be paid to the internal "hydrodynamic" factory complexity within the atomism (cell, brain, organism, society) (*18*) and (ii) that the cascade complexity of the turbulent hydrodynamic field, such as the atmosphere, be used as a prototype model exercise.

As an organizing view for the analysis of viable complex systems, we present the new physical doctrine of homeokinesis, a dynamic regulation scheme whereby homeostatic persistence is maintained by the action of chains of thermodynamic engine processes. The homeokinetic view of a complex atomism itself as a factory field establishes a natural hierarchy of organizational levels. The basic physics underlying this description is illuminated by five level-bridging propositions.

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Economics of Nuclear Power

Nuclear plants have been good investments and have produced substantial savings to consumers.

A. D. Rossin and T. A. Rieck

In 1977 nuclear power plants produced about 12 percent of the nation's electric power. This was 20 years after the first almost-commercial-size unit began operating (*1*), 17 years after the first privately financed nuclear plants went into service (*2*), and 8 years after the first large units went on line (*3*). Since 1973 the increase in nuclear energy production has been rapid, averaging 30 percent per year from 1973 to 1977. In 1977 nuclear energy production increased 29.5 percent over 1976, while total electric energy production in the United States increased only about 5 percent.

This article deals with only one aspect of nuclear power: the economics. The industry states that despite problems, delays, and cost increases, nuclear plants saved U.S. consumers well over $1 billion each year in 1975, 1976, and 1977. Nuclear critics claim either that the savings are artificial, or that they will not be there in the future, or that they are irrelevant for various reasons. Some argue that the costs have not all been internalized or that vast hidden subsidies exist.

We believe that documented evidence is publicly available with which to sort out these arguments. In this article we examine the performance of nuclear power in the United States to date by evaluating its economic record relative to that of alternative sources of electricity, with particular reference to nuclear and coal-fired plants in the Commonwealth Edison Company (CECo) generating system. We also evaluate the available electric energy supply options for the late 1980's and discuss what the critics consider hidden costs or subsidies.

Energy Supply Options for Utilities

Utilities must choose between supply options that are technologically feasible, meet environmental criteria, are economically competitive, and for which the fuel supply is reasonably ensured over the expected life of the facility. Today the only available options that meet this test for new plants are nuclear and coal.

A few utilities may have particular options that are not generally available. Some hydroelectric sites may still be capable of development, but the estimates of lead time and the licensing uncertainties exceed those for nuclear plants. In addition, water has other uses, so regulatory bodies as well as the whims of

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nature control its availability. Apart from this, a few systems have geothermal sources and can use them for base load.

Solar-generated electricity—when, if, and to the extent that it can be furnished to utility systems—will be on a "when available" basis. Because of its high capital cost and zero fuel cost, solar energy, like hydropower, would be used whenever possible. To take advantage of intermittent solar electricity will require a reliable electric system with a larger reserve than systems have today. Until reliable and inexpensive batteries or other energy storage systems are developed, solar energy will be available only during the day, the time when demand peaks, and thus will replace peaking capacity and not base load capacity. Utilities will welcome the contribution solar can make to the extent that it can meet reliability and economic requirements.

Since the year-round load factors of most electric power systems are in the range 50 to 70 percent, a mix of various types of generating capacity (base load, cycling, and peaking) is required to optimize system economics. Nuclear often proves to be the more economical base load option, but coal may be better for cycling or peaking duty. Thus, every new plant must be fit logically into an existing generating system. Moreover, the advantage of having a mix of fuels is obvious: the eggs are not all in one basket. This offers some protection against monopoly pricing, strikes, embargoes, and weather effects.

As an example, to meet its load patterns reliabily and economically, CECo's system planners suggest that a maximum of 50 to 60 percent nuclear is appropriate for our system. The optimum will be different for other utility systems.

Utility management decisions are subject to approval by state regulatory commissions, Environmental Protection Agency (EPA) regulations, a myriad of permit requirements, and the Nuclear Regulatory Commission (NRC) licensing process, complete with public hearings and full National Environmental Policy Act (NEPA) cost-benefit presentations. Utilities are obligated by their charters not only to supply reliable electric service to all customers in the region they serve but also to do it at reasonable rates, both for the short run and the long run. As a result, both utilities and regulators are interested in the economics.

Summary. With 12 percent of U.S. electricity now being supplied by nuclear power, Commonwealth Edison has found nuclear plants to be good investments relative to other base load energy sources. The country's largest user of nuclear power, Commonwealth Edison, estimates that its commitment to nuclear saved its customers about 10 percent on their electric bills in 1977, compared to the cost with the next best alternative, coal. This advantage is seen as continuing, contrary to criticisms of the economics and reliability of nuclear power and claims that it has hidden subsidies. It is concluded that there is a need for both nuclear and coal and that government policy precluding or restricting either would be unwise.

Economic Performance of Nuclear and Coal in Commonwealth Edison

Commonwealth Edison Company has six large nuclear and six large coal-fired units in operation, in addition to some 22 smaller coal- and oil-fired units and one smaller nuclear unit. This provides an opportunity to compare the economics and reliability of the different units under one corporate management and in a single geographic region, northern Illinois and the Chicago metropolitan area.

Table 1 is a list of CECo's 12 large nuclear and coal-fired units, their age, size, type, and actual construction cost. The performance of an individual unit is important, but it must be kept in mind that the utility's financial success depends on the combined economic performance of all the units in its generating system. One index of performance is the capacity factor, the ratio of the energy produced by a generating unit in a stated period of time to the theoretical maximum energy it could produce if it ran at its net capability 100 percent of that time. It pays to achieve high capacity factors on base load units, but system reliability and overall economics are the real figures of merit for consumers, stockholders, and regulators alike.

Table 2 shows the actual 1977 generation costs at the bus-bar (the cost of delivering energy to the transmission system at the generating station bus-bar) for CECo's large coal and nuclear units. The costs are divided into three parts: fuel, operation and maintenance, and carrying charges. Carrying charges include depreciation (including the accumulation of a reserve for interim cleaning and end-of-life decommissioning), return on investment (both interest on borrowed money and return on equity), property taxes, insurance, and income taxes.

For 1977 CECo's total nuclear bus-bar generating cost was 13.3 mills per kilowatt-hour, which was lower than the system average cost of generation with coal (24.1 mills/kWh), the average cost of generation from our six newest and largest coal-fired units (20.9 mills/kWh), or the average cost of generation from Powerton units 5 and 6, our two newest and largest coal-fired units (21.3 mills/kWh).

Comparisons with Powerton 5 and 6 are perhaps the most meaningful because if we had not built our six big nuclear units, we would probably have had to install six additional coal-fired units of the 800-MWe (megawatt electric) class, similar to those two Powerton units. However, Powerton 5 and 6 burn only high-sulfur Illinois coal and do not have stack-gas scrubbers to remove sulfur dioxide. By 1 July 1979, in order to comply with emission control standards for existing plants, we must either install stack-gas scrubbers on these units or convert to low-sulfur coal. The use of low-sulfur coal, determined to be least expensive alternative, would increase the Powerton bus-bar costs by about 6.3 mill/kWh to a total of about 27.6 mills/kWh, more than double the total nuclear cost.

During 1977 these six large nuclear units (plus the 207-MWe Dresden unit 1) provided 26.6 billion kWh to the CECo system. This was equal to 41.8 percent of our total net electric generation for the full year. Had this energy been provided by units similar to our six large coal units rather than our nuclear units, our increased cost would have amounted to about $200 million (26.6 billion kWh at an increased cost of 7.6 mills/kWh) (*4*). And if all of these units were required to burn low-sulfur western coal instead of high-sulfur Illinois coal, the differential would increase by about 3.9 mills to 11.5 mills/kWh, or over $300 million for the 26.6 billion kWh. Since the total revenue we collected in 1977 was $2.1 billion, these savings amount to 10 to 15 percent in our customers' bills.

Costs of Alternative Fuels

As shown in Table 2, the fuel cost accounts for the greatest portion of the overall differential between the total generating costs with nuclear and coal. In this section we discuss the actual 1977 fuel costs in greater detail.

1) *Nuclear*. Nuclear fuel cost CECo 3.5 mills/kWh in 1977, of which 1.0 mills/

kWh was included to cover the maximum estimated future cost of the back end of the nuclear fuel cycle (the cost associated with the disposition of discharged or "spent" nuclear fuel). We do not know exactly what the back-end cost will be; the 1.0 mill estimate is for the case in which we are not allowed to reprocess and recycle our spent fuel, but have to pay the government the highest figure we have heard discussed as a one-time fee for government storage and disposal ($250 per kilogram of uranium). If we were to temporarily store the spent fuel ourselves and then pay the government only for ultimate disposal of the unreprocessed spent fuel, the cost would only be about 0.5 mill/kWh, the amount we are now accumulating for this cost through book depreciation on the fuel. Either of these alternatives appears to us to be very costly and unattractive in the long run compared to reprocessing.

2) *Coal*. High-sulfur Illinois coal cost us 8.8 mills/kWh in 1977, averaged over all units that burned it. Low-sulfur western coal averaged 14.1 mills/kWh. About half of the cost of western coal represents transportation from Montana and Wyoming. Over most of the 1200-mile trip the coal is transported by highly efficient 100-car unit trains powered by several diesel locomotives (*5*).

3) *Oil*. Number 6 heavy oil is burned at two generating stations that provide cycling service, one (606 MWe) that was converted from coal in 1970, the other (1010 MWe now and to be enlarged) built because the licensing process for LaSalle County Nuclear Station was extended by more than 3 years; the intervention hinged on questions of land use. In 1977 that oil, most of which was imported, cost us 29.6 mills/kWh, more than double the total bus-bar cost at our nuclear stations.

In some parts of the United States coal burning has been limited by air pollution regulations, and many utilities have been forced to convert large coal units to burn oil or gas. With oil prices now in the range $10 to $15 a barrel and natural gas in limited supply, these units have fuel costs in the range 20 to 25 mills/kWh. Even ignoring the associated operating, maintenance, and plant carrying charges, this fuel cost alone is significantly greater than the total bus-bar cost of 13.3 mills/kWh for CECo's nuclear units in 1977.

4) *Peaker oil*. Number 2 diesel oil is burned by some 104 modified aircraft jet turbines (about 18 MWe each) that are used for peaking and emergency power. This fuel, which has been and may in the future be in short supply for electric generation, cost 48 mills/kWh in 1977. Although it is economical to be able to run these peaking units when we need them, we try to keep their operation to a minimum. In 1977 these units had an average capacity factor of 8.1 percent.

5) *Natural gas*. Natural gas is still sold at regulated prices; a typical price in 1977 gave a cost of about 22.7 mills/kWh for fuel alone when gas was substituted

Table 1. Commonwealth Edison's large generating units.

Unit	In-service date	Net capability* (MWe)	Type†	Construction cost ($/kWe)
Coal				
Joliet 7	9 April 1965	537	Western	113
Joliet 8	21 March 1966	537	Western	113
Kincaid 1	7 June 1967	606	Illinois	118
Kincaid 2	10 June 1968	606	Illinois	118
Powerton 5	30 September 1972	850	Illinois	231
Powerton 6	19 December 1975	850	Illinois	218
Nuclear				
Dresden 2	11 August 1970	794	BWR	147
Dresden 3	30 October 1971	794	BWR	147
Quad Cities 1	16 August 1972	789‡	BWR	165
Quad Cities 2	24 October 1972	789‡	BWR	165
Zion 1	2 October 1973	1040§	PWR	280
Zion 2	19 September 1974	1040§	PWR	280

*Net capability is the maximum dependable rating of the unit, that is, what the utility expects it can get from the unit. This may be limited by design, license, or environmental conditions. †For coal units, Illinois refers to high-sulfur Illinois coal and western refers to low-sulfur Colorado, Montana, and Wyoming coal. For nuclear units, BWR refers to boiling water reactor and PWR to pressurized water reactor. ‡The Iowa-Illinois Gas and Electric Company owns 25 percent of these units. §These units were limited by the NRC to approximately 850 MWe prior to 25 June 1976.

Table 2. Commonwealth Edison's 1977 bus-bar generating costs.*

Generating unit group	Cost (mills per kilowatt-hour of net generation)			
	Fuel	Other production, operation, and maintenance	Carrying charges†	Total
Nuclear				
System average	3.5	2.2	7.6	13.3
Six big units	3.5	2.1	7.5	13.1
Coal				
System average	12.1	3.0	9.0	24.1
Six big units	10.1	2.4	8.4	20.9
Powerton 5 and 6	7.7	2.1	11.5	21.3

*All data shown are taken directly from the company's books for 1977, except as follows: 1.3 mills is added to the nuclear fuel expense on the books to reflect the estimated cost of carrying charges on nuclear fuel in the reactor (0.8 mill), plus an additional allowance of 0.5 mill for the net cost of ultimate disposition of spent fuel. The per-books data already include about 0.5 mill for spent fuel disposition. The coal fuel expense figures per books were increased by 0.6, 0.5, and 0.4 mills/kWh, respectively, to reflect the estimated carrying charges for maintaining a 90-day coal stockpile. †Carrying charges were computed by applying a 20 percent annual fixed charge rate to the gross plant investment in the generating units in question and dividing by the number of kilowatt-hours generated (net) by such units in 1977.

Table 3. Performance of nuclear and large (≥ 400 MWe) coal-fired units from a data compilation by Edison Electric Institute (*8*).

Year	Number of units		Availability† (%)		Capacity factor (%)	
	Coal	Nuclear*	Coal	Nuclear	Coal	Nuclear
1970	51	9	75	85	59	73
1971	64	11	77	79	61	57
1972	80	11	73	77	60	63
1973	93	22	77	78	62	65
1974	108	42	72	68	56	54
1975	117	49	74	70	58	59
1976	123	53	73	68	59	58
	Average‡		74	72	59	59

*The EEI data base includes five nuclear units smaller than 400 MWe which could not be excluded from this comparison. †Availability is the fraction of time the unit was available for service to produce any power at all, whether it was used or not. ‡Weighted by number of unit years.

for coal in a steam-electric unit. We have reduced the use of gas for electric generation to a minimum, below 1 percent in 1977. It is now used mostly to light various large coal-burning boilers and to stabilize the flame pattern at reduced power levels in large pulverized-coal boilers.

Effect of inflation. The bus-bar cost advantage for our existing nuclear units compared with our coal units will grow in the future with inflation. This is because operating, maintenance, and fuel costs will continue to rise with inflation, but the increase will be greater for the coal units. Meanwhile, carrying charges on plant investment, which has already been expended, essentially do not change.

For example, if the operating, maintenance, and fuel costs shown in Table 2 were to double (which would occur in 12 years with the current 6 percent per year inflation rate), the bus-bar cost would increase by 5.6 mills for our six large nuclear units and 12.5 mills for our six large coal units. That would increase the nuclear advantage from 37 percent (7.8 mills) to 44 percent (14.7 mills).

Operating Performance: Nuclear and Coal

Some nuclear critics, on the basis of projections of past operating data, have claimed that future nuclear plants will have low capacity factors, while future coal plants will have very high capacity factors (*6*). Such claims lead to the further conclusion that coal plants will have lower bus-bar costs. We disagree with both the projections and the claims.

Although much has been made of the capacity factors of nuclear and coal-fired plants, it must be remembered that the capacity factor is only one input into the economics of power plants. The actual bus-bar cost is the most important basis for comparing single units (*7*). A low bus-bar cost may be achievable with a high capacity factor and high construction cost, or with a low capacity factor and low construction cost, and most plant designs fall somewhere between these extremes. It is misleading to project capacity factors of future units from historical unit performance alone without evaluating changes that have taken place in plant design based on the operating experience that is gained from year to year.

Comparison of data on coal and nuclear units is complicated for a number of reasons. Many coal plants switched to gas or oil and back again to coal. Units have been uprated, modernized, or derated. Switches from high- to low-sulfur coal have meant reduced capacity ratings, as have additions of stack gas scrubbers and cooling towers. A unit can have a long outage or major overhaul that gives it a very low capacity factor one year and then perform admirably several years in succession. Thus, there is a good deal of scatter in individual unit data above and below annual averages. Large generating stations are built to run for 30 years or more, and care must be used in evaluating annual data because extreme values can have exaggerated effects on annual averages.

Although the coal data base is complex, the Edison Electric Institute (EEI) has compiled 10-year data (*8*) on some 100 coal units larger than 400 MWe which are sufficient for a reasonable comparison. In Table 3 we compare the EEI data over the period 1970 through 1976 for large coal-fired units with all available data for nuclear units. The comparison shows that the availability and capacity factor averages for large coal and nuclear plants are in the same range.

One of the issues in debate is whether future large units will have lower capacity factors than smaller ones, and what significance that would have if it proved to be the case. The record shows, however, that the performance of large units is not much below that of smaller ones. A close look at low capacity factors of large units reveals either that there are unique problems not related to unit size or that the units in question are relatively new and have not matured (*9, 10*). In fact, since the large units are the newer ones, simple statistical analyses (*10*) fail to differentiate between newness and size (*11, 12*).

At the end of 1977 there were ten nuclear units with capacity ratings larger than 1000 MWe. Table 4 lists these units and their capacity factors in 1976 and 1977. The sizable difference between the average capacity factors for 1976 and 1977 is largely due to the long shutdown

Table 4. Capacity factors of nuclear units larger than 1000 MWe in 1976 and 1977 from a Nuclear Regulatory Commission report (*24*).

Name	Net design capability (MWe)	Commercial service date	Capacity factor* (%) 1976	Capacity factor* (%) 1977
Browns Ferry 1	1065	1 August 1974	13.9	54.1
Browns Ferry 2	1065	1 March 1975	16.8	66.7
Browns Ferry 3	1065	1 March 1977		74.8
Cook 1	1054	27 August 1975	73.5	51.8
Peach Bottom 2	1065	5 July 1974	59.5	43.1
Peach Bottom 3	1065	23 December 1974	64.7	51.2
Salem 1	1090	30 June 1977		42.5
Trojan	1130	20 May 1976	27.3	65.6
Zion 1	1040	31 December 1973	52.1†	55.3
Zion 2	1040	17 September 1974	50.8†	68.9
Average‡			45.8	57.9

*These are annual capacity factors for full months since entering commercial service. †The Zion units were limited by the NRC to approximately 850 MWe net prior to 25 June 1976. The 1976 capacity factors based on the allowable NRC net rating would have been 57.1 percent and 55.6 percent for Zion 1 and 2, respectively. Based on the allowable ratings, the 1976 average for all units above 1000 MWe would have increased to 47.1 percent. ‡Weighted by number of full months of commercial service.

Table 5. Yearly availability and capacity factors of CECo's large nuclear and coal plants.*

Year	Large nuclear† Number of units	Large nuclear† Availability (%)	Large nuclear† Capacity factor (%)	Large coal Number of units	Large coal Availability (%)	Large coal Capacity factor (%)
1970	1	60.6	31.5	4	77.0	58.1
1971	2	61.8	39.5	4	71.7	53.7
1972	4	68.6	61.1	5	71.0	55.5
1973	5	77.4	66.3	5	69.2	54.3
1974	6	59.5	51.1	5	72.6	58.0
1975	6	64.4	50.7	5	67.5	53.5
1976	6	71.4	57.3	6	60.0	44.7
1977	6	79.9	60.7	6	66.5	46.2
Average		70.0	56.3		68.6	52.2

*Availability and capacity factors were calculated beginning with the first full month after the in-service date, weighted by the number of in-service months and net capabilities. †The values for Zion 1 and 2 are based on net capabilities of 851 and 852 MWe, respectively, prior to 25 June 1976 and 1040 MWe thereafter.

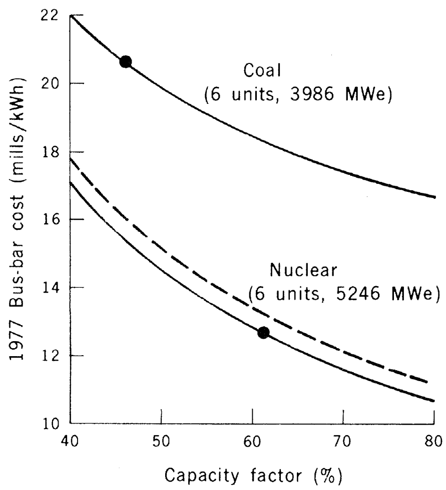

Fig. 1. (○) Actual bus-bar cost of electric generation for CECo's six large coal-fired and six large nuclear units. (Solid curves) How generation costs would vary as a function of the average capacity of the coal-fired and nuclear units. (Dashed curve) Nuclear generation costs if the cost assigned to spent fuel storage and waste disposal were doubled, from 0.5 to 1.0 mill/kWh. Note: one-fourth of the Quad Cities station (395 MWe) is owned by the Iowa-Illinois Gas and Electric Company but is operated by CECo and is included in this graph.

of Browns Ferry units 1 and 2 because of fire, an event having nothing to do with unit size.

The average annual availability and capacity factors of CECo's large nuclear and coal units since 1970, given in Table 5, show how such units perform relative to each other in a single utility system. Although there are year-to-year variations, there is no significant difference in performance between the nuclear and coal units on the average.

The variations in performance shown in Table 5 were due to a number of problems. The CECo boiling-water reactors had poor years in 1974 and 1975. Sparger replacements and inspection and repair of cracked recirculation bypass and core spray piping, in addition to the traditional run of operating difficulties, ate into their performance. The Zion station also has a unique history. Zion 1 was declared commercial at the end of 1973 and, in addition to first-year problems, required a 17-week shutdown to rebuild the electric generator. Zion 2 was declared commercial on 17 September 1974 after similar reworking of the generator. The Zion units were the first pressurized water reactors of the 1000-MWe class to go into operation. Thus they provided some learning experience for CECo (which has four more similar units under construction) as well as for the entire nuclear industry. Since they were the first 1000-MWe pressurized water reactors to go into service, the NRC restricted their licenses to 85 percent until the first refueling, a conservative and costly approach, but one that was agreed to by all parties.

The coal units were not without their own problems. The Kincaid units were plagued by boiler tube, air heater, and turbine problems. The new Powerton units had periods of good performance, but their availability suffered from a main transformer failure, a turbine feed-pump failure, boiler chemical cleaning problems, as well as unique coal-handling problems brought on by a severe winter, such as coal frozen on conveyor belts, in railroad cars, and in barges on the river.

Effect of Capacity Factor on Economics

Although nuclear and coal units should not be compared on the basis of capacity factors alone, a comparison of generating costs at different capacity factors is enlightening.

The curves in Fig. 1 show the bus-bar cost of CECo's six large nuclear and six large coal units as a function of capacity factor (the actual 1977 bus-bar costs are indicated with circles). These curves were developed from the information presented in Table 2. To a first approximation, the fuel cost and about half of the other costs (mostly operating and maintenance) do not vary with capacity factor. The plant carrying charges, however, are spread over the total kilowatt-hours. Therefore, the higher the capacity factor, the less it costs to generate each kilowatt-hour.

From the curves in Fig. 1 it can be concluded that if nuclear and coal units are expected to have about the same capacity factor, the nuclear units will have an economic advantage over the coal units. If they are expected to have different capacity factors, the coal units will be more economical only if they have significantly greater capacity factors than the nuclear units. However, these curves are somewhat misleading for predicting future costs because the coal units were installed earlier than the nuclear units and because of new air-quality regulations. To make a valid comparison of the generation costs the carrying charges on the coal-fired units should be increased by approximately 15 percent, reflecting the fact that they were installed about 3 years earlier on the average than the nuclear units and that the effect of inflation on construction costs over those years amounted to about 15 percent.

Table 6. Estimated construction costs per kilowatt for nuclear and coal base load units in CECo's Northern Illinois area, in 1977 dollars.

Plant type	Cost* ($/kWe)
Nuclear (two 1200-MWe units)	692
Coal with scrubbers (two 550-MWe units)	638
Coal without scrubbers (two 575-MWe units)	484

*Reflects a 7 percent annual allowance for funds used during construction.

Of the coal-fired units in this group, Joliet 7 and 8 burn low-sulfur western coal exclusively; Powerton and Kincaid (a mine-mouth station with no rail or barge access) use high-sulfur Illinois coal exclusively. As we mentioned earlier, the average generation costs for these six units would have been 3.9 mills/kWh higher in 1977 if they had all burned western coal, which now appears to be our least expensive alternative for complying with the latest emission control standards.

Future Plant and Energy Costs

Although nuclear power has been the most economical choice for CECo in the recent past, changing regulations, construction costs, and fuel costs require a new evaluation for future decisions. We recently made such an evaluation for new nuclear or coal units for service in the late 1980's (*13*).

Our most recent construction cost estimates (made in early 1978 and expressed in 1977 dollars) for nuclear and coal base load units in CECo's Northern Illinois service area are shown in Table 6. The estimated construction cost of a nuclear generating plant comprising two 1200-MWe nuclear units is $692 a kilowatt. That of a coal-fired generating plant consisting of four 550-MWe coal-fired units equipped with flue-gas scrubbers is $638 a kilowatt. [The estimated cost for a coal-fired unit not equipped with flue-gas scrubbers is $484 per kilowatt (*14*), but that is not considered a viable option today because of emission control standards for new power plants.]

These cost estimates (except for the coal plant without scrubbers) were made assuming compliance with the latest government regulations related to environmental, health, and safety matters. They include a cost allowance for funds used during construction based on a 7 percent annual rate. Because of inflation and the lead time of 10 years or more, the installed cost for a plant going in service in the late 1980's will be almost double these estimates.

Estimated carrying charges on plant investment can be calculated for nuclear and coal-fired plants by applying a 20 percent annual fixed charge rate to the estimated construction costs and assuming a 60 percent capacity factor for both nuclear and coal. We consider a 20 percent annual fixed charge rate appropriate for making investment and replacement decisions. It is purposely on the high side, reflecting today's overall capital shortages and financing difficulties. This penalizes the nuclear alternative, with its higher capital cost, to some degree.

Based on 1977 dollars, the carrying charges per kilowatt-hour on plant investment would be 26 mills for nuclear, 24 mills for coal with scrubbers, and 18 mills for coal without scrubbers. Fuel charges are derived from the assumed long-run replacement costs presented in Table 7.

Table 8 shows the estimated total bus-bar generating costs for these future plant options. Oil is included for illustration only (*15*). The comparative bus-bar costs per kilowatt-hour for Northern Illinois are 35 mills for nuclear, 42 mills for high-sulfur coal, 43 mills for low-sulfur coal with scrubbers, and 42 mills for oil, giving a nuclear advantage over the latter three options of 17, 19, and 17 percent, respectively. The nonviable low-sulfur coal case without scrubbers turned out to break even with nuclear.

How important are these differences? A 1200-MWe nuclear unit operating at a capacity factor of 60 percent saves $6.3 million per year for each mill per kilowatt-hour differential in its favor. Therefore, since nuclear has an advantage of 7 mills/kWh over the cheapest coal option, high-sulfur coal, our customers would be saved about $44 million a year for each such nuclear unit installed.

Subsidies and Hidden Costs

It has been stated that nuclear power is subsidized and that its apparent cost advantage has been made possible only by federal subsidies and covers certain hidden costs. However, the figures do not show that nuclear manufacturers or utilities are the beneficiaries of government subsidies.

1) *Enrichment*. The major area of government involvement is enrichment. According to the latest published financial statements, the U.S. government had a net income of $110 million from its enrichment operations in the fiscal year ending 30 June 1976. This was a rate of return of 13 percent (*16*), which might be compared with the 9.3 percent the Illinois Commerce Commission allows CECo on its invested capital. In addition, the government collected $50 million for depreciation of plants originally built for weapons material production, which it would not have recovered if commercial nuclear power had not been developed. Furthermore, although carrying charges on the enrichment plants, which were built years ago, should have remained constant, the price of enrichment services has nearly trebled since 1967 and is predicted to go higher (*17*). To quote Gordon Corey, vice-chairman of CECo, "If this is a subsidy, it is different from any other kind of subsidy I know" (*17*).

2) *Waste disposal*. There are uncertainties about waste disposal today, largely as a result of delays in government demonstration projects and the Administration's policy of deferring reprocessing. The 0.5 mill/kWh we charge on our books should be sufficient to provide for all disposal costs by the time final disposition is made of all nuclear fuel on hand, including spent fuel. In any event, the fuel cycle services the government provides will be billed to the utilities without subsidy, like the enrichment services. Even if this estimate turns out to be 100 percent low, its impact on overall generation costs will not be enough to change the competitive position of nuclear power compared with coal.

3) *Decommissioning*. It is estimated that the cost of decommissioning a nuclear plant will be between $20 million and $40 million 30 or 40 years after start-up, depending on the criteria that are ultimately adopted (*18*). (Feasibility is not really in question; there are several options, with different price tags, from which to choose.) This translates into a cost of about 0.2 mill/kWh, and substantially less than this after present value discounting. We are providing for these costs through depreciation provisions, which are charged to expense and accumulated in the depreciation reserve over the useful life of the facility. This is a matter that state regulatory commissions and accounting experts will debate, but in any case it will have a very small impact on utility rates or the viability of nuclear power.

4) *Nuclear insurance*. Price-Anderson indemnity (*19*) deserves more discussion than this space permits. However, there

Table 7. Fuel cost assumptions (1977 dollars).

Assumptions	Cost (mills/kWh)
Nuclear fuel*	
Yellow cake, $40 per pound	3.5
Uranium for conversion to UF6, $2.75 per pound	0.1
Enrichment (0.20 percent tails assay), $75 per SWU†	1.8
Fabrication, $110 per kilogram of uranium	0.7
Net salvage‡	1.0
	7.1
Fossil fuel§	
High-sulfur coal, $1.20 per million Btu, with scrubber	13
Low-sulfur coal, $1.40 per million Btu, with scrubber	16
Number 6 oil, $2.50 per million Btu, without scrubber	26

*Burnup is assumed to be 33,000 megawatt-days per ton for pressurized water reactors and 29,000 megawatt-days per ton for boiling-water reactors. †SWU, separative work unit, as defined by the Department of Energy. ‡We assumed a net salvage cost (cost associated with the ultimate disposition of discharged or spent nuclear fuel) of 1 mill/kWh. §Cost delivered in the Chicago area, including estimated carrying charges for maintaining a 90-day fuel inventory.

Table 8. Estimated total bus-bar generating costs for future plants, in 1977 dollars.

Plant type	Cost (mills/kWh)				Nuclear advantage	
	Fuel	Operation and maintenance	Carrying charges	Total	(mills/kWh)	(%)
Nuclear	7	2	26	35		
High-sulfur coal with scrubbers	13	5	24	42	7	17
Low-sulfur coal						
Without scrubbers*	15†	2	18	35	0	0
With scrubbers	16	3	24	43	8	19
Oil without scrubbers	26	1	15	42	7	17

*Not viable under existing emission control standards. †Higher fuel cost in scrubber case is for additional fuel to make up for inefficiencies in the scrubber operation.

have been no claims against the government to date, and the utilities have been receiving rebates against premiums they pay to private insurance pools. Even if there were no Price-Anderson indemnity, it would not affect our decision to go forward with nuclear power. However, it would almost certainly delay licensing. Antinuclear interveners have stated that, if there were no limit on liability, any utility or vendor could be challenged about his ability to cover an improbable but potentially exorbitant set of claims. The constitutionality of the Price-Anderson Act was reaffirmed by the Supreme Court (June 1978). It should be noted that similar limits on liability exist for airlines and ships, as well as for the government and its suppliers of swine flu vaccine, for example. The issue is the limit itself, not the premiums.

5) *Research and development*. The United States has invested more than $9 billion in R & D on nuclear power. About one-third of this, or $3 billion, was applied to light-water reactor development, safety, fuel cycle, and supporting work (the other $6 billion was applied to advanced nuclear power concepts including breeder reactors and to general research on materials, radiation effects, applied mechanics, instrumentation, and so on). The capital investment in the 64 nuclear units that were on line at the end of 1977 was about $20 billion and that in plants now under construction is about $75 billion. Commonwealth Edison's nuclear construction budget from 1978 through 1984 is $4.0 billion.

Considering the $6 billion (oil equivalent) value of nuclear-generated energy in 1977, the $3 billion spent over the last 30 years may be the best investment in R & D the United States has ever made. In addition, the savings in cost of generating electric energy compared to the available coal and oil alternatives has returned the $3 billion and more since the oil embargo.

Capital Costs and Profits

A popular charge against nuclear power is that, regardless of favorable lifetime economics, so much capital is required to build nuclear plants that not enough is left for other investments, as in industry, housing, education, or welfare. At first glance this argument might appear plausible, because individual utilities have been forced to postpone projects for lack of capital. But the availability of capital to any single company depends on its earnings and financial soundness.

In 1977, the United States sent $40 billion out of the country to pay for oil and the amount is expected to increase in the future. In view of this, it is difficult to see how one can honestly charge that investment of a fraction of this amount in nuclear plants, and but a fraction of that in nuclear research, is the reason that capital for other investments is in short supply.

Investment in new power plants will not continue unless there is reason to believe that people and industry will need the electricity. The existence of power plants is not enough to ensure a growing economy (witness Britain in the last decade until North Sea oil and gas cut its export of capital). But failure to build capacity will ensure energy shortages in the future.

The issue of capital is even weaker in view of the data in Table 6, which show that the capital costs of a coal plant are only 8 percent lower than those of a nuclear plant. Finally, Forbes and Turnage (*20*) have calculated that even a low-growth scenario, the "soft path" proposed by Lovins (*21*), would require three times as much capital to produce the same amount of energy as conventional nuclear and coal-fired power plants.

A popular charge against utilities is that they are willing to pay higher costs because they can pass them on to their customers. It is a fact that sooner or later the costs of the electric energy delivered will be charged to the people who are served; there is no other source of revenue. If the costs to utilities rise, the communities suffer; people must pay a larger fraction of their income for utilities, leaving less for spending locally, for enjoying life, and for savings; industry and new developments are attracted elsewhere, putting more pressure on local tax bases. When utilities increase their rates, the customers do not like it. When the increase is not enough for the utility to meet its costs, it must defer spending on things that are essential. The costs of these deferrals ultimately come home to the customers, and experience shows they are generally later but greater.

Utilities do not have a financial incentive to invest in new plants today. Interest costs are at an all-time high; new borrowing increases the average cost of the corporation's debt. Because of inflation, new plants of any type will generate at higher cost than existing units. The days when a utility could build a new plant, increase its rate base, and reduce its overall generation costs have been gone for more than a decade. To the extent that conservation can reduce future demand, utilities will postpone their next commitment.

The real concern of the public today should be that utilities are underinvesting for future plant needs. Delay in investing in base load plants carries two serious risks: (i) if capacity is short, supply will have to be made up by burning more oil and gas and (ii) if future capacity appears inadequate, industrial investments will be made elsewhere or not at all, and the jobs and economic benefits they would have brought will be lost (*22*).

Conclusions

Because the cost picture for nuclear power has looked so favorable compared to that for alternative energy sources, it has become tempting to accept cost increments in all kinds of areas rather than risk long delays to argue points of technical judgment. It is widely recognized that nuclear plants are overdesigned from seismic and safety standpoints. Efforts to achieve standardization in the hope of shortening the licensing process have meant increased costs. Backfits have been extremely expensive. Regulatory delays, and indeed the long period required for NEPA, site, and safety review, have meant absorbing huge costs in interest charges and replacement power. Adding increments cannot go on indefinitely. The technology could someday be priced out of the market. We believe the loser in that event would be the American people.

The present nuclear cost advantage will probably continue. But even if nuclear power were to have a slight cost disadvantage, it would be essential for diversity of supply to guard against the depletion of domestic oil and gas and the debilitating effect of huge oil imports, and to compete with coal in order to keep all fuel prices from skyrocketing further (*23*). In fact, for diversity of supply or for geographic and system planning reasons, a utility might choose the option that appears to have the higher bus-bar cost if the differential is small, should it appear possible that the choice might result in lower long-term costs to its customers.

In our opinion, if projected bus-bar costs differ by as little as 20 percent, there is an essential role for both technologies, coal and nuclear. There is simply too much uncertainty to claim that any projections will be wholly accurate over the next 40 years. Furthermore, uranium and plutonium have virtually no other use than for energy. This is not true for oil, coal, and gas, which have important nonenergy uses for plastics, chemicals, and other purposes.

Therefore in making generating plant

decisions, CECo is unwilling to choose sole dependence on either coal or nuclear generation on the basis of a 20 percent cost advantage either way. As of 1978 CECo has six nuclear units of the 1100-MWe class under construction. We project that in the mid-1980's about 60 to 65 percent of our generation will be nuclear, about 30 percent will be coal, and the remainder will be oil. Generating unit commitments for the foreseeable future will be nuclear and coal. We believe that any policy that precludes or restricts either technology would be unwise for the United States as a whole.

References and Notes

1. Shippingport, Pa. (90 MWe).
2. Dresden 1, Morris, Ill. (200 MWe); Indian Point, Peekskill, N.Y. [265 MWe (now shut down)]; and Yankee Rowe, Rowe, Mass., 175 MWe.
3. Nine Mile Point, Oswego, N.Y. (610 MWe), and Oyster Creek, Toms River, N.J. (650 MWe).
4. Utilities that have fuel adjustment clauses in their rates pass on fuel cost increases (above a stipulated level) directly to their customers and thus make no profit on that portion of the rate. Nuclear fuel is generally not covered by such clauses. As part of the regular rate structure, it can only be increased in regular rate-making proceedings.
5. A typical unit train is 100 cars long, each car carrying about 90 tons of coal. Edison's coal-burning plants keep 32 such trains in operation, each making weekly round trips. It takes 10,000 to 20,000 gallons of diesel fuel per round trip, depending on route and weather conditions. A simple calculation reveals that this haulage requires about 500,000 barrels of oil per year.
6. For example, see C. Komanoff, *Power Plant Performance* (Council on Economic Priorities, New York, 1976).
7. A. D. Rossin, *Economics and Reliability of Light Water Reactors* (American Nuclear Society, LaGrange, Ill., 1976).
8. *Report on Equipment Availability for the Ten-Year Period 1967–1976* (EEI No. 77–64, Edison Electric Institute, New York, 1977).
9. M. E. Lapides, *Power Eng.* **80**, 52 (October 1977).
10. ———, *Nuclear Unit Productivity Analysis, 1976 Update* (EPRI NP-559-SR, Electric Power Research Institute, Palo Alto, Calif., 1977).
11. *The Edison Electric Institute's Comments and Critique of the Council on Economic Priorities Report* Power Plant Performance *and Its Later Update* (Edison Electric Institute, New York, July 1977).
12. L. J. Perl, *Review and Critique of the CEP Study* Power Plant Performance (National Economic Research Associates, Washington, D.C., 1977).
13. In 1972, CECo filed load projections showing an average peak load growth of 7.6 percent per year through 1982 and 7.1 percent per year thereafter (Byron Station Environmental Report, docket numbers STN 50-454 and 50-455, docketed 20 September 1973). Minimal load growth occurred in 1974 and 1975. The load projections now being used by CECo estimate load growth at 5.3 percent per year from 1978 to 1982 and about 5.0 percent per year thereafter. The reduction is due to a combination of slower economic growth and increased energy conservation. The new peak load projection for 1982 is 17,720 MWe, compared to 24,350 MWe in the 1972 forecast. Since a 5.0 percent growth rate after 1982 still calls for about 900 MWe of new capacity annually (plus replacement of obsolete plants, if any), CECo still expects to add a large nuclear unit almost each year in the late 1980's. It is important to note that the entire increase in U.S. electricity use from 1976 to 1977 was 4.9 percent and the peak load was up 6.5 percent (press release, Edison Electric Institute, New York, 11 January 1978).
14. Although it is not a viable option for new capacity under the National Energy Plan, the estimated cost for an oil-fired station without flue gas scrubbers is about $400 per kilowatt. We have limited station size for coal and oil to approximately 1100 MWe to comply with the Clean Air Act amendments of 1977, using available emission control technology. Two 550-MWe units were considered rather than a single 1000-MWe unit because we have not had experience with fossil units in the 1000-MWe class.
15. It has been the policy of the government to discourage the use of oil and gas for the production of electricity. The Department of Energy has the authority to demand conversion of oil- or gas-fired units to coal. In view of this and the obvious risks in further reliance on oil, utilities do not consider oil a viable alternative.
16. *Uranium Enrichment Services Activity Financial Statements* (ERDA 77-27 UC-2, Energy Research and Development Administration, Washington, D.C., March 1977).
17. G. R. Corey, testimony before the Environment, Energy, and Natural Resources Subcommittee of the Committee on Government Operations, U.S. House of Representatives, 88th Congress, 1st session, 19 September 1977.
18. *An Engineering Evaluation of Nuclear Power Reactor Decommissioning Alternatives* (AIF/NESP-009, Atomic Industrial Forum, Washington, D.C., 1976).
19. The Price-Anderson Act requires nuclear plant operators to obtain as much liability and property damage insurance as the private insurance industry is willing to offer, and beyond that provides government indemnity, increasing from $560 million originally to $1 billion by 1987, which is also paid for by premiums from the utilities (no government subsidy is involved). As private industry is willing to provide more, the government share will be phased out. Price-Anderson puts an upper limit on the liability of a utility for accident claims. Elimination of this upper limit would leave an open-ended potential liability on a corporation's books.
20. I. A. Forbes and J. C. Turnage, *Exclusive Paths and Difficult Choices* (Energy Research Group, Framingham, Mass., 1978).
21. A. B. Lovins, *Foreign Affairs* **55**, 65 (October 1976).
22. Press release, National Association for the Advancement of Colored People, Washington, D.C., February 1978.
23. Nuclear generation in the United States in 1977 was 240 billion kWh. This was equivalent to 125 million tons of coal or 430 million barrels of residual oil.
24. *Operating Unit Status Report* (NUREG 0020, Nuclear Regulatory Commission, Washington, D.C., April 1974 to February 1978).

Need for Reform in Health Professions Accrediting

A multiprofessional mechanism offers a means of reform in health professions accrediting.

Donald C. Brodie and Robert P. Heaney

Accreditation in postsecondary education in the United States applies to institutions of higher learning and programs within those institutions, that is, institutional accrediting and program accrediting. Institutional accrediting is carried out by six regional accrediting bodies, whereas program accrediting in the health field is a responsibility of some 20 specialized accrediting agencies. Both types are coordinated by the Council on Postsecondary Accreditation (COPA) (*1*). This arrangement is nongovernmental in origin, in contrast to the system in most other nations where ministries of education within the government are responsible for setting and maintaining standards. Dickey and Miller (*2*) place the subject in a contemporary framework as follows:

> Accreditation . . . permits and encourages the professions to contribute to the assurance that their future members will be adequately educated and prepared to serve societal needs.
>
> The role of accreditation in American Society has grown to the extent that virtually every institution and many programs of study are forced to seek accredited status. Institutions may exist but few thrive without accreditation. Seen in this light, it is a misnomer to term accreditation voluntary. The function accreditation serves must be performed for a complex society. If it were not performed by private groups, government agencies would have to step in to fill the void. Because of its growing social role, many have termed accreditation a quasi-governmental function. But accreditation also serves narrower, less public functions (*2*, pp. 2–3).

The authors go on to acknowledge both the growing national commitment to education at all levels through the granting of public money and a concern for educational opportunities and fulfillment for the disadvantaged. Because education has become "recognized as indispensable to private individual benefit and to the public welfare" the accrediting process is now viewed as serving a social

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