_8 consumption would reach 351 thousand tons in 2037 for the all nuclear, high growth option; about 17 times current consumption.

Mine development is the critical path step in the expansion of uranium production. The current capacity of United States uranium mines is uncertain. Many mines have shut down because of the depressed state of the industry. But if all of the U_3O_8 requirements in the all-nuclear option of the middle scenario were met by domestic mines, United States uranium production would reach new peaks about 1997 (U_3O_8 production peaked at 22,000 tons in 1980) (DOE 86c, p. 40). The amount of uranium imports, which is a major factor in the domestic supply, will determine the need for domestic mine development. The long lead times for power plant construction should provide sufficient time for obtaining U_3O_8 supplies, either foreign or domestic, to meet the growing needs.

Uranium Enrichment

Existing United States enrichment capacity (currently 27 million separative work units; DOE 85e, p. 40) appears to be adequate for at least

20 years. Under the half-nuclear option for the middle growth scenario, the separative work capacity would be reached about 2015 (Table 11). By this time, new enrichment capacity or plutonium recycle would be required to maintain the reference fuel exposure, assuming no imports of enrichment services. The year in which existing enrichment capacity is reached for each of the scenarios is shown in Table 11.

Spent Fuel Disposal

The federal government, through the nuclear waste policy act, is planning to provide waste repositories for spent nuclear fuel. The first repository is planned to begin operation about 2003. Assuming a once-through cycle and spent fuel cooled 10 years: 1) the middle growth scenario with the 50% nuclear option would require a second repository (70,000 MTU capacity) in 2021 and a third repository would be needed in 2033; 2) the middle growth all nuclear scenario would require the second repository in 2017 and the third repository in 2028; 3) the high growth scenario with the all nuclear option would require the second repository in 2015 and the third in 2023. The all coal options for all scenarios would require only one repository.

TABLE 11. Year in which Existing Enrichment Capacity is Reached under Alternate Scenarios

<u>Electricity Growth Rate</u>	<u>% New Nuclear Base Load Plants</u>	
	<u>50</u>	<u>100</u>
High, 3.5%/year	2010	2000
Medium, 2.5%/year	2015	2010
Low, 1.5%/year	2030	2020

Reprocessing

Reprocessing of spent nuclear fuels provides a potential to conserve enrichment capacity, uranium resources, and waste generation. Reprocessing is capital intensive and requires a lengthy lead time. Although reprocessing is currently not included in fuel cycle planning, the lack of capacity could constrain nuclear power growth under high growth scenarios in which U_3O_8 depletion becomes significant. Reprocessing is required for breeder reactor deployment.

Potential Growth in Annual Fuel and Waste Disposal Requirements

In 1987, coal generated 1453 billion kWh and the coal consumption was 705 million tons (NERC 87). For illustration, the coal consumption and waste generation in 1987 is compared with the projected consumption and waste generation in 2037 for the all coal option for the middle growth scenario (Table 12). The consequences of pursuing the all coal option would lead to a 3.5 fold increase in annual coal consumption and waste generation.

In 1987, nuclear generated 452 billion KWh; 20,000 tons of U_3O_8 were consumed in fabricating 2000 MT (U) of enriched UO_2 fuel assemblies to produce this electricity. Pursuing the all nuclear option in the middle growth scenario would lead to a ten-fold increase in the nuclear fuel cycle requirements and nuclear waste generation (Table 13).

Comparing Tables 12 and 13 also illustrates the orders of magnitude greater fuel consumption and waste generation associated with coal compared to nuclear fuel. The fuel consumption and waste generation for selected intermediate years for all scenarios and fuel options are shown in Appendix F.

TABLE 12. Estimated Fuel Requirements and Waste Generation for Coal-Generated Electricity in 1987 and 2037(a)

	<u>1987</u>	<u>2037(a)</u>
Mining (tons mined)	840,000,000	2,945,000,000
Mine and Mill Waste (cubic yards)	110,000,000	391,000,000
Coal Shipments (tons)	705,000,000	2,474,000,000
Electricity Generation (TWh)(b)	1,453	6,109
Non-Radioactive Waste (cubic yards)	115,000,000	403,000,000
Gaseous Emissions (thousands of tons)		
SO ₂	2,800	9,900
NO _x (c)	3,900	14,000
CO ₂	2,300,000	7,900,000

(a) For middle growth (2.5%) scenario-all coal option.

(b) TWh = one billion kWh.

(c) Based on current emission limits.

TABLE 13. Estimated Fuel Cycle Requirements and Waste Generation for Nuclear-Generated Electricity in 1987 and 2037

	<u>1987</u>	<u>2037(a)</u>
Mining (tons mined)	16,000,000	165,000,000
Mine and Mill Waste (cubic yards)	13,000,000	137,000,000
U ₃ O ₈ Shipments (tons)	20,000	208,000
Uranium Enrichment (millions of separative work units)	9	97
Fuel Fabrication (Equivalent number of PWR fuel assemblies)	4,300	45,000
Electricity Generation (TWh)(b)	452	5,943
Non-Radioactive Waste (cubic yards)	4,400	46,000
Low Level Radioactive Waste (cubic yards)	77,000	832,000
High Level Radioactive Waste (cubic yards)	1,300	13,000
Gaseous Emissions	0	0

(a) For middle growth (2.5%) scenario-all nuclear option.

(b) TWh = one billion kwh.

FOREIGN NUCLEAR TRENDS

World-wide trends are toward increasing use of nuclear power in most of the nations that now have nuclear capacity and towards the introduction of nuclear capacity into some developing nations. The incentives are reduced dependence on imported energy supplies, cost competitiveness, and reduced environmental pollution. Increasing foreign usage should impact the U.S. situation in several ways. First, increased resource depletion could lead to increased fuel costs and greater incentives for fuel recycle and breeding. Second, greater activity and competition should spur technological advances. Third, increased operating experience should lead to improved designs and operating procedures. Fourth, more widespread usage should provide more opportunities for creative solutions to political and institutional issues. And fifth, an active global market should provide competitive state-of-the-art production capabilities and supporting infrastructure for reactor construction and for all parts of the fuel cycle.

Most nations plan to build light water reactors, particularly the large PWR. The trend is toward larger units of a standardized design: for instance, in France new plants will be 1400 MW PWRs with plans for 2000 MW later. The USSR is building 1000 MW PWRs and designing an 1800 MW PWR. Great Britain is planning to construct several 1150 MW PWRs.

Foreign and U.S. nuclear policies differ notably in their plans for reprocessing spent LWR fuel and recycling the uranium and plutonium into LWRs. The foreign nations with the largest nuclear capacities plan to reprocess and recycle. Japan and France are most advanced in their reprocessing and recycling programs. After Pu fuel irradiation tests now underway in Japan are completed, up to 23 Japanese reactors will burn mixed oxide (MOX) fuel reloads by late 1990's. Japan is also developing Pu-burning advanced thermal reactors. France plans to load mixed oxide fuel into sixteen 900 MWe PWRs by 1995. The net savings in France from recycle fuel is estimated at \$98 million per year by 1995 and the cumulative savings are put at \$770 million in constant 1987 dollars: \$570 million in U₃O₈ purchases and \$200 million in separate work (Nuclear Fuel, November 16, 1987).

Foreign commercial reprocessing capacity is 2738 MT(HM) per year; new capacity under construction is 6150 MT(HM) per year (Table 14).

France, West Germany, Japan, and Belgium are known to have operable MOX fuel fabrication facilities (NEI89); the total current capacity for MOX fuel fabrication is estimated to be over 100 MT/year. In Belgium the Dessel plant has a MOX capacity of 35 MT/year. Existing MOX plants in France and West Germany each have capacities of 25 MT/year. The new Melox plant in France will have 150 MT/year MOX capacity and should be commissioned in 1992. The UK participates with France and Belgium in MOX fuel R&D. A new UK MOX fuel plant may be brought into operation in late 1990's.

Many European countries have joined together with Japan, under cooperative agreement, to develop the breeder reactor. However, no large scale deployment is planned during the next 20 years.

TABLE 14. Foreign Reprocessing Capacity (MT/year)

	<u>Operable</u>	<u>Under Construction</u>	<u>Total</u>
France	800	1600	2400
West Germany	40	350	390
India	280	1000	1280
Japan	210	800	1010
UK	1008	1200	2208
USSR	400	1200	1600
Total	2738*	6150	8888*

*Some existing capacity may be shutdown or decommissioned when new capacity is brought online.

Sources: Nuclear Engineering International, World Nuclear Industry Handbook, 1989, Sutton Surry, UK and CR Cooley, OCRWM-DOE, Foreign Travel Report: IAEA International Waste Management Advisory Committee meeting, Vienna, Austria, April 10-14, 1989; presentation and discussion by AS Nikiforov, USSR.

Many of the 31 nations that now have nuclear power plants in operation or under construction plan to increase their nuclear capacity. New nuclear plants are now under construction in 22 nations.

World nuclear capacity increased 4% in 1988 to 310 GW with 428 reactors in operation. Twelve new reactors, with a combined capacity of 12 GW, were completed in France, Germany (FRG), Korea, Spain, UK, USSR, and the U.S. (Nuclear News, April 1989, p. 80). Nuclear power was being produced in 26 countries at the end of 1988. An additional 109 nuclear plants, representing 88 GW, were under construction. Completion of these units will increase nuclear capacity to 398 GW or about 25% of the world's total generating capacity.

Nuclear energy provides 20% of the world's electricity generation and a much larger fraction of the electricity supply in several nations. Nearly all of the nations with substantial nuclear capacity strongly support nuclear power since continued and increased reliance on nuclear energy is vital to their economic competitiveness, environmental objectives, and energy security (Nucleonics Week 12/10/87). The International Chamber of Commerce (ICC) in a policy statement said that nuclear energy "should be retained as a major source of energy for electricity generation" and that nuclear energy has "proved its competitiveness" and "its environmental advantages" during normal operation.

Opposition to nuclear power is strong in several countries. Moratoria, phase-outs, and construction bans are in-place or planned in West Germany, Sweden, Italy, Spain, and Yugoslavia, all of which now have operating nuclear plants. Several nations, e.g., Austria and Ireland which do not have nuclear plants, have banned nuclear construction.

Most of the national policies for radioactive waste disposal assume interim storage for periods of 10 to 60 years followed by geologic disposal of either vitrified high level waste or spent fuel assemblies.

The ordering rate for new nuclear capacity has slowed recently in response to slower growth rates in electricity demand and opposition to nuclear power, and should continue slow over the next decade.

DISCUSSION AND CONCLUSIONS

Growth in electricity demand has historically been closely linked to growth in GNP. For the first three-quarters of the twentieth century, a period of declining real electricity costs, the electricity demand grew faster than the growth in GNP. Since the 1973 oil embargo, real electricity costs have increased and the growth rate of electricity consumption has been approximately the same as that of the GNP.

During the next decade electricity demand is likely to increase at a slightly faster rate than real GNP growth because the real price of electricity should decline over this period. There are several reasons to expect reductions in the real price of electricity:

- Energy supplies should remain abundant during most of the decade because of current over-capacity.
- Completion of new power plants will slow markedly, resulting in fewer additions to utility rate bases.
- Lower interest rates are permitting refinancing of existing utility debt, thus lowering fixed charges.
- Current surplus capacity will be eliminated through growth, thus increasing the overall system capacity factor.
- The potential exists for increased competition between electricity suppliers in the future.

Over the longer term, the potential exists for continued reductions in the real price of electricity through technology improvements, continued low interest rates, and construction cost decreases resulting from the standardization of plant designs, shorter construction periods, and increased regulatory stability. If the real price of electricity declines, electricity demand will probably increase at a rate faster than that of the real GNP.

On the other hand, several factors could result in increasing prices of electricity and slower growth rates over the long-term. Some possibilities are:

- Introduction of more stringent limits on emissions resulting from coal combustion could significantly increase the costs of electricity generated by coal plants.
- Over-reliance on a single technology could decrease the competitive environment that now exists between technologies (e.g., coal and nuclear).
- Utilities could choose to use higher cost technologies for new capacity because of shorter lead times and reduced financial risks (e.g., gas turbines).
- Under-estimating growth in demand could cause increased utilization of higher cost, short lead time technologies.

On balance we believe that real electricity prices are more likely to either fall or hold steady than rise. Therefore, we expect electricity demand to grow or remain constant relative to GNP. Over the long term GNP should continue to grow in the 2-3% range in response to productivity improvements and population growth. Even if population stabilizes, the desire for higher standards of living should cause continued growth in GNP. In fact, increased electricity usage is usually involved in productivity and materials improvements.

Most forecasts of electricity demand project an average growth rate between 1.5 and 3.5% per year over the next three decades. At these growth rates new plants will be required in the year 2000 at a "best estimate" annual rate of about 30 GW per year. This is comparable to the 33 GW per year that were added during the 1973-1977 time period and is significantly more than the planned addition of about 7 GW per year during the 1991-1995 time frame. It is important to recognize that once the current surplus capacity no longer exists, 10-25 GW per year will be required to meet growth needs alone (excluding the need for replacement of obsolete capacity).

The need to replace obsolete capacity will have a significant impact on the need for building new plants. For instance, if the average age of plants at retirement is 60 years, only 10 GW of obsolete capacity will have to be replaced during the 1995-2005 time frame; whereas 200 GW of obsolete capacity must be replaced for average plant lifetimes of 40 years. Thus, the average annual requirement for replacement of obsolete capacity during that time frame will range from 1 GW to 20 GW. The wide range in potential requirements for replacing old plants demonstrates the enormous incentives that might be realized if the lifetimes of these plants can be extended from 40 to 60 years. This should give planners some sense of urgency in the need to pursue plant life extension efforts.

Based on current experience, only coal and nuclear technologies have the abundant indigenous resources and demonstrated capability to economically meet new growth requirements. In 1984, coal and nuclear plants generated 68% of the electricity; this increased to 74% in 1987 and is projected to continue at about 74% through 1997. Planned additional new baseload capacity through 1997 is about equally divided between coal and nuclear plants. For a number of decades beyond that time frame, sufficient indigenous resources exist such that either coal or nuclear technologies alone could meet growth requirements. However, because of concerns over each energy source and because of benefits associated with utilizing both technologies, an over-dependence on either should continue to be avoided. Significant concerns and benefits are summarized below.

- The continuing fuel requirements and waste generation associated with coal plants are orders of magnitude greater than for nuclear plants. Nothing can change this. There are already concerns over the risks and environmental consequences of the existing level of coal usage. These concerns could limit future increases in coal usage. Research is needed to determine acceptable emission limits relevant to acid rain and possibly, in the future, to CO₂ emissions. New technologies will be needed to meet future emission limits and handle the solid waste residues.

- Many concerns over the safety and economic viability of nuclear power have increased public opposition and eroded utility support. These concerns, unless resolved, could limit the future rate of growth of nuclear energy. Measures are needed to reduce financial risk to utilities, simplify licensing, reduce reactor construction times and costs, resolve nuclear waste disposal concerns, and alleviate public concerns about nuclear safety.
- Reliance on a single technology would lead to a less competitive environment, probably resulting in higher electricity prices. For example, a measure of the economic success of a particular nuclear power plant design is its ability to compete economically with coal plants.
- Although we have large domestic coal reserves, 25% or more would be consumed in the next 50 years if we were to rely exclusively on coal for new baseload capacity. It is probably not in the long-term national interest to deplete this resource at that rate. Much of the coal reserves are in the West on federal lands. These lands would have to be opened to leasing and mine development. Large scale importation of coal is not a viable option. However, utilization of large amounts of imported uranium is feasible because compared to coal, the transportation requirements are orders of magnitude lower, stockpiling costs are lower, and the cost per unit of electricity production is substantially lower. Additionally, nuclear power holds the promise for extending domestic uranium supplies for many centuries through the use of breeder reactors.
- The drop-off in domestic orders threatens the viability of the domestic nuclear industry, but increasing foreign use of nuclear power should preserve the nuclear option for the U.S. Adoption of foreign technology could impact the U.S. in several ways, such as, by limiting the reactor options to large or larger PWRs of standardized designs. Increasing foreign usage should increase resource depletion and potentially lead to increased fuel costs.

A growing foreign market could provide foreign suppliers with a competitive advantage in having modern production facilities and supporting infrastructure.

All of the foregoing data point to the general conclusion that new base load plants must and will be constructed. The future demand is immense, easily large enough to support development of completely new generating technologies. The future demand is also too large to be filled solely by a new technology in less than 30 years, given typical technology penetration rates. Thus, existing technologies must continue to play an important role in the near to mid term.

The United States and the world should develop and apply the best technology to make maximum use of limited resources to meet future energy demands, notably electricity. Technology improvements and waste management practices obviously must be pursued and implemented to mitigate environmental impacts from electricity generation. Improvements in safety over the entire fuel cycle are always motivating factors in technology development and application. Additions to generating capacity and improvements in the quality of generating technology are not options but imperatives.

REFERENCES

- BL 87 Bloomster, C. H., and E. T. Merrill. 1987. Long-Term Need for New Generating Capacity. PNL-6193, Pacific Northwest Laboratory, Richland, Washington.
- DOE 83 Energy Projections to the Year 2010. 1983. DOE/PE-0029/2. NTIS-PR-360, National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia.
- DOE 84 U.S. Department of Energy (DOE). 1984. "The Role of Nuclear Power," DOE/NE-0054. Washington, D.C.
- DOE 85 Energy Information Administration. 1985. Commercial Nuclear Power: Prospects for the United States and the World. DOE/EIA-0438(85), U.S. Government Printing Office, Washington, D.C.
- DOE 85a Energy Information Administration, Office of Coal, Nuclear, Electric, and Alternate Fuels. 1985. Annual Outlook for U.S. Electric Power 1985. DOE/EIA-0474(85), U.S. Government Printing Office, Washington, D.C.
- DOE 85b Cornett, C. M. 1984. Analysis of Growth in Electricity Demand. 1980-1984. DOE/EIA-0476. Superintendent of Documents, U.S. Government Printing Office, Washington, D.C.
- DOE 85c Inventory of Power Plants in the United States 1984. 1984. DOE/EIA-0095(84), Superintendent of Documents, U.S. Government Printing Office, Washington, D.C.
- DOE 85d Energy Information Administration. 1985. Electric Power Annual 1984. DOE/EIA-0348(84), U.S. Government Printing Office, Washington, D.C.
- DOE 85e Energy Information Administration. 1985. World Nuclear Fuel Cycle Requirements 1985. DOE/EIA-0436(85), U.S. Government Printing Office, Washington, D.C.
- DOE 86a Energy Information Administrations. 1986. Domestic Uranium Mining and Milling Industry: 1985 Viability Assessment. DOE/EIA-0477(85), U.S. Government Printing Office, Washington, D.C., November 13, 1986.
- DOE 86b Energy Information Administrations. 1986. Domestic Uranium Mining and Milling Industry: 1986 Viability Assessment. DOE/EIA-0477(85), U.S. Government Printing Office, Washington, D.C., November 13, 1986.

- DOE 86c Energy Information Administration. October 9, 1987. Uranium Industry Annual 1986. DOE/EIA-0478(86), U.S. Government Printing Office, Washington, D.C.
- DOE 87 Energy Information Administration, Commercial Nuclear Power 1987: Prospects for the United States and the World, DOE/EIA-0438(87) (Washington, DC, July 1987), Table 8.
- DOE 87a Energy Information Administration. October 1987. Uranium Industry Annual 1986, DOE/EIA-0478(86), U.S. Government Printing Office, Washington, D.C.
- ED 86 "Virginia Power Orders New Gas-Fired Plant." 1986. The Energy Daily. Vol. 14, No. 162.
- EPRI 78 Costs and Benefits of Over/Under Capacity in Electric Power System Planning. 1978. EPRI EA-927, Decision Focus, Incorporated, Palo Alto, California.
- EPRI 84 Kurgan, G. J., J. M. Balestrino, and J. R. Daley. 1984. Coal Combustion By-products Utilization Manual - Volume 1. EPRI CS-3122, Electric Power Research Institute, Palo Alto, California.
- EPRI 85 Electric Power Research Institute (EPRI). 1985. NERC Summary Load Forecasts: A Retrospective Appraisal and Technical Analysis.
- EPRI 86 Douglas, J. 1986. "The Value of Reliability." In the EPRI Journal. Vol. 11, Number 2.
- EW 85 "36th Annual Electric Utility Industry Forecast." Electrical World, September 1985.
- EW 88 "Annual Industry Forecast." Electrical World, October 1988, pp. 67-72.
- Fi 84 Finley, N. C., and N. H. Clark. 1984. Review and Evaluation of Literature on Coal and Nuclear Fuel Cycle Risk Comparisons. DE840D15124, Sandia National Laboratories, Albuquerque, New Mexico.
- Hy 85 Hyman, L. S. 1985. America's Electric Utilities: Past, Present, and Future. No. ISBN 0-910325-08-1. Public Utilities Reports, Inc., Arlington, Virginia.
- NCA 85 National Coal Association. 1985-86 Facts About Coal. Washington, D.C.
- NERC 85 North American Electric Reliability Council. 1985. Electric Power Supply & Demand for 1985-1994, October 1985.

- NERC 86 North American Electric Reliability Council. 1986. Electricity Supply and Demand for 1986-1995, October 1986.
- NERC 87 North American Electric Reliability Council. 1987. Electricity Supply and Demand for 1987-1996, October 1987.
- NERC 88 North American Electric Reliability Council. 1988. Electricity Supply and Demand for 1988-1997, October 1988.
- NRC 86 Committee on Electricity in Economic growth, Energy Engineering Board, Commission on Engineering and Technical Systems, National Research Council. 1986. Electricity in Economic Growth. National Academy Press, Washington, D.C.
- OTA 84 U.S. Congress, Office of Technology Assessment. 1984. Nuclear Power in an Age of Uncertainty. E OTA-E-216, Washington, D.C.
- Pi 85 Piepel, G. F., L. W. Long, R. A. McLaren, and C. E. Ford. 1981. Probabilistic Estimates of U.S. Uranium Supply. PNL-3595, Pacific Northwest Laboratory, Richland, Washington.
- Se 85 Searl, M. F. 1985. Electricity and Economic Growth in the U.S. 1947-2000. Paper presented at the ANS Annual Meeting, June 11, 1985, Boston, Maine.
- Senate 85 Committee on Energy and Natural Resources. 1985. Hearings before the Committee on Energy and Natural Resources United States Senate Ninety-Ninth Congress. No. 53-859 0, U.S. Government Printing Office, Washington, D.C.
- Wi 75 Williams, Roy E. 1975. Waste Production and Disposal in Mining, Milling, and Metallurgical Industries. ISBN 0-87931-035-3, Milton Freeman Publications, Inc.

GLOSSARY

Baseload Capacity: The generating equipment normally operated to serve loads on an around-the-clock basis.

Boiling-Water Reactor (BWR): A light-water reactor in which water, used as both coolant and moderator, is allowed to boil in the reactor core. The resulting steam can be used directly to drive a turbine.

Capability: The maximum generating capacity available at a given instant of time, usually the summer peak. The capability is often less than the rated capacity because of deratings caused by high cooling water temperatures in the heat rejection system and other factors.

Capacity: The load for which a generating unit is rated, either by the user or by the manufacturer.

Capacity Factor: The ratio of the electricity produced by a generating unit, for the period of time considered, to the energy that could have been produced at continuous full-power operation during the same period.

EIA: Energy Information Administration, part of DOE.

Elasticities of Demand: The proportionate change in the quantity of energy demanded resulting from a proportionate change in price. The income elasticity of demand is defined similarly for changes in income. Elasticities are calculated as the ratio of the respective proportionate changes.

Generation (Electricity): The process of producing electric energy from other forms of energy; also, the amount of electric energy produced, expressed in watthours (Wh).

Gross Generation: The total amount of electric energy produced by generating units in a generating station or stations, measured at the generator terminals.

Net Generation: Gross generation less the electric energy consumed at the generating station for station use. (Energy required for pumping at pumped-storage plants is regarded as plant use and is subtracted from gross generation or from hydroelectric generation.)

Gigawatt (GW): One billion watts.

Gross National Product (GNP): A measure of the final output of goods and services by citizens of a country, whether living at home or in foreign countries. GNP comprises GDP and factor incomes from abroad accruing to residents, less the income earned in the domestic economy accruing to citizens of other countries.

HTGR: High Temperature Gas-cooled Reactor, a graphite-moderator helium-cooled reactor operating at a high temperature and high thermal to electric conversion efficiency.

Intermediate or Load-following Capacity: Generating capacity that operates on an intermediate (between the baseload and peaking capacities) basis.

Kilowatt (kW): One thousand watts.

Kilowatthour (kWh): One thousand watthours.

Light Water: Ordinary water (H_2O), as distinguished from heavy water or deuterium oxide (D_2O).

Light-Water Reactor (LWR): A nuclear reactor that uses water as the primary coolant and moderator, with slightly enriched uranium as fuel. There are two types of commercial light-water reactor--the boiling-water reactor (BWR) and the pressurized-water reactor (PWR).

Load Following: Regulation of the power output of electric generators within a prescribed area in response to changes in system frequency, tieline loading, or the relation of these to each other, so as to maintain the scheduled system frequency and/or the established interchange with other areas within predetermined limits.

Megawatt (MW): One million watts.

Megawatthour (MWh): One million watthours.

Nameplate Capacity: The nominal electrical output of a generator, as specified by the manufacturer.

NERC (North American Electric Reliability Council): An organization of the electric utility industry founded to promote the reliability of bulk power supply in the electric utility systems of North America.

Net Energy for Load: The annual electrical energy needed to serve the utilities customers. It includes transmission losses. It represents the net energy generated internally plus energy purchases (imports) less energy sales (exports).

Nuclear Power Plant: A single- or multi-unit facility in which heat produced in a reactor(s) by the fissioning of nuclear fuel is used to drive a steam turbine(s).

Nuclear Reactor: An apparatus in which the nuclear fission chain can be initiated, maintained, and controlled so that energy is released at a specific rate. The reactor apparatus includes fissionable material (fuel) such as uranium or plutonium; fertile material; moderating material (unless it is a fast reactor); a heavy-walled pressure vessel; shielding to protect personnel; provision for heat removal; and control elements and instrumentation.

Peaking Capacity: Generating capacity operated for short periods of time to meet peak demands on a daily or seasonal basis.

Peak Demand: In this report peak demand usually refers to the highest annual national demand. This is the sum of the peak annual demands in each region. The regional peaks are non-coincident. There are daily peak demands and seasonal peak demands for which peaking capacity is required.

Planned Resources: The total generating capacity, existing, under construction, or planned, plus scheduled capacity purchases less capacity sales.

Plutonium (Pu): A heavy, fissionable, radioactive, metallic element (atomic number 94). Plutonium occurs in nature in trace amounts. It can also be produced as a byproduct of the fission reaction in a uranium-fueled nuclear reactor and can be recovered for future use.

Pressurized-Water Reactor (PWR): A nuclear reactor in which heat is transferred from the core to a heat exchanger via water kept under high pressure, so that high temperatures can be maintained in the primary system without boiling the water. Steam is generated in a secondary circuit.

Reliability: The degree to which the performance of the elements of a bulk power electric system results in power being delivered to consumers within accepted standards and in the amount desired.

Reserve Margin: The installed capacity above the peak demand, defined as, (capacity less peak demand)/peak demand, and expressed in percent.

Separative Work Unit (SWU): A measure of the work or energy expended to separate a quantity of uranium of a given assay into two components, one having a higher percentage of uranium-235 and one having a lower percentage.

Summer Capability: The gross electrical output measured at the output terminals of the turbine generator(s) at the summer peak.

Terawatthour (TWh): One trillion (10^{12}) watthours.

Uranium (U): A heavy, naturally radioactive, metallic element (atomic number 92). Its two principally occurring isotopes are uranium-235 and uranium-238. Uranium-235 is indispensable to the nuclear industry, because it is the only isotope existing in nature to any appreciable extent that is fissionable by thermal neutrons. Uranium-238 is also important, because it absorbs neutrons to produce a radioactive isotope that subsequently decays to plutonium-239, an isotope that also is fissionable by thermal neutrons.

APPENDIX A

PROJECTIONS OF ELECTRICITY DEMAND

APPENDIX A

PROJECTIONS OF ELECTRICITY DEMAND

This appendix lists the projections of electricity demand made over the past several years by numerous forecasters. The base (reference) year and the forecasted year are listed for each forecast. The average annual growth rate is the value of interest in comparing the forecasts covering different base years and time frames.

TABLE A.1. Projections of Electricity Demand

Source	Base Year	Base Value, (a) billions kWh	Average Annual Growth Rate, %	Forecast Year	Forecast Value, (a) billions kWh	Reference
DOE-EIA (High)	1985	2470	3.8	1995	3586	1
DOE-EIA (Low)	1985	2470	3.7	1995	3552	2
DOE-EIA (Base)	1985	2470	3.2	1995	3384	3
Siegel/Sillin	1983	2310	4.5	2000	4881	4
DOE-EIA	1983	2310	3.3	1995	3410	5
Data Resources, Inc.	1983	2310	3.1	2000	3881	6
DOE	1982	2241	2.8	2000	3683	7
Electrical World	1983	2310	2.8	2000	3693	8
Dept. of Commerce	1983	2310	2.5	2000	3514	9
Ntl. Coal Assoc.	1982	2241	2.3	1995	3011	10
Wharton	1983	2310	3.0	1994	3197	11
GRI	1983	2310	2.4	2000	3457	12
Conoco, Inc.	1982	2241	2.1	2000	3257	13
R.W. Sant, et al.	1981	2295	1.5	2000	3045	14
National Audubon Society	1980	2286	-0.8	2000	1946	15
NERC	1983	2310	2.7	1993	3015	16
Chemical Bank	1982	2241	2.9	2000	3749	17
NERC	1984	2413	2.35	1994	3044	18
Wharton	1984	2413	2.8	1994	3180	19

(a) All values converted to net generation basis. Base values are as reported by EIA. Net generation is approximately 9% greater than end use consumption.

TABLE A.1. (contd)

Source	Base Year	Base Value, (a) billions kWh	Average Annual Growth Rate, %	Forecast Year	Forecast Value, (a) billions kWh	Reference
DRI	1985	2470	2.9	1995	3287	20
Koomanoff	1983	2310	0.5	1990	2392	21
DOE-CPPA Scenario B	1982	2241	4.5 3.2 3.0 2.8 2.5	1985 1990 1995 2000 2005	2600 2900 3300 3700 4500	22
Scenario A	1982	2241	4.5 2.9 2.4 2.2 2.1 1.9	1985 1990 1995 2000 2005 2010	2600 2800 3100 3300 3600 3800	23
Scenario C	1982	2241	4.5 3.4 3.1 2.9 2.7 2.6	1985 1990 1995 2000 2005 2010	2600 2900 3300 3700 4100 4700	24
Low GNP	1982	2241	2.6 2.5 2.0 2.0 2.0 1.9	1985 1990 1995 2000 2005 2010	2400 2700 2900 3200 3500 3800	25
High GNP	1982	2241	5.8 4.5 3.7 3.4 3.2 3.0	1985 1990 1995 2005 2015 2010	2700 3200 3600 4100 4600 5200	26
Roles Reference Cases	1980	2286	3.5 3.0 3.1	1990 2000 2010	3200 4100 5700	27

(a) All values converted to net generation basis. Base values are as reported by EIA. Net generation is approximately 9% greater than end use consumption.

TABLE A.1. (contd)

Source	Base Year	Base Value, (a) billions kWh	Average Annual Growth Rate, %	Forecast Year	Forecast Value, (a) billions kWh	Reference
Roles (Enhanced)	1980	2286	3.4	2010	6300	28
Oil Co. A	1982	2241	3.1	2000	3800	29
Oil Co. D	1982	2241	2.4	2000	3434	30
AGA	1982	2241	1.9	2000	3100	31
GRI	1982	2241	2.7	2000	3600	32
DRI	1982	2241	2.8	2000	3600	33
AES	1982	2241	1.8	2000	3000	34
ORAU	1982	2241	2.3	2000	3300	35
Electrical World	1986	2487	2.3	1995	3052	36
			2.3	2000	3442	36
DOE (base)	1985	2470	2.8	1995	3242	37
(low growth)	1985	2470	2.5	1995	3176	37
(high growth)	1985	2470	3.0	1995	3313	37
(high demand)	1985	2470	3.2	1995	3401	37
(reduced capacity)	1985	2470	2.8	1995	3250	37
GRI	1985	642 (GW)	3.0	1990	744 (GW)	38
			2.2	1995	801	
			2.2	2000	883	
			2.0	2005	958	
			1.9	2010	1017	
GRI	1985	2470	3.0	1990	2862 ^(b)	38
			3.3	1995	3433 ^(c)	
			2.9	2000	3785 ^(c)	
			2.6	2005	4106 ^(c)	
			2.3	2010	4359 ^(c)	
AER	1985	2470	2.4	2000	3526	39

(a) All values converted to net generation basis. Base values are as reported by EIA. Net generation is approximately 9% greater than end use consumption.

(b) 44% system capacity factor.

(c) 49% system capacity factor.

TABLE A.1. (contd)

Source	Base Year	Base Value, (a) billions kWh	Average Annual Growth Rate, %	Forecast Year	Forecast Value, (a) billions kWh	Reference
Electrical World	1985	2470	2.5	2000	3577	40
NEMA	1985	2470	2.0	1994	2952	40
NERC	1985	2470	2.1	1995	3041	41
NERC	1986	2487	1.9	1996	2990	42
NCA (Low)	1987	2599	1.8	2000	3277	43
NCA (Moderate)	1987	2599	2.2	2000	3449	43
NCA (High)	1987	2599	2.6	2000	3628	43
EEI	1987	2599	2.6	2000	3628	44
EEI	1987	2599	2.0	2015	4525	44
Electrical World	1987	2599	2.0	2000	3362	45

(a) All values converted to net generation basis. Base values are as reported by EIA. Net generation is approximately 9% greater than end use consumption.

TABLE A.1. (contd)

Reference:

- 1-3 DOE, Energy Information Administration. "Annual Outlook for U.S. Electric Power 1985." DOE/EIA-0474 (85).
- 4-17 From William W. Hogan, "Energy Demand and the Outlook for Electricity." July 1985 in hearings before the Committee on Energy and Natural Resources, United States Senate, July 23 and 25, 1985. SHRG 99-253.
- 15 The Audubon forecast assumed the adoption of certain energy conservation policies that did not occur.
- 18 North American Electric Reliability Council. "1985 Electric Power Supply and Demand." Princeton, New Jersey.
- 19 Mark W. French. SHRG 99-253, p. 129.
- 20 Stephen A. Smith. SHRG 99-253, p. 148.
- 21 As reported in Siegel and Sillin, "Revitalizing Nuclear Power. The Case for Deregulation." Public Utilities Fortnightly, January 23, 1986.
- 22-26 DOE, Office of Policy, Planning and Analysis. "Energy Projections to the Year 2010" DOE PE-0029/2. October 1983.
- 27,28 DOE, Assistant Secretary for Nuclear Energy, "The Role of Nuclear Power." DOE/NE-0054. July 1984.
- 29-35 Derived from data in DOE/PE-0029/2, p. 7-18.
- 36 Electrical World, September 1987, p. 37.
- 37 Annual Outlook for U.S. Electrical Power, 1986, DOE/EIA-0474 (86), p. 14.
- 38 Energy Daily, November 16, 1987, pp. 1-2; DOE/EIA-0474 (86), p. 14.
- 39 Public Utilities Fortnightly, April 30, 1987, p. 6; DOE/EIA-0474 (86), p. 14.
- 40 Energy Security, DOE-0057/S, p. 137, March 1987.
- 41 NERC, "1986 Electricity Supply and Demand," p. 34.
- 42 NERC, "1987 Electricity Supply and Demand," pp. 6 and 15.

TABLE A.1. (contd)

- 43 National Coal Association, reported in Energy Daily, March 2, 1989, p. 2.
- 44 EEI, reported in Energy Daily, February 9, 1989, pp. 1-2.
- 45 Electrical World, October 1988, pp. 67-72.

APPENDIX B

PROJECTIONS OF THE RATIO OF ELECTRICITY DEMAND
GROWTH TO GNP GROWTH

APPENDIX B

PROJECTIONS OF THE RATIO OF ELECTRICITY DEMAND GROWTH TO GNP GROWTH

This appendix list projections of the ratio of electricity demand growth to GNP growth made by numerous forecasters. Both the mean and median values are slightly below unity. Many, probably most, electricity demand forecasts are based, at least partly, on an imputed relationship between electricity demand and GNP. Table B.2 lists several recent projections of GNP growth rates. Note that the average projection (excluding DOE) is 2.50, which when combined with the mean elasticity ratio 0.97 in Table B.1 converts to a projected growth rate of 2.4% for electricity demand.

TABLE B.1. Projections of the Ratio of Electricity
Demand Growth to GNP Growth

<u>Number</u>	<u>Source</u>	<u>Period</u>	<u>Ratio</u>
1	Siegel	1983-2000	1.29
2	AEO	1983-1995	1.14
3	Data Resources, Inc.	1983-2000	1.07
4	DOE	1982-2000	1.00
5	Electrical World	1983-2000	0.97
6	Dept. of Commerce	1983-2000	0.93
7	National Coal Association	1982-1995	0.92
8	Wharton	1983-1994	0.91
9	GRI	1983-2000	0.86
10	Conoco, Inc.	1982-2000	0.75
11	R. W. Sant	1980-2000	0.58
12	National Audubon Society	1980-2000	-0.32
13	DRI	1985-1995	1.00
14	Roles-Reference	1980-2010	1.15
15	Roles-Enhanced	1980-2010	1.13
16	DOE-OPPA Scenario B	1982-2010	0.96
17	Scenario A	1982-2010	0.79
18	Scenario C	1982-2010	1.04
19	Low GNP	1982-2010	0.87
20	High GNP	1982-2010	1.06
21	DOE- EIA (Middle)	1985-1990	1.10
22	DOE-EIA (Middle)	1991-1995	1.35
23	DOE-EIA (Middle)	1985-1995	1.19
24	DOE-EIA (Low)	1985-1995	1.35
25	DOE-EIA (High)	1985-1995	1.12
26	Oil Co. A	1982-2000	1.11
27	Oil Co. B	1982-2000	1.00
28	AGA	1982-2000	0.66
29	GRI	1982-2000	1.04

TABLE B.1. (contd)

Number	Source	Period	Ratio
30	DRI	1982-2000	1.00
31	AES	1982-2000	0.69
32	ORAU	1982-2000	0.79
33	Electrical World	1986-1995 1986-2000	0.97 1.00
34	DOE-EIA		
	Low Growth	1985-1995	1.04
	Base	1985-1995	0.98
	High Growth	1985-1995	0.94
	High Electricity Demand	1985-1995	0.91
	Reduced Capacity	1985-1995	0.99
35	National Coal Association	1985-2000	0.91
36	Department of Commerce	1985-2000	0.96
37	ICF, Inc.	1985-2000	0.85
38	Data Resources	1985-2000	1.00
39	GRI	1985-2000	0.67
40	Electrical World	1985-2000	1.00
41	Applied Energy Services	1985-2000	0.93
42	Wharton	1985-2000	0.86
43	DOE	1985-2000	0.86
44	Electrical World	1987-2000	0.96
45	EEI	1987-2000	1.04
46	EEI	1987-2015	0.87
47	NCA - Low	1987-2000	0.78
48	NCA - Moderate	1987-2000	0.96
49	NCA - High	1987-2000	1.13
	Mean		0.97 ^(a)
	Median		0.97
	Median w/o DOE		0.96 ^(b)
	Median recent		0.96 ^(c)

TABLE B.1. (contd)

<u>Number</u>	<u>Source</u>	<u>Period</u>	<u>Ratio</u>
References:			
1-12	Hogan op. cit., p. 96		
13	Smith op. cit., p. 149		
14-15	DOE, Assistant Secretary of Nuclear Energy, op. cit.		
16-20	DOE, Office of Policy, Planning and Analysis, op. cit.		
21-25	DOE, EIA - 0474 (85) op. cit.		
26-32	Derived from DOE (PE-0029/2, pp. 7-13 and 7-18)		
33	Derived from Electrical World, September, 1987, pp. 37 and 38.		
34	Derived from DOE/EIA-0474 (86), pp. 14 and 21.		
35-43	Derived from DOE-0057/S, March 1987, p. 137.		
44	Derived from Electrical World, October 1988, pp. 67-72.		
45-46	Derived from Energy Daily, February 9, 1989, pp. 1-2.		
47-49	Derived from Energy Daily, March 2, 1989, p. 2.		

-
- (a) Excluding Audubon projection.
 (b) Excluding all DOE projections.
 (c) Most recent projections, references 33-49.

TABLE B.2. GNP Projections

<u>Number</u>	<u>Source</u>	<u>Period</u>	<u>Annual Growth Rate (%)</u>
1	Electrical World	1986-2000	2.4
2	DOE/EIA		
	Low Growth	1985-1995	2.4
	Base	1985-1995	2.8
	High Growth	1985-1995	3.2
	High Electricity Demand	1985-1995	3.6
	Reduced Capacity	1985-1995	2.8
3	National Coal Association	1985-2000	2.3
4	Department of Commerce	1985-2000	2.5
5	ICF, Inc.	1985-2000	2.6
6	Data Resources	1985-2000	2.6
7	GRI	1985-2000	2.7
8	Electrical World	1985-2000	2.5
9	Applied Energy Service	1985-2000	2.8
10	Wharton	1985-2000	2.9
11	DOE	1985-2000	2.9
12	Electrical World	1987-2000	2.1
13	EEI	1987-2000	2.5
14	EEI	1987-2015	2.3
15	NCA	1987-2000	<u>2.3</u>
	Average		2.64
	Average w/o DOE		2.50

Reference:

- 1 September 1986, p. 36.
- 2 DOE/EIA-0474, "Annual Low Outlook for Electric Power," 1986, p. 13.
- 3-11 DOE-0057/S, p. 137.
- 12 October 1988, p. 68.
- 13-14 Energy Daily, February 9, 1989, pp. 1-2.
- 15 Energy Daily, March 2, 1989, p. 2.

NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

ECAR

East Central Area Reliability Coordination Agreement

ERCOT

Electric Reliability Council of Texas

MAAC

Mid-Atlantic Area Council

MAIN

Mid-America Interconnected Network

MAPP

Mid-continent Area Power Pool

NPCC

Northeast Power Coordinating Council

SERC

Southeastern Electric Reliability Council

SPP

Southwest Power Pool

WSCC

Western Systems Coordinating Council

UNITED STATES OF AMERICA

UNITED STATES OF AMERICA
 DEPARTMENT OF COMMERCE
 BUREAU OF ECONOMIC ANALYSIS
 WASHINGTON, D. C. 20540
 OFFICE OF INTERNATIONAL TRADE
 1400 K STREET, N.W.
 WASHINGTON, D. C. 20004
 TEL: 202-446-1000
 FAX: 202-446-1001
 WWW: WWW.DOT.GOV

APPENDIX D

LOAD DURATION CURVES

APPENDIX D

LOAD DURATION CURVES

The need for each type of capacity is determined by the shape of the load duration curve. A typical load duration curve is illustrated in Figure D.1. The load duration curve shows the hours of operation (abscissa) at each load level (ordinate) throughout the year. The three types of capacity (base, intermediate, and peak) are shown on the right vertical axis. The boundaries between each type are somewhat arbitrary. Assuming that the area, M, under the line ABC represents the electricity generated by the baseload capacity, then the average capacity factor for the baseload capacity is $M/(M+N)$. Similarly, assuming that the area P is generated by the intermediate load capacity, then the average capacity factor for the intermediate load capacity is $P/(P+Q)$. Correspondingly, the average capacity factor for the peak load capacity is $R/(R+S)$. Collectively, the average capacity factor of the entire system is $(R+P+M)/(R+P+M+S+Q+N)$. The fraction of electricity generated by the baseload capacity is $M/(M+P+R)$; this is typically on the order of 80% in many systems. Note that if outages occur in the baseload capacity, particularly during the hours from A to B, the baseload capacity would not be able to supply M amount of energy. The deficit in that case would be made up by the other capacity. The area N is mainly used for scheduled outages of base load capacity.

The distribution of the need for baseload or peak load capacity is profoundly impacted by the shape of the load duration curve. This is easily illustrated by two hypothetical extreme examples (Figures D.2 and D.3). In Figure D.2, the need for peaking capacity far exceeds the need for baseload capacity. In Figure D.3, the reverse is true.

FIGURE D.1. Relationship of Typical Load Duration Curve to Generating Capacity

FIGURE D.2. Low Baseload Example

FIGURE D.3. High Baseload Example

Hypothetical Examples Illustrating Extreme Diversity in Load Duration Curve

FIGURE 2. Low Barload Example

FIGURE 3. High Barload Example

FIGURE 4. Example illustrating excessive divergence in load duration curve

APPENDIX E

CAPACITY PROJECTIONS

APPENDIX E

CAPACITY PROJECTIONS

Capacity projections for each of the scenarios are summarized for selected years on page E.2. The base year is 1987. Yearly capacity projections are shown on page E.3 for the three scenarios; years 1984 through 1987 are historical data. Years 1988 through 1996 corresponds to NERC plans until additional capacity is required, i.e., 1992 for the high scenarios, 1995 for the middle scenarios, and 2000 for the low scenario.

Projected Peak Demand

<u>Year</u>	<u>Low</u>	<u>Middle</u>	<u>High</u>
1987	494	494	494
1996	565	617	673
2005	646	770	918
2015	750	986	1294
2025	870	1263	1826
2037	1040	1698	2759

Capacity Requirements

<u>Year</u>	<u>Low</u>	<u>Middle</u>	<u>High</u>
1987	593	593	593
1996	678	740	808
2005	775	925	1101
2015	899	1184	1553
2025	1044	1515	2191
2037	1248	2038	3311

Incremental Capacity Requirements

<u>Year</u>	<u>Low</u>	<u>Middle</u>	<u>High</u>
1996	-38	24	92
2005	59	209	385
2015	183	468	837
2025	328	799	1475
2037	532	1322	2595

Cumulative Capacity Retired

<u>Year</u>	<u>Low</u>	<u>Middle</u>	<u>High</u>
1996	9	13	62
2005	22	71	165
2015	81	180	410
2025	190	424	571
2037	481	617	861

Cumulative Need for New Baseload Capacity

<u>Year</u>	<u>Low</u>	<u>Middle</u>	<u>High</u>
1996	-24	16	86
2005	42	161	324
2015	152	382	742
2025	304	727	1221
2037	601	1156	2067

Annual Need for New Capacity

<u>Year</u>	<u>Low</u>	<u>Middle</u>	<u>High</u>
1996	9	15	28
2005	10	30	44
2015	22	37	71
2025	25	58	75
2037	41	67	129

Annual Need for New Baseload Capacity

<u>Year</u>	<u>Low</u>	<u>Middle</u>	<u>High</u>
1996	6	9	17
2005	6	18	26
2015	13	22	42
2025	15	35	45
2037	25	40	77

Year	Capacity Projections		
	Low(a)	Likely(b)	High(c)
1984	604	604	604
1985	617	617	617
1986	633	633	633
1987	647	647	647
1988	662	662	662
1989	674	674	674
1990	681	681	681
1991	690	690	690
1992	694	694	704
1993	699	699	729
1994	705	705	754
1995	710	722	781
1996	716	740	808
1997	716	759	836
1998	716	778	865
1999	716	797	896
2000	719	817	927
2001	730	838	960
2002	741	859	993
2003	752	880	1028
2004	764	902	1064
2005	775	925	1101
2006	787	948	1140
2007	798	971	1180
2008	810	996	1221
2009	823	1021	1264
2010	835	1046	1308
2011	847	1072	1354
2012	860	1099	1401
2013	873	1126	1450
2014	886	1155	1501
2015	899	1184	1553
2016	913	1213	1608
2017	927	1243	1664
2018	940	1275	1722
2019	955	1306	1782
2020	969	1339	1845
2021	983	1373	1909
2022	998	1407	1976
2023	1013	1442	2045
2024	1028	1478	2117
2025	1044	1515	2191
2026	1059	1553	2268
2027	1075	1592	2347
2028	1091	1631	2429
2029	1108	1672	2514
2030	1124	1714	2602
2031	1141	1757	2693
2032	1158	1801	2788
2033	1176	1846	2886
2034	1193	1892	2986
2035	1211	1939	3091
2036	1230	1988	3199
2037	1248	2038	3311

(a) Low indicates a growth rate of 1.5% per year and 60 year life.

(b) Likely indicates a growth rate of 2.5% per year and 50 year life.

(c) High indicates a growth rate of 3.5% per year and 40 year life.

Note that early years are history or NERC plans.

Table 1			
Year	1980	1981	1982
1980	100	100	100
1981	100	100	100
1982	100	100	100
1983	100	100	100
1984	100	100	100
1985	100	100	100
1986	100	100	100
1987	100	100	100
1988	100	100	100
1989	100	100	100
1990	100	100	100
1991	100	100	100
1992	100	100	100
1993	100	100	100
1994	100	100	100
1995	100	100	100
1996	100	100	100
1997	100	100	100
1998	100	100	100
1999	100	100	100
2000	100	100	100
2001	100	100	100
2002	100	100	100
2003	100	100	100
2004	100	100	100
2005	100	100	100
2006	100	100	100
2007	100	100	100
2008	100	100	100
2009	100	100	100
2010	100	100	100
2011	100	100	100
2012	100	100	100
2013	100	100	100
2014	100	100	100
2015	100	100	100
2016	100	100	100
2017	100	100	100
2018	100	100	100
2019	100	100	100
2020	100	100	100
2021	100	100	100
2022	100	100	100
2023	100	100	100
2024	100	100	100
2025	100	100	100
2026	100	100	100
2027	100	100	100
2028	100	100	100
2029	100	100	100
2030	100	100	100

Table 1 shows the results of the survey for the years 1980 to 2030. The data is presented in a table with four columns: Year, 1980, 1981, and 1982. The values for each year are consistently 100, indicating a constant level of the measured variable over the entire period.

APPENDIX F

TABULATION OF RESOURCE CONSUMPTION AND WASTE GENERATION
FOR THREE GROWTH SCENARIOS

APPENDIX F

TABULATION OF RESOURCE CONSUMPTION AND WASTE GENERATION FOR THREE GROWTH SCENARIOS

The electricity generation, resource requirements, and waste generation for the three growth scenarios and three supply options are tabulated in this appendix.

ASSUMPTIONS USED IN THE SCENARIOS

We assumed that the proportion of coal plus nuclear generation to the total generation would remain constant at 68%.^(a) As noted earlier, coal plus nuclear electricity generation was 72% of the internal generation in 1987 and is expected to remain near 72% through 1997. Thus, 68% is a conservative assumption over the next decade or two.

We assumed that the coal and nuclear plants now under construction would be completed by 1996 according to NERC plans. We further assumed that the nuclear plants would gradually increase their average capacity factor from 60% in 1984 to 65% in the year 2000.

In the all-coal scenarios, no new nuclear plants are ordered. If the coal plus nuclear generation based on NERC plans exceeds 68% of the total generation projected for any year, the planned NERC generation for coal is used and nuclear is cut back. The nuclear plants are retired in 40, 50, or

-
- (a) By implication we assume that 32 percent of the future electricity generation will come from other fuels. We expect those to be hydro, natural gas, oil, geothermal, solar, biomass, refuse, waste heat, etc. Current trends point to a decline in the percentage of hydro, natural gas, and oil used in utility generation. If the trends continue, this assumption would imply substantial growth in the alternative generation technologies and in non-utility generation. Much of this growth during the next ten years will come from non-utility generators (NUG). The fuel usage identified to date by the NUG is predominately natural gas, followed by coal and geothermal. The fuel type for most of the planned capacity additions by the NUG has not yet been specified.

60 years after startup according to the growth scenario. The coal generation is calculated by subtracting the nuclear generation from the total coal plus nuclear generation.

In the all-nuclear scenarios, coal generation is calculated as above for nuclear. This generation is reduced year-by-year in proportion to the generation capacity retired, assuming a 40, 50, or 60 year plant life as appropriate. The nuclear generation is then obtained by difference.

The impacts of the half-coal/half-nuclear scenarios were estimated to be midway between the all-coal and all-nuclear scenarios.

The calculations are based on state-of-the-art technology assumptions (Appendix G). Improvements in technology could reduce fuel requirements and/or impacts. For simplicity, all steps of each fuel cycle were assumed to occur in the same year as electricity production.

Low Growth Scenario

Electricity Generation (Billions of kWh)

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	1549	476	1467	558	1386	839
2005	1709	641	1631	719	1553	797
2015	2086	641	1754	974	1421	1306
2025	2525	640	1850	1315	1175	1990
2037	3401	383	1958	1826	515	3269
Total	105553	28688	84678	49781	63803	70636

Annual Rate of Change in Generation for Selected Years
Percent Change from Previous Year

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	1.8%		1.8%	0.7%		0.7%
2005	2.1%		1.0%	2.8%		4.7%
2015	2.0%		0.6%	3.2%		4.8%
2025	1.9%		0.6%	2.8%		3.8%
2037	2.7%		0.8%	2.3%		3.6%

Number of 100 Car Coal Trains

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	69687	0	66026	0	62365	0
2005	76894	0	73400	0	69906	0
2015	93871	0	78912	0	83953	0
2025	113619	0	83245	0	52070	0
2037	153050	0	88122	0	23195	0
Total	4749891	0	3810519	0	2871147	0

Millions of Tons of Carbon Dioxide Released

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	2013	0	1907	0	1802	0
2005	2221	0	2120	0	2020	0
2015	2712	0	2280	0	1848	0
2025	3282	0	2405	0	1527	0
2037	4421	0	2548	0	670	0
Total	137219	0	110082	0	82944	0

Millions of Tons of Coal or Ore Mined

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	746	13	707	16	668	18
2005	824	18	786	20	749	22
2015	1005	18	845	27	685	36
2025	1217	18	892	37	566	55
2037	1639	11	944	51	248	91
Total	50877	803	40615	1383	30753	1984

Thousands of Cubic Yards of Nonradioactive Solids

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	102234	4	96822	4	91478	5
2005	112794	5	107646	6	102498	8
2015	137676	5	115764	8	93786	10
2025	168650	5	122100	10	77550	16
2037	224466	3	129228	14	33990	26
Total	6966498	225	5588748	388	4210998	551

Low Growth Scenario (contd)

Thousands of Tons of Sulfur Oxides Released
(Assuming 90% Recovery in Scrubbers)

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	2508	0	2375	0	2244	0
2005	2767	0	2641	0	2514	0
2015	3377	0	2840	0	2300	0
2025	4088	0	2995	0	1902	0
2037	5506	0	3170	0	834	0
Total	170890	0	137094	0	103297	0

Thousands of Tons of Oxides of Nitrogen Released
(Assuming Maximum Allowable Released)

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	3484	0	3301	0	3118	0
2005	3845	0	3670	0	3495	0
2015	4694	0	3946	0	3198	0
2025	5681	0	4162	0	2644	0
2037	7652	0	4406	0	1160	0
Total	237495	0	190526	0	143557	0

Thousands of Tons of Coal or Uranium Shipped

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	627183	17	594233	20	561283	22
2005	692043	22	660599	25	629155	20
2015	844843	22	710209	34	575575	46
2025	1022573	22	749203	46	475833	70
2037	1377449	13	793102	64	200750	114
Total	42749015	1011	34294669	1742	25840323	2472

Thousands of Cubic Yards of Low Level Radioactive Waste

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	0	67	0	78	0	89
2005	0	90	0	101	0	112
2015	0	90	0	136	0	183
2025	0	90	0	184	0	279
2037	0	54	0	256	0	458
Total	0	4044	0	6967	0	9889

Requirements* for Spent Fuel Shipments Assuming Rail
(Multiply by Six for Truck)

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	0	0	0	351	0	403
2005	0	404	0	453	0	502
2015	0	404	0	613	0	823
2025	0	403	0	829	0	1254
2037	0	241	0	1150	0	2059
Total	0	18198	0	31349	0	44501

Tons of Fluoride Released to Air

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	0	3	0	4	0	4
2005	0	4	0	5	0	6
2015	0	4	0	7	0	9
2025	0	4	0	9	0	14
2037	0	3	0	13	0	23
Total	0	202	0	348	0	494

* Shipments will begin when a licensed facility is available.

Low Growth Scenario (contd)

Millions of Cubic Yards of Mine and Mill Waste

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	99	11	94	13	89	15
2005	109	15	104	17	99	18
2015	134	15	112	22	91	30
2025	162	15	118	30	75	48
2037	218	9	125	42	33	75
Total	6755	664	5419	1145	4083	1625

Cubic Yards of High Level Radioactive Waste

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	0	1072	0	1255	0	1438
2005	0	1443	0	1618	0	1792
2015	0	1443	0	2191	0	2939
2025	0	1441	0	2959	0	4478
2037	0	862	0	4109	0	7355
Total	0	64994	0	111962	0	158931

Cumulative Consumption of Coal and U3O8
(Millions of Tons)

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	4788	0.11	4499	0.13	4230	0.15
2005	11286	0.30	10833	0.33	10380	0.38
2015	19028	0.49	17743	0.59	16458	0.69
2025	28432	0.69	25072	0.95	21711	1.21
2037	42749	0.90	34295	1.54	25840	2.19

Total

Millions of Separative Work Units for Uranium Enrichment

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	0	8	0	9	0	10
2005	0	10	0	12	0	13
2015	0	10	0	16	0	21
2025	0	10	0	21	0	32
2037	0	6	0	30	0	53

Middle Growth Scenario

Electricity Generation (billions of kwh)

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	1551	639	1550	640	1549	642
2005	2162	641	1808	996	1454	1350
2015	2949	640	2080	1509	1211	2378
2025	4161	433	2413	2181	665	3929
2037	8109	69	3172	3006	235	5943
Total	153224	26395	103728	75893	54228	125391

Annual Rate of Change in Generation for Selected Years
Percent Change from Previous Year

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	2.2%		2.5%	2.5%		1.7%
2005	3.3%		1.4%	4.6%		7.0%
2015	3.1%		1.6%	3.8%		5.0%
2025	3.8%		1.9%	3.1%		4.6%
2037	3.8%		3.0%	2.0%		3.2%

Number of 100 Car Coal Trains

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	69800	0	69743	0	69687	0
2005	97304	0	81357	0	65410	0
2015	132685	0	93584	0	54484	0
2025	187239	0	106580	0	29921	0
2037	274926	0	142760	0	10595	0
Total	6895062	0	4667667	0	2440271	0

Millions of Tons of Carbon Dioxide Released

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	2016	0	2015	0	2013	0
2005	2811	0	2350	0	1890	0
2015	3833	0	2704	0	1574	0
2025	5409	0	3137	0	864	0
2037	7942	0	4124	0	306	0
Total	199191	0	134844	0	70497	0

Millions of Tons of Coal Or Ore Mined

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	748	18	747	18	748	18
2005	1042	18	871	28	701	38
2015	1421	18	1002	42	584	66
2025	2006	12	1163	61	320	109
2037	2945	2	1529	84	113	165
Total	73854	734	49996	2110	26138	3486

Thousands of Cubic Yards of Nonradioactive Solids

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	102366	5	102300	5	102234	5
2005	142692	5	119328	8	95964	11
2015	194634	5	137280	12	79926	19
2025	274626	3	159258	17	43890	31
2037	403194	1	209352	23	15510	46
Total	10112784	206	6845916	592	3579048	978

Middle Growth Scenario (contd)

Thousands of Tons of Sulfur Oxides Released
(Assuming 90% Recovery in Scrubbers)

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	2511	0	2509	0	2508	0
2005	3500	0	2927	0	2354	0
2015	4774	0	3368	0	1961	0
2025	6737	0	3906	0	1077	0
2037	9890	0	5135	0	380	0
Total	248070	0	167932	0	87795	0

Thousands of Tons of Oxides of Nitrogen Released
(Assuming Maximum Allowable Released)

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	3490	0	3487	0	3484	0
2005	4885	0	4088	0	3271	0
2015	6834	0	4879	0	2724	0
2025	9362	0	5429	0	1496	0
2037	13746	0	7138	0	530	0
Total	344753	0	233383	0	122014	0

Thousands of Tons of Coal or Uranium Shipped

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	628197	22	627690	22	627183	22
2005	875738	22	732215	35	588693	47
2015	1194167	22	842260	53	490354	83
2025	1685154	15	977224	76	269293	138
2037	2474331	2	1284841	105	95352	208
Total	62055562	924	42009002	2656	21962442	4389

Thousands of Cubic Yards of Low Level Radioactive Waste

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	0	89	0	90	0	90
2005	0	90	0	139	0	189
2015	0	90	0	211	0	333
2025	0	61	0	305	0	550
2037	0	10	0	421	0	832
Total	0	3695	0	10625	0	17555

Requirements* for Spent Fuel Shipments Assuming Rail
(Multiply by Six for Truck)

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	0	403	0	403	0	404
2005	0	404	0	627	0	851
2015	0	403	0	951	0	1498
2025	0	273	0	1374	0	2475
2037	0	44	0	1894	0	3744
Total	0	16629	0	47813	0	78996

Tons of Fluoride Released to Air

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	0	4	0	4	0	4
2005	0	4	0	7	0	9
2015	0	4	0	11	0	17
2025	0	3	0	15	0	28
2037	0	0	0	21	0	42
Total	0	185	0	531	0	878

* Shipments will begin when a licensed facility is available.

Middle Growth Scenario (contd)

Millions of Cubic Yards of Mine and Mill Waste

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	99	15	99	15	99	15
2005	138	15	116	23	93	31
2015	189	15	133	35	77	55
2025	266	10	154	50	43	90
2037	391	2	203	69	15	137
Total	9806	607	6638	1746	3471	2884

Cubic Yards of High Level Radioactive Waste

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	0	1438	0	1441	0	1444
2005	0	1443	0	2240	0	3038
2015	0	1441	0	3398	0	5351
2025	0	975	0	4908	0	8841
2037	0	155	0	6764	0	13372
Total	0	59390	0	170759	0	282129

Cumulative Consumption of Coal and U3O8 (Millions of Tons)

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	4769	0.13	4643	0.14	4517	0.15
2005	12358	0.33	11540	0.40	10722	0.46
2015	22802	0.53	19458	0.79	16114	1.04
2025	37166	0.71	28564	1.37	19962	2.03
2037	62056	0.82	42009	2.35	21962	3.89

Millions of Separative Work Units for Uranium Enrichment

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	0	10	0	10	0	10
2005	0	10	0	16	0	22
2015	0	10	0	25	0	39
2025	0	7	0	38	0	64
2037	0	1	0	49	0	97

High Growth Scenario

Electricity Generation (billions of kWh)

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	1728	639	1638	729	1549	818
2005	2699	840	2034	1305	1370	1969
2015	4277	433	2570	2140	882	3848
2025	6446	198	3487	3157	529	6115
2037	10039	0	5020	5020	0	10039
Total	223244	20480	135286	100438	47329	196395

Annual Rate of Change in Generation for Selected Years
Percent Change from Previous Year

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	4.8%		3.2%	4.1%		7.0%
2005	4.4%		2.3%	5.4%		7.4%
2015	4.9%		2.9%	4.3%		5.9%
2025	4.5%		3.0%	3.3%		4.3%
2037	3.5%		3.0%	4.0%		4.0%

Number of 100 Car Coal Trains

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	77760	0	73723	0	69687	0
2005	121441	0	91536	0	81631	0
2015	192456	0	115632	0	38809	0
2025	290065	0	158929	0	23793	0
2037	451778	0	225880	0	0	0
Total	10045971	0	6087883	0	2129796	0

Millions of Tons of Carbon Dioxide Released

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	2248	0	2130	0	2013	0
2005	3508	0	2644	0	1780	0
2015	5580	0	3340	0	1121	0
2025	8380	0	4534	0	687	0
2037	13051	0	6526	0	0	0
Total	290217	0	175872	0	61527	0

Millions of Tons of Coal Or Ore Mined

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	833	18	790	20	748	23
2005	1301	18	980	38	660	55
2015	2061	12	1239	60	418	107
2025	3107	6	1881	80	255	170
2037	4839	0	2420	140	0	279
Total	107604	569	65208	3015	22812	5460

Thousands of Cubic Yards of Nonradioactive Solids

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	114048	5	108108	6	102234	6
2005	176154	5	134244	10	90420	15
2015	202282	3	169620	17	56892	30
2025	425436	2	230142	25	34914	48
2037	862574	0	331320	39	0	78
Total	14734104	160	8928876	846	3123714	1532

High Growth Scenario (contd)

Thousands of Tons of Sulfur Oxides Released
(Assuming 90% Recovery in Scrubbers)

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	2798	0	2852	0	2508	0
2005	4370	0	3293	0	2218	0
2015	6924	0	4161	0	1396	0
2025	10438	0	5645	0	856	0
2037	16253	0	8127	0	0	0
Total	361432	0	219028	0	76626	0

Thousands of Tons of Oxides of Nitrogen Released
(Assuming Maximum Allowable Released)

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	3888	0	3686	0	3484	0
2005	6072	0	4577	0	3082	0
2015	9623	0	5782	0	1940	0
2025	14503	0	7646	0	1190	0
2037	22589	0	11294	0	0	0
Total	502299	0	304394	0	106490	0

Thousands of Tons of Coal or Uranium Shipped

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	699839	22	663511	28	627183	29
2005	1092967	22	823822	46	554678	69
2015	1732104	15	1040691	75	349277	135
2025	2610586	7	1412362	110	214138	214
2037	4065987	0	2032994	176	0	351
Total	90413735	717	54790950	3795	19168166	6674

Thousands of Cubic Yards of Low Level Radioactive Waste

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	0	89	0	102	0	115
2005	0	90	0	183	0	278
2015	0	61	0	300	0	539
2025	0	28	0	442	0	858
2037	0	0	0	703	0	1406
Total	0	2867	0	15181	0	27495

Requirements* for Spent Fuel Shipments Assuming Rail
(Multiply by Six for Truck)

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	0	125	0	459	0	516
2005	0	403	0	822	0	1241
2015	0	273	0	1348	0	2424
2025	0	125	0	1989	0	3853
2037	0	0	0	3162	0	6325
Total	0	12902	0	68316	0	123729

Tons of Fluoride Released to Air

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	0	4	0	5	0	8
2005	0	4	0	9	0	14
2015	0	3	0	15	0	27
2025	0	1	0	22	0	43
2037	0	0	0	35	0	70
Total	0	143	0	759	0	1375

* Shipments will begin when a licensed facility is available.

High Growth Scenario (contd)

Millions of Cubic Yards of Mine and Mill Waste

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	111	15	105	17	99	19
2005	173	15	130	30	88	45
2015	274	10	164	49	55	88
2025	413	5	223	73	34	141
2037	643	0	321	115	0	231
Total	14288	471	8658	2494	3029	4517

Cubic Yards of High Level Radioactive Waste

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	0	1438	0	1840	0	1842
2005	0	1441	0	2938	0	4431
2015	0	975	0	4816	0	8857
2025	0	446	0	7102	0	13759
2037	0	0	0	11294	0	22589
Total	0	46080	0	243985	0	441889

Cumulative Consumption of Coal and U₃O₈ (Millions of Tons)

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	4929	0.14	4794	0.16	4659	0.17
2005	13974	0.34	12316	0.47	10859	0.60
2015	28066	0.52	21648	1.01	15225	1.50
2025	49897	0.62	33891	1.85	17884	3.07
2037	90414	0.63	54791	3.38	19188	6.09

Millions of Separative Work Units for Uranium Enrichment

Year	All Coal Case		50/50 Case		All Nuclear Case	
	Coal	Nuclear	Coal	Nuclear	Coal	Nuclear
1995	0	10	0	12	0	13
2005	0	10	0	21	0	32
2015	0	7	0	35	0	63
2025	0	3	0	51	0	100
2037	0	0	0	82	0	164

APPENDIX G

FUEL CYCLE ASSUMPTIONS

APPENDIX G

FUEL CYCLE ASSUMPTIONS

DESCRIPTION OF COAL AND NUCLEAR FUEL CYCLES

A brief description of the steps in each fuel cycle is presented below. The assumed values are representative of current technology for each fuel cycle. Over the long term improvements in coal technology are likely to be made in conversion efficiency, in controlling emissions, and in cleaning coal prior to combustion. Improvements in nuclear technology are likely to be made in conversion efficiency, where the potential is greater than for coal, in achieving higher fuel burnups, and in increasing fuel utilization efficiency through uranium and plutonium recycle and eventually breeding. Thus, the state of the art assumptions used below are likely to prove pessimistic and overstate the impacts over the long term.

Coal Fuel Cycle

Coal is produced from underground and surface mines. Most of the underground production (65%) is in the eastern United States (NCA 85, p. 30). The western mines, which produced 35%, are primarily surface mines. Since most reserves are in the West, the proportion of production in the West should gradually increase. Eastern coal is generally higher in sulfur content and heating value than western coal.

Coal varies widely in properties important to its use as a utility fuel. The sulfur content may range from 0.6 to 6.0%. The ash content usually ranges from 8 to 12%, although much higher values are possible. The heating values range from 6,000 Btu/lb for lignite to 14,000 Btu/lb for bituminous. As mined, coal is diluted with additional impurities. Coal preparation plants, located near the mine, remove most of the mine waste. Mine waste can range from negligible amounts to 30% or more. The coal composition and utilization assumptions used in this study are summarized in Table G.1.

TABLE G.1. Assumptions Used in Coal Fuel Cycle Analysis

Composition

Heating value of as-burned coal: 21,000,000 Btu/ton, 10,500 Btu/lb
8,500 Btu/kWh (heat rate)(c)

Sulfur Content: 2.0%

Ash Content: 10.0%

Mine Waste: 16.0%

Mine Waste Properties^(a)

Dry Density = 90 lb/ft³
Wet Density = 106 lb/ft³
Specific Gravity = 1.95

Sludge from Coal Preparation Plants^(b)

Dry Density = 54 lb/ft³
Wet Density = 78 lb/ft³
Specific Gravity = 1.36 to 1.66

Coal Transport

90 tons coal/carload
100 cars/train; total length - 5,500 feet
Average speed = 10 miles/hour
Average distance = 1,800 miles round trip
Fraction hauled by rail = 64%
Coal car utilization = 2,160 hours per year
(hauling coal and returning)

Power Plant Waste Products (EPRI 84, pp. 3-50 to 3-53)

Solid Waste

Total ash = Coal consumption x 0.10
Total fly ash = Total ash x 0.8
Fly ash collected in precipitator = Total fly ash x 0.9
Total bottom ash = Total ash - Total fly ash

(a) Wi 75, p. 398.

(b) Wi 75, p. 400.

(c) The average heat rate experienced in 1987 was
10,200 Btu/KWh.

TABLE G.1. (contd)

Power Plant Waste Products (contd)

- A Fly ash collected in scrubber = Total fly ash x (0.997 - 0.900)
- B Weight of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ = Coal consumption x % S x 0.9 x 0.2 x $\frac{172}{32}$
- C Weight of $\text{CaSO}_4 \cdot 1/2\text{H}_2\text{O}$ = Coal consumption x % S x 0.9 x 0.8 x $\frac{145}{32}$
- D Weight excess reagents as CaCO_3 =
 Coal consumption x % S x 0.9 x $\frac{100}{32}$ x 0.2
 Total solids weight = A + B + C + D
 Weight of water = $\frac{40}{60}$ x Total solids weight
 Total weight of sludge = $\frac{100}{60}$ x Total solids weight

Bulk Density

- Fly ash = 90 lb/ft³
 Bottom ash = 80 lb/ft³
 Dry FGD sludge = 80 lb/ft³

Atmospheric Emissions

- CO_2 = 44/12 Carbon content
- SO_2 = 0.4 lb per million Btu assuming a scrubber efficiency of 90%. The emission standard is 1.2 lb per million Btu (Max)^(a)
- Particulates = 0.03 lb per million Btu (Max)^(a)
- NO_x = 0.6 lb per million Btu (Max) for bituminous coal^(a)
 0.5 lb per million Btu (Max) for sub-bituminous coal^(a)

(a) 40 CFR 60.42a.

The fuel requirements and waste generation to produce one trillion KWh from coal under these assumptions is summarized in Figure G.1.

Nuclear Fuel Cycle

In the United States, uranium is produced from underground and surface mines. The uranium content in the ore is low, about 0.2% for underground and about 0.1% for surface mines. Uranium is also produced as a by-product of other mining operations. The uranium is concentrated in mills located near the mines. Mill tailings are ponded near the mill; some are returned to the mine as back-fill. Disposal practices must guard against excessive radon releases from mill tailings to nearby populations. Uranium imports are substantial in relation to domestic production. In 1986, net imports exceeded United States mine production by 45% (DOE 87a, pp. 39, 63).

(a) Regulatory limits, actual emissions may be lower.

FIGURE G.1. Coal Plant Fuel Cycle Mass Flows

The mill concentrate, as ammonium diuranate, is transported by truck or train to a conversion plant where it is converted into UF_6 . The UF_6 is transported by truck or train to an enrichment plant where the ^{235}U content is increased three-to-five fold. Depleted uranium tails are produced and stored at the enrichment plant.

The enriched UF_6 is transported by truck or train to a fuel fabrication plant. There it is converted to UO_2 and fabricated into fuel assemblies. The fuel assemblies are transported by truck to the reactor site.

After irradiation and cooling at the reactor site the fuel assemblies will be transported by train or truck to a national waste disposal site.

The assumptions used in the nuclear scenarios are shown in Table G.2.

The fuel requirements and waste generation to produce one trillion KWh from nuclear fuel under these assumptions is summarized in Figure G.2.

Note that the shipments from the mine are 10,000 times greater by weight for a coal plant than for a nuclear plant. The coal plant burns 100,000 times more fuel by weight than the nuclear plant. For comparison, one PWR fuel assembly generates electricity equivalent to six coal trains, each with 100 cars (Figure G.3). Consequently, solid waste generation and atmospheric emissions from the coal plant are enormous, compared to the nuclear plant.

TABLE G.2. Nuclear Fuel Cycle Assumptions

Ore Grade	0.14% U_{308}
Mine Dilution	10.0%
Milling Losses	10.0%
Enrichment	3.5% ^{235}U
Tails Composition	0.25% ^{235}U
Fuel Exposure	37,500 MWd(th)/metric ton ^(a)
Capacity Factor	65%
Non-Radioactive Waste	0.25 cubic yards/ton of U_{308}
Low Level Waste	136 cubic yards/TWh

(a) The average fuel exposure in 1987 was about 30,000 MWd/MT.

FIGURE G.2. Nuclear Plant Fuel Cycle Mass Flows

(a) 7600 spent fuel assemblies (shipped about 10 years after energy generation or when the repository is ready, whichever is later).

FIGURE G.3. Equivalent Electricity Generation

APPENDIX H

ESTIMATED NUCLEAR CONTRIBUTION BY NERC REGION IN 1988

APPENDIX H

ESTIMATED NUCLEAR CONTRIBUTION BY NERC REGION IN 1988

Region	Energy Production, TWh			Capacity, GW		
	Nuclear	Total	% Nuclear	Nuclear	Total	% Nuclear
ECAR	38	432	9	7.7	97	8
ERCOT	6	198	3	1.3	50	3
MAAC	57	183	31	11.7	49	24
MAIN	81	183	44	15.0	50	30
MAPP	25	125	20	3.7	31	12
NPCC	60	218	28	9.6	54	18
SERC	156	572	27	27.9	139	20
SPP	37	230	16	5.8	66	9
WSCC	69	476	15	11.8	123	10
TOTAL	529	2620	20	94.1	658	14

NOTE: Totals may not add due to rounding.

Source: NERC 88

DISTRIBUTION

No. of
Copies

No. of
Copies

OFFSITE

111 DOE/Office of Scientific and
Technical Information

50 E. Mastal
U.S. Department of Energy
Office of Nuclear Energy
19901 Germantown Road
Germantown, MD 20874

J. Ahearne
Vice President
Resources for the Future, Inc.
1616 P Street, NW
Washington, DC 20036

W. Allen, Jr.
Chairman and CEO
Stone & Webster, Inc.
PO Box 1244
New York, NY 10116

R. Balzhiser
President
Electric Power Research Institute
PO Box 1D412
Palo Alto, CA 94303

J. Barry
International President
International Brotherhood
of Electrical Workers
1125-15th St., NW
Suite 1201
Washington, DC 20005

N. Beckman
Director, Washington Office
Council of State Governments
444 North Capitol Street, NW
Washington, DC 20001

S. Brewer
Executive Vice President
Nuclear Power Systems
Combustion-Engineering, Inc.
1000 Prospect Hill Road
Windsor, CT 06095-1521

R. Campbell
Chairman, President & CEO
Pennsylvania Power and Light Co.
2 North Ninth Street
Allentown, PA 18101

D. Connor
Director, Energy Programs
Nat'l Conference of
St. Legislatures
1D5D-17th Street
Suite 2100
Denver, CO 80265

T. Curtis
Director, Energy Committee
National Governors' Association
444 North Capitol St., NW
Suite 250
Washington, DC 20001

G. Dau
Sr. Program Manager
Materials & Systems Develop. Dept.
Electric Power Research Institute
PO Box 10412
Palo Alto, CA 94303

W. Donnelly
Congressional Research Svc.-ENR
The Library of Congress
101 Independence Avenue, SE
Washington, DC 20540

No. of
Copies

J. Eckert
Vice President and Group Executive
Defense and Nuclear Power Group
Babcock & Wilcox Company
PO Box 1165
Lynchburg, VA 24506-1165

H. Finger
President and Chief Executive
Officer
U.S. Council for Energy Awareness
17761 I Street, NW
Suite 400
Washington, DC 20006-2495

R. Georgine
President
Building and Construction Trades
Dept.
AFL-CIO
815-16th Street, NW
Suite 603
Washington, DC 20006

D. Geraghty
Assistant to the President
Electric Power Research Institute
PO Box 10412
Palo Alto, CA 94303

C. Grant
Vice President, Communications
Chamber of Commerce of the U.S.
1615 H Street, NW
Washington, DC 20006

R. Jones
Sr. Program Manager
Electric Power Research Institute
Materials & Systems Develop. Dept.
PO Box 10412
Palo Alto, CA 94303

No. of
Copies

F. Kalhammer
Energy Management & Utilization
Electric Power Research Institute
PO Box 10412
Palo Alto, CA 94303

D. Louison
Director, Energy Programs
National Conference of
St. Legislatures
444 North Capitol Street, NW
Suite 203
Washington, DC 20001

N. Metzger
Deputy Director
Office of Government and
Public Affairs
National Academy of Sciences
2101 Constitution Avenue, NW
Washington, DC 20418

K. Miller
Sr. Planning Economist
Planning & Evaluation Division
Electric Power Research Institute
PO Box 10412
Palo Alto, CA 94303

D. Nevius
Vice President
North American Electric
Reliability Council
101 College Road East
Princeton, NJ 08540-6601

A. Osso
Executive Director
National Association of State
Energy Officials
613 G Street, NW
5th Floor
Washington, DC 20001

No. of
Copies

No. of
Copies

D. Ray
Dixy Lee Ray
600-3rd Avenue
Fox Island, WA 93888

R. Ross
Director, Energy Programs
Western Governors' Association
600-17th St.
Suite 1705, South Tower
Denver, CO 80202

D. Spencer
Advanced Power Systems
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94303

J. Taylor
Vice President & Director
Nuclear Power Division
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94303

U.S. Council for Energy Awareness
PO Box 1537
Ridgely, MD 21681

O. Yu
Manager
Planning Evaluation Division
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94303

R. Zeren
Director
Planning & Evaluation Division
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94303

ONSITE

DOE Richland Operations Office

D. R. Segna

53 Pacific Northwest Laboratory

C. H. Bloomster (20)
S. H. Bush
J. A. Christenson
T. T. Claudson
L. R. Dodd (10)
E. A. Eschbach
J. F. Fletcher
M. D. Freshley
S. W. Heaberlin
R. A. Libby
R. P. Marshall
J. P. McNeece
E. T. Merrill
R. E. Nightingale
A. W. Prichard
W. D. Richmond
W. B. Scott
B. D. Shipp
R. D. Widrig
Publishing Coordination
Technical Report Files (5)

Westinghouse-Hanford Company

H. D. Brager
L. G. Niccoli
J. A. Rawlins
A. E. Waltar