MARYLAND INTERINDUSTRY FORECASTING PROJECT

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THE FUTURE USE OF NUCLEAR ENERGY IN THE GENERATION OF ELECTRIC POWER

by

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This study will try to forecast the amount of electricity which will be produced by nuclear energy during the period 1973-1980. Production between now and 1973 is already determined by plants under construction. The demand for nuclear power generation will depend largely on the cost of nuclear power relative to the cost of electricity generated by conventional fuels. Since a large part of the cost of conventional fuels is transportation costs, the demand for nuclear fuels will vary greatly from region to region. Therefore, I will forecast nuclear power generation in each state.

After estimating nuclear power production, we shall adjust the inputs into the electric power industry to reflect this technological change.

The main measurable variable determining the percentage of new electric generating capacity which will be nuclear is the cost per kwh relative to the cost of conventional power sources. The first step in the study will be to project future prices of conventional fuels based on the recent price changes for these fuels.

The cost of a kwh generated by nuclear energy relative to the cost of a kwh from conventional fuels will determine, by and large, the nuclear share of future expansions.

The second step in the study will be to estimate future cost of nuclear power generation. It is necessary to estimate future nuclear power plant construction costs and operating and maintenance costs as well as fuel costs.

By comparing nuclear and conventional power generating costs by state, it will be possible to determine the potential market for nuclear power generation.

This method has been used previously in a study by George Hogerton for Arthur D. Little, Inc. (1) and by James Lane in a study sponsored by the A.E.C. (2). My study differs from these in several ways. It benefits from more recent information. It will derive regional electricity demand from a comprehensive regional forecasting model. It uses different criteria for determining the potential market and for estimating the percentage of the potential market which will lead to actual sales. It is programmed for the computer, so that the effects of alternative assumptions can be easily checked.

In Sections 1, 2, and 3, I will describe the methods used to project future conventional fuel costs, nuclear power costs, and national electric power requirements. Section 4 contains a description of the method by which the forecasts were made. Section 5 deals with expenditures on nuclear fuels and Section 6 contains the results of the study.

1. Fuel Prices

All fuel prices are expressed in cents per million B.T.U., as burned. For the years 1957-1966 fuel prices were obtained, for each state, from Steam Electric Plant Factors, published by the National Coal Association.

Prices for the years 1967-1980 are not yet available so they have been projected under the following assumptions.

A. States where Natural Gas is the Dominant Fuel Source

In the ten states where natural gas has provided more than 75 percent of the conventional fuel,[1] it has been assumed that prices will remain constant to 1980.

Natural gas prices have, in fact, been rising, sharply in the 1957-1961 period, then slowly in the 1961-1966 period. The assumption of constant prices is supported by the continuation of an adequate supply of natural gas deposits and adequate pipeline facilities. In the absence of competition from nuclear power, natural gas prices might rise during the period, but once nuclear power becomes competitive in natural gas regions, prices could be brought back to 1966 levels. Thus for the purposes of this model, the assumption of constant natural gas prices seemed best.

Natural gas prices are expressed in terms of "coal equivalent," the conversion being necessary to account for cheaper plant construction and operation costs of natural-gas fired plants. The "coal equivalent" price is four cents per million B.T.U. less than the actual price.[2]

B. States where Oil is the Dominant Fuel Source

In two states (Maine and Washington), oil is the major fuel source.

For Washington it was assumed that prices would be constant over the next 14 years, as they have been over the last six. For Maine a 1 percent decline per year has been forecasted. Actually, the high price of conventional fuel in Maine makes it almost certain that most new plants there will be nuclear, so the future price trends of oil are unimportant.

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1. These ten states are: Kansas, Nebraska, Mississippi, Arkansas, Louisiana, Oklahoma, Texas, California, Oregon, and Nevada.

2. This is a rough estimate of the differential. It is of the same magnitude as those used in the Hogerton study for Arthur D. Little, Inc. (1) and the study by James Lane for the A.E. C. (2).

C. Coal Consuming States

For those states where coal provides more than 75 percent of conventional fuel, coal prices were the only ones considered. Where more than one type of fuel accounted for a significant proportion of fuel consumption, we used weighted average of fuel prices.[3] Such a weighted average was necessary in 16 states.[4] Coal prices, alone, were used in 21 states.[5]

Where we used the weighted average, future price trends for each component in the average were combined to form the trend for the state's fuel prices. For example, in South Dakota, where coal and gas each accounted for 50 percent of fuel consumed, coal prices were assumed to decline by 2.5 percent per year while natural gas prices remain constant. Thus, the weighted average declines by 1.25 percent.

Possible shifts from one conventional fuel to another have not been considered except for the cases of Nebraska and Arizona. Declining coal prices with constant natural gas prices may lead to such shifts. However, the present "coal equivalent" price of natural gas is substantially below the coal price in most states which use both fuels. This should prevent such shift throughout most of the forecast period.

Assumptions about future trends in coal prices vary by region.

a. Northeast (New England, New York, New Jersey, Pennsylvania)

   Coal prices in the northeastern region have declined steadily over the past ten years. The annual rate of decline has been 2.98 percent in Connecticut, 2.69 percent in New York, 2.0 percent in Pennsylvania, with similar declines in the other states.

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3. Gas and oil prices were here again expressed in terms of "coal equivalent."

4. These were: Massachusetts, New Hampshire, Rhode Island, New Jersey, New York, Iowa, Minnesota, Missouri, Nebraska, South Dakota, Florida, Arizona, Colorado, Montana, New Mexico, Utah.

5. These were: Connecticut, Vermont, Pennsylvania, Illinois, Indiana, Michigan, Ohio, Wisconsin, North Dakota, Delaware, District of Columbia, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia, Alabama, Kentucky, Tennessee, Wyoming.

To reflect what has been called "tiredness" or "resignation to the inveitable" on the part of the coal industry,[6] prices are assumed to remain constant through 1968. It has been assumed that they will decline by 2.0 percent per year from 1968 to 1980. Part of this decline comes from decline in transportation costs.

b. Southeastern Region (Delaware, District of Columbia, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia)

Prices declined in this region during the last decade, but the amount of decline varied from state to state. (Maryland 3.3 percent per year, Virginia 2.4 percent per year, South Carolina 1.3 percent per year, Georgia .3 per year.)

Within certain bounds, recent trends have been extrapolated over the next 14 years. We limited the maximum decrease to 2.0 percent per year. Because there have already been significant declines in transportation costs, we felt 2 percent to be the largest decline that could be expected. Secondly, we imposed a minimum of 1 percent to 1972 and 1.5 percent from 1973 to 1980, for where no declines have taken place there is room for cost reductions and there will be the greatest competition from nuclear power since conventional costs have remained high.

c. East and West North Central (Illinois, Indiana, Michigan, Ohio, Wisconsin, Iowa, Minnesota, Missouri, North Dakota)

Prices of coal in the North Central region have declined very little in the past decade. Some representative annual declines have been: Illinois .5 percent, Ohio 1.6 percent, North Dakota .2 percent, Missouri 1.3 percent. The competition from nuclear power will be especially great in this area. We have assumed that the coal and railroad industry will respond to this threat to their market with price reductions similar to those in the Northeast, where a similar situation existed during the last decade. Specifically, prices are expected to decline by 2.5 percent annually in the 1966-1972 period and 2.0 percent in the 1972-1980 period in states where at least large areas are near coal mines. We chose 2.0 percent because it was the rate in Pennsylvania over the past decade.[7]

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6. These were comments on the state of the industry by Phillip Sporn, Nuclear Power Economics, Report to Joint Committee on Atomic Energy (3).

7. It should be noted that for states where the weighted average is used, only the coal component of the average declines, while gas and oil prices are constant even in this region.

d. Mining States (West Virginia, Kentucky, Tennessee)[8]

Mining states offer the least opportunity for reductions in transportation costs and suffer the least competition from nuclear power, so coal prices were assumed to decline by only 1.0 percent in the 1966-1972 period and by 1.5 percent thereafter.

e. Far Western Coal Consuming States (Arizona, Colorado, Montana, New Mexico, Utah, Wyoming)

As much for lack of information as any other reason, coal prices in the far west are assumed to remain constant throughout the period of the forecast.

Prices of conventional fuels have generally been rising in this area but competition from nuclear power should halt, if not reverse, this trend. The study for the F.P.C. Power Survey of 1964 also concluded that future fuel prices would remain at present levels.

The only exception to this treatment is Arizona where falling prices are expected as a shift takes place from natural gas to coal.

The treatment of conventional fuel prices rests more on economic than technological assumptions. The most basic assumption is that competition from nuclear power will cause conventional fuel suppliers to reduce prices, in much the same manner as they have in areas where such competition already exists.

<u>Alternative Treatment of Coal Prices</u>

The above projections of fossil fuel prices present an optimistic view of the ability of both the railroads and coal mining industry to continue to reduce coal prices. This is a more optimistic view than is held by

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8. Pennsylvania and Ohio are not included in this category. While they contain "mine mouth" areas, they also included large cities, some distance from mines. For this reason, there are more opportunities for declining transportation costs as well as increased competition from nuclear fuels.

many experts on the industry, or than is suggested by the behavior of coal prices during the past two years.

To see what effect more rigid coal prices would have on the demand for nuclear power generation, I have run the forecasting program using two additional projections of coal prices.

The first allows for a decline in coal prices but a much smaller decline than in the original projections. A comparison of annual rate of price decline for the two projections is given in Table 1.

The second of these assumes that coal prices remain constant throughout the country over the whole period of the forecast.

For each case, oil and gas prices were held constant.

TABLE 1[1]

Region	Original	First Alternative
Northeast	2.0	.5
Southeast	1%-2%	1.0%
North Central	2%-2.5%	1.5%
Mining States	1%-1.5%	0.0%
Far West	0.0%	0.0%

1. Annual percentage reduction in price.

2. Projection of Future Nuclear Power Costs

Future costs of nuclear power generation will be an important factor in the demand for nuclear power plants. It is convenient to express nuclear costs as breakeven coal prices in cents per million B.T.U. That is, nuclear costs of X cents per million B.T.U. mean that a nuclear plant is the equivalent of a coal fired plant which receives coal at X cents per million B.T.U.

To arrive at this breakeven coal price, I have taken the nuclear fuel cost in mills per kwh and added to that the capital cost differential between nuclear and coal fired plants. The capital cost differential is the result of the higher plant construction costs for nuclear plants. I have assumed that there will be no operation and maintenance differential. In the past there has been such a differential. However, increased efficiency, resulting from larger plant size, should lower operation and maintenance costs in nuclear plants to the level of such costs in coal fired plants.

Breakeven coal prices were calculated for plants of three sizes, entering service in 1972-74 and entering service in 1980. The calculations are shown in Tables 2 and 3. 1967 breakeven prices were taken from Atomic Energy Commission estimates. Prices for intervening years were projected by interpolation.

Sources of data on future nuclear power costs included: A.E.C. reports, F.P.C. estimates[9], the studies by Lane and Hogerton, (1) (2), studies made by Phillip Sporn for the Joint Committee on Atomic Energy, (3) and several other reports supplied to us by General Electric.

In a field undergoing such rapid change, the accuracy of any forecast is doubtful, but the above sources are at least in substantial agreement, especially about nuclear fuel costs. On the other hand, recent increases in all power plant construction costs have led to great uncertainty about future capital costs. I have used estimates neglecting increases in construction costs which affect both conventional and nuclear power plants. Therefore, while I believe estimates of future capital cost differentials to be reasonable, total capital cost figures may not be reasonable.

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9. Reports used are all reprinted in a recent J.C.A.E. publication, Nuclear Power Economics 1962-1967, (3).

TABLE 2

NUCLEAR COST CALCULATIONS

YEAR PLACED IN SERVICE 1972-1974

	Coal Fired			Nuclear		
Plant Size (MW)	0-500	500-1000	1000+	0-500	500-1000	1000+
(1) Capital Costs $/kw	137	129	126	194	155	142
(2) Nuclear Fuel Costs mills/kwh				1.67	1.57	1.54
(3) Capital Cost Differential $/kw				57	26	16
(4) Capital Cost Differential mills/kwh				1.0	.47	.29
(5) Heat Rate BTU/kwh	8800	8700	8600			
(6) Competitive[1] Coal Costs mills/kwh				2.67	2.04	1.83
(7) Competitive Coal Costs[2] ¢/million BTU				30.3	23.4	21.2
(8) Competitive Oil & Gas Prices ¢/million BTU				34.3	27.4	25.2

1. Equals sum of items (2) and (4).

2. Equals (mills/kwh X 105)/Heat Rate.

TABLE 3

NUCLEAR COST CALCULATIONS

YEAR PLACED IN SERVICE 1980

	Coal Fired			Nuclear		
Plant Size (MW)	0-500	500-1000	1000+	0-500	500-1000	1000+
(1) Capital Costs $/kw		107	105		132	119
(2) Nuclear Fuel Costs mills/kwh					1.34	1.32
(3) Capital Cost Differential $/kw					25	14
(4) Capital Cost Differential mills/kwh					.45	.25
(5) Heat Rate BTU/kwh		8500	8500			
(6) Competitive[1] Coal Costs mills/kwh					1.79	1.57
(7) Competitive Coal Costs[2] ¢/million BTU					21.1	18.5
(8) Competitive Oil & Gas Prices ¢/million BTU					25.1	22.5

1. Equals sum of items (2) and (4).

2. Equals (mills/kwh X 105)/Heat Rate.

3. Future Electric Generating Capacity

Estimates of future power requirements by state will be derived from the regional model now being developed at the University of Maryland. Since these estimates are not yet available, a makeshift treatment is now used in the program.

Total additions to capacity are taken from Federal Power Commission estimates, while the additions by state are from estimates by the Atomic Energy Commission. The A.E.C. estimates are only for plants larger than 300 MW, and only for the 1970-1980 period. I have assumed that the distribution by state of additional small plants and of plants added in the 1967-1970 period will be the same as the distribution of large plants in the 1970-1980 period.

The F.P.C. and A.E.C. estimates were made during 1964 and are now being revised upwards. Recent estimates supplied by General Electric indicate that a total addition of 380 thousand MW, by 1980, is reasonable. So, all state totals have been scaled upwards to this new national total.

The size of the average generating plant has risen rapidly in the past decade and even more rapid increases are expected as pooling agreements becomes more widespread. Since the cost of nuclear power generation declines more rapidly as a function of plant size than does the cost of power produced by conventional fuels, the size mix of new plants will be an important factor in determining the demand for nuclear power. Assumptions concerning the size mix of plants added during the forecast period are given in Table 4.

TABLE 4

	PERCENT OF NEW CAPACITY OF PLANT SIZE		
Year	0-500 MW	500-1000	1000 and over
1967	40	60	0
1968	30	70	0
1969-71	20	80	0
1972-74	10	45	45
1975-80	0	25	75

4. Forecasting Method

After projecting nuclear costs, conventional fuel prices and electricity requirements, I used a computer program to make forecasts of the demand for nuclear power plants. This program is described in the Appendix. Here I shall describe briefly the logic behind the program and the specific assumptions used to generate the forecasts which appear in Section 6.

In the first place, we assume that the demand for nuclear power will be a function the size of the cost advantage of nuclear power over power produced by conventional fuels and also a function of time. That is:

$$(1) \quad D_n = f(CP/PN, T)$$

where

D_n = fraction of new electric generating capacity which will be nuclear

CP = conventional fuel prices

PN = nuclear costs

T = time

The second assumption is that while all the variables in equation (1) may be significantly different in each state as well as in each size plant, they are relatively uniform within each state and plant size. Therefore, individual forecasts are made for each state, for each size plant. The influence of the time variable requires that forecasts be made separately for each year. Thus,

$$(2) \quad TCAPAC = \sum_{k=1}^{48} \sum_{i=1}^{14} \sum_{j=1}^{3} CAPACY_{(k, i, j)}$$

where

TCAPAC = total new capacity (1967-1980)

CAPACY = capacity in one state, in one year, for one plant size

k = state

i = year

j = plant size

The user of the program can vary the form of equation (1), or the values of its parameters. In the absence of any knowledge of the specific form of the relationship, I have tried to account for the influences of time and an increasing cost advantage, by making the assumptions contained in Table 5. (The way these assumptions would have worked for the 1967-1972 period is shown in Section 6.)

TABLE 5

Nuclear Cost Advantage (cents/per million BTU)	Year 1967-70	1970-75	1975-80
	Percentage of CAPAC$_{(k, i, j)}$ which will be nuclear		
less than 0	0	0	0
0 - 1	50	75	100
1 - 3	75	100	100
3 or more	100	100	100

Thus, the forecasting method consists of comparisons between nuclear costs and conventional power costs. Comparisons are made separately for each state, for each plant size, in each year. Depending on the cost of nuclear power relative to the cost of conventionally produced power and on the year, different percentages of new capacity are assigned to nuclear power plants.

5. Expenditures on Nuclear Fuels

Once the installed nuclear capacity has been projected, expenditures on nuclear fuels can be estimated. Future nuclear fuel costs in mills per kwh have already been estimated. Total output in kwh will be equal to:

$$\text{KWH} = \text{Capacity (KW)} \cdot 365 \cdot 24 \cdot \text{Plant Factor}$$

The plant factor must be the same one used for the estimate of nuclear fuel costs in mills per kwh. So, annual fuel expenditures will equal:

$$\text{Fuel Expenditures(\$)} = \text{Capacity (MW)} \cdot \text{Plant Factor} \cdot 365 \cdot 24 \cdot \text{Fuel Cost (mills/kwh)}$$

My original estimates assumed a plant factor of 80 percent. Eighty percent is the figure commonly used by the Federal Power Commission. Predictions of fuel expenditures with accompanying capacity figures are given in Table 1. Table 2 gives the breakdown of total fuel expenditure into the components of the fuel cycle.

TABLE 6

Year	Nuclear Capacity (mw)	Fuel Expenditure (millions of dollars)
1966	1,866	27.5
1972	31,800	357.9
1980	188,500	1,757.0

TABLE 7[10]
Fuel Cost Components

Component	Percentage of Fuel Cost[11]
Uranium Oxide	33%
Conversion	5%
Enrichment	37%
Fabrication	33%
Reprocessing	10%
Plutonium Credit	-12%
Uranium Credit	- 6%

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10. This breakdown of full cycle costs is reprinted from a report supplied by General Electric Corp.

11. For the purposes of Maryland Forecasting Model, 67% of fuel costs are regarded as a sale from basic chemicals to electric utilities while 33% (cost of uranium oxide) is considered a sale from nonferrous ore mining to electric utilities.

6. Results

This section will summarize the results of the study. Three different forecasts of nuclear capacity were made, using three different assumptions as to future coal prices.[12] For forecast I, a sharp decline in coal prices was projected. Forecast II was made on the assumption of a moderate decline in coal prices, and forecast III was made on the assumption of constant conventional fuel prices. Forecast II is probably the most realistic in the light of present expectations about coal prices. Forecasts I and III show to what extent a highly competitive or resigned attitude, on the part of the railroads and the coal industry, could influence the demand for nuclear power.

Table 8 shows the projected nuclear capacity, for each forecast, in three selected years.

TABLE 8

	Installed Nuclear Capacity (MW)		
	1972	1975	1980
Forecast I	31,800	70,600	163,200
Forecast II	34,700	79,000	188,500
Forecast III	39,600	91,600	224,100

Table 9 shows what these megawatt projections will mean in terms of the nuclear share of total U.S. Thermal electric generating capacity.

TABLE 9

	Nuclear Share of Total U.S. Thermal Electric Generating Capacity		
	1972	1975	1980
Forecast I	10.5%	19%	31%
Forecast II	11.5%	21%	36%
Forecast III	13.0%	25%	43%

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12. See Section 2.

The influence future coal prices will be greatest on the North Central region, for it is there that the closest competition with nuclear power will occur. Table 10 shows projected installed nuclear capacity for the North Central region.

TABLE 10

	Installed Nuclear Capacity (MW) North Central Region	
	1975	1980
Forecast I	9,100	24,872
Forecast II	11,600	33,787
Forecast III	21,385	65,482

Actual nuclear capacity in 1972 can be closely approximated, independently of the forecasts, because plants which will be in service by that time are already being constructed, or at least being planned. This independent estimate provides a partial check of the accuracy of the forecasts. Table 11 compares actual 1972 nuclear capacity with the three projections.

TABLE 11

	1972 Installed Nuclear Capacity (MW)
Actual	31,800
Forecast I	31,800
Forecast II	34,800
Forecast III	39,600

Table 12 gives a regional breakdown of nuclear capacity added to 1980. This breakdown is on the basis of Forecast II

TABLE 12

	1980 Installed Capacity (MW)
New England	15,200
Middle Atlantic	32,600
North Central	33,800
South Atlantic	53,900
South Central	4,000
Maintain States	8,300
Pacific Region	38,900

Conclusion

All of the above estimates depend upon the accuracy of the assumptions about future coal prices, nuclear costs, additions to generating capacity and the size mix of future plants. The aim of this study has been, not so much to make specific forecasts as, to establish a framework within which the effect of changing any or all of these assumptions can be easily tested. I have demonstrated this only in the case of varied projections of future coal prices, but the same process could be applied to any of the variables.

APPENDIX

Explanation of the Program

The use of a computer program for this study makes it possible to easily test alternative assumptions about the behavior of the relevant variables. Projections of future nuclear power costs, future conventional fuel prices, and future electricity requirements can be easily changed. Assumptions about the size mix of new capacity and the percentage of potential nuclear sales which will become actual sales, can also be varied.

In what follows, I will describe the program which was used to forecast the demand for nuclear power.

The program makes separate forecasts for each state. In the first part of the program (statements preceding No. 11), variables and parameters, which will be the same for all states, are read in.

These variables are:

PN (14, 3) = Nuclear costs in each year for each of three plant sizes (expressed as "coal equivalents").

A(14), B(14), C(14), D(14) = Percentages of the potential market which will become actual sales for each of four magnitudes of nuclear cost advantage, in each year.

G(14), E(14), F(14) = Percentages of new plant capacity which will be of each plant size, (three sizes) in each year.

X, Y, Z = Three magnitudes of the cost advantage of nuclear power.

R, S, T = Exponential rates of decline to be applied to coal prices.

Statements from No. 11 to No. 300 form the main loop of the program. First a 1966 conventional fuel price is read in and future prices are generated on the basis of a constant exponential rate of decline (the DO 60 loop) or on the assumption of constant prices (the DO 71 loop). Next, future capacity estimates are read in, and divided among, three plant sizes (the DO 15 loop). TCAPAX and TCAPAC are used to store state and national capacity totals.

The actual market forecasts are made in the DO 112 loop. This loop compares nuclear costs with conventional fuel costs for each plant size, in each year. If for a given plant size, in a given year, conventional fuel costs are found to be lower, no part of the market will be assigned to nuclear power. The computer will return to the beginning of the loop and repeat the comparison for the next year. (If 1980 has been reached, the comparison will be made next for a new plant size in 1967.)

If the cost of nuclear power is lower than conventional power costs, a series of statements (22 to 32) will determine the size of this cost advantage by the following process. Successive increments (X, Y, Z) are added to nuclear costs. After the addition of each increment, nuclear costs are again compared to conventional power costs. This process defines four magnitudes of nuclear cost advantage.

0 to X cents/per million BTU

X to Y cents/per million BTU

Y to Z cents/per million BTU

Z or greater

A different percentage of the new capacity is assigned to nuclear power depending upon the size of the cost advantage. (Statements No. 25, 30, 40, 42) YTEMP and XTEMP are used to store state and national nuclear capacity totals.

When the DO 112 loop is completed, we return to statement No. 11 and repeat the whole process for the next state. When forecasts for all the states are completed, national totals for nuclear capacity and for all new capacity installed by 1980 are written out.

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