ATOMIC POWER AND ENERGY RESOURCE PLANNING

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Atomic energy was introduced to the world as a force of unprecedented destructive power, but in opposition to its military potential, scientists emphasized the physical similarity between destructive and commercial applications. Both utilize the same atomic fuels and are founded upon the same basic science concepts. Atomic swords could be made into atomic plowshares in a direct sense.

The high hopes for commercial applications were incorporated in domestic legislation and became the cornerstone of the United States proposals for international control of all atomic energy applications. Realization of these hopes, however, was necessarily postponed in deference to the more immediate and increasingly apparent requirements for manufacturing atomic armaments. The prospects of international agreement faded, and with them the prospects of early commercial application. The United States atomic energy industry grew rapidly as a result of the impetus of defense preparedness.

In recent years, sufficient capacity for production of atomic fuels has been available to satisfy military goals and at the same time to permit the growth of peaceful applications. Atomic electric power, atomic space and process heat, food irradiation, thermonuclear power, atomic propulsion, and related civil applications are being studied. Radioisotopes, a longstanding commercial (and research) byproduct, are being used on a large scale in American science and industry.

From an energy resource standpoint, the most important of these in the foreseeable future will be atomic electric power and atomic space and industrial process heat. Others are in too early a stage of development to permit meaningful discussion of their commercial prospects, or, like radioisotopes and food irradiation, are not primarily energy sources.

THE ENERGY RESOURCE PROBLEM

There are four major limitational factors in man's environment: food, water, energy, and other mineral and nonmineral resources. We need no figures to remind us of the general significance of each of these, though their quantitative relationships to material welfare are far from simple in advanced economies. For present purposes, we shall rely upon accepted projections of economic growth as these determine (and are determined by) human needs, giving sole attention to energy requirements and energy resource availability.

The quantitatively most significant energy resources in the world today are coal, oil, gas, and vegetable fuels. The first three taken together account for three-quarters of present world energy consumption, while vegetable matter, which (in the form of fuel wood) was the most important source of energy a century ago, accounts for another

15 percent.[1] The remainder of the energy is derived from falling water, direct muscular efforts of men and draft animals, and other sources quite unimportant quantitatively. In the United States, approximately 96 percent of the energy is derived ultimately from coal, oil, and gas. The rest is from falling water (in the form of hydroelectric power) and unclassified noncommercial sources.

As a first approximation in analyzing energy needs and resources, we shall lump together all energy from whatever source, usually on the common basis of electricity equivalents, in kilowatt-hours, at full calorific value. This means, for example, that a short ton of bituminous coal contains approximately the same energy as 7,680 kilowatt-hours of electricity; a barrel of crude oil, 1,700 kilowatt-hours of electrical equivalent; and so on.

It does not mean that either the coal or the oil will actually produce the corresponding amounts of electricity, simply because there are energy losses in the process of converting these fuels to their electrical equivalents. If there were no such losses, however, the coal and the oil would in fact yield the indicated kilowatt hours. In expressing all energy resources on the common basis of energy content, we are merely assuming (for the time being) that they are good substitutes for one another in satisfying (by one means or another) various ultimate consumer wants.

Energy and economic growth

A rough but unmistakable correlation between energy consumption and economic progress can be shown in two ways.

First, while real national income in the United States increased 3.83 times from 1900 to 1950,[2] the total amount of energy consumed increased 3.48 times.[3] At the same time, efficiency in heat collection and conversion to other energy forms increased 2.7 times.[4] In other words, the economic growth of the United States in the first half of the 20th century was accompanied by an almost proportionate increase in energy consumed, but a 9.4-fold increase (2.7×3.83) in energy used per dollar of real national income.

Second, comparing the countries of the world today, we find a roughly equivalent percentage improvement in per capita real national income with greater per capita consumption of fuels. Using data for 1949, one study reported that approximately a 3-percent improvement in national income corresponded to a 2-percent increase in energy consumption.[5] Another study reported 1952 data for 42 individual countries showing a range from Burma with lowest per capita annual income of $43 (and annual per capita energy consumption of 0.27 metric ton of coal equivalent) and Haiti with lowest energy consumption of 0.25 metric ton of coal equivalent (and per capita income of $65) to the United States with highest values of

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[1] United Nations Department of Economic and Social Affairs, World Energy Requirements in 1975 and 2000, Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, vol. 1 (United Nations, 1956), pp. 21, 22.

[2] J. F. Dewhurst and Associates, America's Needs and Resources (Twentieth Century Fund, 1955), pp. 40–41.

[3] Calculated from data given by J. F. Dewhurst et al., ibid., p. 1114.

[4] P. C. Putnam, Energy in the Future (Van Nostrand, 1953), p. 90.

[5] E. A. G. Robinson and G. H. Daniel, Need for a New Source of Energy, Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, vol. 1 (United Nations, 1956), pp. 36–41.

both at $1,857 and 8.18 metric tons of coal equivalent.[6] In other words, the extremes of the data show a forty-three-fold increase in real income accompanied by a thirtyfold increase in energy consumption, and a twenty-nine-fold increase in real income accompanied by a thirty-three-fold increase in fuel consumption. This is essentially the same relation as found in the other nation-by-nation study in that it indicates a slightly less than proportional increase in energy consumption with economic growth.

Certain conceptual difficulties attend the nation-by-nation comparisons. There are differences in energy costs which account for more or less intensive use of energy by countries having approximately the same levels of national income. Another aspect of the same point is that differences in other mineral and nonmineral resources help determine the product mix of industry, which in turn may be more or less energy intensive.[7] Finally, differences in climate have an obvious effect upon requirements for space heating, which accounts for a surprisingly large proportion of energy consumed. Putnam assigns 34 percent of the fuel consumed in the United States in 1947 to the end use of comfort heating.[8]

These qualifications are considerable, but not sufficient to prevent our drawing meanful conclusions. The most serious difficulty, due to space heating, would appear to have a systematic effect in that the more advanced nations happen to lie in the temperate and colder areas of the world. To the extent that this is true, the data are no less regular, but the relation between real national income and energy consumption is reduced to one in which energy consumption increased at a relatively constant, but lower rate with real national income.

Neither of the nation-by-nation studies took into account differences in efficiency of energy conversion, which we have noted were important (by a factor of 2.7) in showing a more than proportionate increase in energy utilization with economic growth in the United States. It is not, however, necessary that they do this, as long as we hypothesize that efficiencies in energy utilization improve in about the same way as economic development proceeds. Then, increases in fuel consumption bring even greater increases in fuel utilization, but in relatively constant proportion. We shall in fact make this hypothesis, except for the mature economies of North America and Western Europe, where technological considerations indicate that future improvements in efficiency of energy conversion, whatever the rate of growth in real national income, will be less marked than in the past.

Projected energy needs

The general basis for projecting energy needs in the future has been established by our discussion of past growth-energy relationships.

Prevailing opinion with respect to future economic growth in the United States puts the matter negatively: there is no basis for thinking that the overall rate of economic growth is slowing down.[9] Over

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[6] E. S. Mason and Associates, Energy Requirements and Economic Growth (National Planning Association, 1955), pp. 3–17.

[7] For a discussion of these and related problems, see Mason, ibid.

[8] Op. cit., supra, note 4, p. 102.

[9] See M. Abramovitz, Resource and Output Trends in the United States Since 1870, American Economic Review, Papers, and Proceedings (May 1956), pp. 14–19, and references cited therein.

the last 10 years, the rate of growth of real gross national product in the United States has averaged about 2½ percent per annum; and over the past 20 years, about 4½ percent.[10] The 20-year period, however, included recovery from the great depression and a major war effort. If we take the 2½ percent per annum as a reasonable figure for the future, past experience suggests a 2¼ percent annual increase in energy consumption.

But we must qualify past experience before applying it to the future. First, we have seen that great improvements in efficiency of energy conversion in the United States kept energy consumption down to the observed rate of increase. The average efficiency of energy conversion was estimated at 11 percent for 1900 and 30 percent for 1950 [11] (giving our previous figure of 2.7-fold increase). The same estimates projected to 2000 A. D. indicate an average efficiency of 42 percent,[12] or only a 1.4-fold increase over 1950. This fact alone would account for almost a doubling of the rate of energy consumption over the rate predicted from experience in the first half of the 20th century. Thus, our 2¼-percent annual increase would become 4½ percent, but we shall round it down to 4 percent to allow for nonlinearity in the relationship of efficiency improvement with time.[13]

At the same time, energy consumption is more strongly affected by industrial activity and manufacturing than by increases in services and commerce. Robinson and Daniel show that a high rate of growth would be required if industrial output were assumed to continue indefinitely as a constant proportion of real gross national product, but argue that the energy-intensive sectors, mining and metals processing, do not normally continue to grow at undiminished rates.[14] It is common experience in advanced economies that primary activities continue to diminish in proportion to tertiary and service functions. This would imply a reduction in the rate of increase of energy needs with growth in these economies.

The President's Materials Policy Commission (Paley Commission) suggested a need for doubling energy consumption in the United States from 1950 to 1975.[15] This corresponds to an annual increase of about 2.8 percent compounded. All things considered, we shall choose 3 percent as the most plausible rate of growth of energy consumption in the United States for the remainder of the 20th century, but recognizing the approximations involved in the proces of selecting any one figure, will use a range of figures: 2½, 3, and 3½ percent.

Similar projections for other regions of the world have been summarized by Mason et al.[16] The net result of their survey of prevailing opinion was a projected 2 to 2½ percent annual growth of energy consumption in the mature industrialized countries of Western Europe, with considerably higher and more approximate estimates for other regions. For the rapidly industrializing countries of Latin America and the Soviet Union, they chose a rough overall average annual rate

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[10] Calculated using a 3-year moving average from data reported in U. S. Department of Commerce, Office of Business Statistics, Survey of Current Business.

[11] Putnam, op. cit., supra, note 4, p. 90.

[12] Ibid., p. 106.

[13] See ibid., fig. 5–3.

[14] Op. cit., supra, note 5.

[15] Resources for the Future, vol. 1, p. 103.

[16] Op. cit., supra, note 6, pp. 3–6.

of 5 percent for the next 25 years; and hazard a guess of 4 percent for the underdeveloped countries of Asia, Africa, and elsewhere. In the absence of any more exact bases for forecasts of energy needs, we shall use these figures, though with an expanded range to allow for error in the latter cases. Thus, for Western Europe, we shall see 2, 2½, and 3 percent; for the countries midway in the process of industrialization, 4, 5, and 6 percent; and for the underdeveloped countries, 3, 4, and 5 percent. Even though these figures cover a wide range of possible levels of energy consumption, we shall see that they permit useful conclusions with respect to energy need and resource balances.

Table 1 shows projected energy consumption on the basis of our different assumed rates of growth. Using as a starting point observed levels of consumption in 1952, table 1 shows corresponding amounts of energy to be consumed in each of the years 1975 and 2000 A. D., with cumulative total consumptions from 1952. All energy has been converted into kilowatt-hours at full calorific value, including both commercial and noncommercial energy sources.

Projected figures are given for the United States and for eight regions into which the world has been divided.[17] The world totals are sums of the estimates for the eight regions. They correspond to world rates of growth of energy consumption slightly greater than 3, 3½, and 4 percent, which are in good agreement with a world total annual rate of 3½ percent derived in another way by the United Nations Department of Economic and Social Affairs.[18]

The principal purpose of table 1 is to provide rough approximations of future needs for later comparison with available energy resources.

TABLE 1.—*Consumption of energy from all sources*

[In kilowatt-hour × 10^{12} electricity equivalent, at full calorific value]

	2½ percent annual increase		3 percent annual increase		3½ percent annual increase	
	Yearly	Cumulative future	Yearly	Cumulative future	Yearly	Cumulative future
United States:						
1952 (actual)	9.75	----------	9.75	----------	9.75	----------
1975 (estimate)	17.3	305	19.4	328	21.8	349
2000 (estimate)	32.3	910	41.0	1,060	52.1	1,235
North America:						
1952 (actual)	10.44	----------	10.44	----------	10.44	----------
1975 (estimate)	18.5	327	20.8	351	23.3	374
2000 (estimate)	34.7	975	44.0	1,140	55.9	1,320
	4 percent annual increase		5 percent annual increase		6 percent annual increase	
	Yearly	Cumulative future	Yearly	Cumulative future	Yearly	Cumulative future
Latin America:						
1952 (actual)	1.07	----------	1.07	----------	1.07	----------
1975 (estimate)	2.68	41.1	3.37	47.3	4.25	54.4
2000 (estimate)	7.27	159.0	10.8	218.0	19.0	307.0

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[17] Countries included within each of the eight regions are shown in appendix A.
[18] Op. cit., supra, note 1.

TABLE 1.—*Consumption of energy from all sources*—Continued

[In kilowatt-hour × 10^{12} electricity equivalent, at full calorific value]

	2 percent annual increase		2½ percent annual increase		3 percent annual increase	
	Yearly	Cumulative future	Yearly	Cumulative future	Yearly	Cumulative future
Western and Southern Europe:						
1952 (actual)	5.49	----------	5.49	----------	5.49	----------
1975 (estimate)	8.7	162	9.73	172	10.9	184
2000 (estimate)	14.3	445	18.2	512	23.1	598
	3 percent annual increase		4 percent annual increase		5 percent annual increase	
	Yearly	Cumulative future	Yearly	Cumulative future	Yearly	Cumulative future
Africa:						
1952 (actual)	0.766	----------	0.766	----------	0.766	----------
1975 (estimate)	1.530	25.8	1.920	29.4	2.420	33.8
2000 (estimate)	3.230	83.5	5.210	114.0	8.440	156.0
Oceania:						
1952 (actual)	.314	----------	.314	----------	.314	----------
1975 (estimate)	.626	10.5	.787	12.1	.990	13.9
2000 (estimate)	1.320	34.2	2.140	46.6	3.460	64.0
Asia (except U. S. S. R. and mainland China):						
1952 (actual)	2.51	----------	2.51	----------	2.51	----------
1975 (estimate)	5.00	84.4	6.30	96.5	7.90	111.0
2000 (estimate)	10.60	274.0	17.10	372.0	27.60	511.0
China (mainland):						
1952 (estimate)	1.40	----------	1.40	----------	1.40	----------
1975 (estimate)	2.79	40.7	3.52	53.8	4.41	61.9
2000 (estimate)	5.90	153.0	9.51	208.0	15.40	286.0
	4 percent annual increase		5 percent annual increase		6 percent annual increase	
	Yearly	Cumulative future	Yearly	Cumulative future	Yearly	Cumulative future
U. S. S. R. and East Europe:						
1952 (estimate)	4.96	----------	4.96	----------	4.96	----------
1975 (estimate)	12.50	191	15.60	220	19.70	252
2000 (estimate)	33.80	736	54.60	1,010	88.30	1,420
World total:						
1952 (estimate)	26.95	----------	26.95	----------	26.95	----------
1975 (estimate)	52.30	883	62.00	982	73.80	1,085
2000 (estimate)	111.10	2,860	161.00	3,620	241.00	4,660

Source: Energy consumption from all sources in 1952 is from United Nations Department of Economic and Social Affairs, "World Energy Requirements in 1975 and 2000" and "Contribution of Nuclear Energy to Future World Power Needs," Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, vol. 1, pp. 19 and 86, respectively. The world totals are the sum of the 8 regions. All figures for 1975 and 2000 were calculated according to indicated annual growt htrends continuously compounded. Countries included within each region are shown in appendix A.

Conventional fuel resources

Western standards of living have been realized especially through technologies that rely upon the conventional mineral fuels, coal, oil, and gas. The crucial role played by coal in the industrial revolution is well known, and the significance of the internal-combustion engine for American society can hardly be understated. Having projected world energy needs for expected rates of growth in the remainder of the 20th century, we now ask whether Western nations have the energy resources to continue their growth in present patterns. And we ask whether other nations, some of which are well along the road to a higher standard of living, will be restrained or redirected in their efforts to attain greater material welfare by the limitations of their fuel endowment.

Estimates of absolute totals of coal, oil, and gas reserves are beset with uncertainties almost as pervasive as those affecting future energy consumption. Table 2 gives a compilation of the most authoritative information presently available for the United States, while tables 3 and 4 provide the same for coal, oil, and gas, respectively, for the 8 regions of the world. Differences in the estimates reflect the limitations of present knowledge.

The concept of energy resources, and all natural resources for that matter, is relative to costs of production and delivery to the place of consumption. A ton of coal in an Antarctic deposit is much less a resource than the same ton in a geologically identical Pennsylvania field. Similarly, a ton of coal in a 10-inch seam 3,000 feet below ground is much less a resource than the same ton in a 6-foot seam accessible to surface earth-moving equipment. Taking this fact into account, our estimates show, insofar as they are known, the different costs of production and delivery to market centers of different resource deposits. As used in tables 2, 3, and 4, "cost" refers to all steps in the process of getting the resource from its place of occurrence in nature (and finding the resource in the first place) to existing market centers, but not to additional processing of the resource, as in the case of oil refining. This means that the figures neglect any changes in the location of industry, which might be brought about by increasing fuel costs themselves. It also means that they take account only of known technologies of extraction, and reasonably foreseeable extensions of these. As a result, we shall be limited in our interpretations of the higher cost data.

The difficulty is compounded when we deal with "ultimately" recoverable reserves. Experts generally interpret this term to mean reserves recoverable under economic conditions as they can conceive of them in the more distant future. The concept, like the idea it attempts to deal with, is wanting in standardization.

Table 2 is divided into four major parts, pertaining to coal, oil, and gas separately, oil and gas lumped together, and oil shale.

The purpose in first showing oil and gas separately is to establish a basis for combining them and to indicate the hazards of the process. In the United States, proved reserves (not ultimate reserves) of crude oil and natural gas presently are found in the ratio of approximately 6,000 cubic feet per barrel of oil. This can be observed in both the Dewhurst and the Pratt estimates of oil and gas shown separately, using an average energy content of 1,700 kilowatt-hours per barrel of oil and 0.293 kilowatt-hours per cubic foot of natural gas, the figures adopted for this study. The Department of the Interior natural gas estimates were calculated using this ratio. (See table 2, footnotes 2 and 3.) We shall see that a different ratio is necessary when dealing with world proved reserves.

The table 2 estimates show a reasonable consistency with respect to resources recoverable at present costs and at levels up to twice present costs. When dealing with ultimate reserves, wide divergences appear, as might be expected.

We shall use table 2 to get representative fuel reserves for costs up to twice the present level. Thereafter, it appears that considerable coal, oil, and gas may still be extracted, but in vaguely known quantities at uncertain costs. Economic and social adjustments will doubtless attend reliance upon ultimate reserves, probably with untoward consequences for economic growth.

TABLE 2.—*Estimates of remaining mineral fuel reserves, United States*

[In kilowatt-hours×10¹² electricity equivalent, at full calorific value]

Estimates by—	Coal and lignite recoverable				
	At or near present costs	Up to 1¼ to 1½ times present costs	Up to 2 times present costs	Up to 4 times present costs	"Ultimate" recovery
U. S. Department of the Interior	1,820	2,090		7,290	
Dewhurst	2,240				7,450
Putnam			1,760		

Estimates by—	Crude oil recoverable		Natural gas recoverable	
	At or near present costs (proved reserves)	"Ultimate" recovery	At or near present costs (proved reserves)	"Ultimate" recovery
U. S. Department of the Interior	[1] 50	420	[2] 53	[3] 445
Dewhurst	[1] 50	107	53	81
Pratt	[4] 60		63	

Estimates by—	Oil and gas total recoverable (exclusive of oil shale)		
	At or near present costs (proved reserves)	Up to 1.3 times present costs	"Ultimate" recovery
U. S. Department of the Interior (sum of above figures)	103		865
Dewhurst (sum of above figures)	103		188
Putnam [5]	73	146	

Estimates by—	Oil recoverable from shale	
	Up to 1.3 times present costs	"Ultimate" recovery
Dewhurst		880
Putnam	117	344

[1] As of Dec. 31, 1954.

[2] Assumes 6,000 cubic feet of gas for each barrel of oil.

[3] Includes Continental Shelf and assumes 6,000 cubic feet of gas for each barrel of oil.

[4] As of Dec. 31, 1954.

[5] Putnam uses 3,000 cubic feet of natural gas per barrel of crude oil.

Source: (1) U. S. Department of the Interior, "Impact of the Peaceful Uses of Atomic Energy on the Coal, Oil, and Natual Gas Industries," (Jan. 13, 1956) Peaceful Uses of Atomic Energy, vol. II, Joint Committee on Atomic Energy, 84th Cong., 2d sess., pp. 68–89. Department of the Interior figures have been converted from tons of coal, barrels of oil, and cubic feet of gas.

(2) J. F. Dewhurst and Associates, America's Needs and Resources (1955), p. 765. Dewhurst's figures have been converted from British thermal units.

(3) W. E. Pratt, "The Impact of the Peaceful Uses of Atomic Energy on the Petroleum Industry" (Jan. 7, 1956), Peaceful Uses of Atomic Energy, vol. II, Joint Committee on Atomic Energy, 84th Cong., 2d sess., p. 93. Pratt's figures have been converted from barrels of oil and cubic feet of gas.

(4) P. C. Putnam, Energy in the Future (1952), ch. 6. Putnam's figures have been converted from British thermal units.

By inspection, we choose the following figures as representative of fuel reserves recoverable at costs up to twice those now prevailing in the United States:

	Kilowatt-hours
Coal	$2,500 \times 10^{12}$
Oil and gas	150×10^{12}
Oil shale	120×10^{12}
Total	$2,770 \times 10^{12}$

These values may be in error by a factor of 2 (i. e., they may be either twice as great or half as great as they should be).

Table 3 follows the pattern of table 2, applied to solid fuel resources in the 8 regions of the world shown in table 1.

TABLE 3.—*Estimates of remaining coal and lignite reserves, world*

[In kilowatt-hours$\times 10^{12}$ electricity equivalent, at full calorific value]

	Recoverable at or near present costs (U. S. Department of the Interior)	Recoverable up to 2 times present costs (Putnam)	Recoverable up to 4 times present costs (U. S. Department of the Interior)	"Ultimate" recovery (United Nations)
North America	2,020.0	2,350	8,070	12,406
Latin America	14.5	2,350	58	165
Western and Southern Europe	515.0		2,360	5,107
Africa	74.0		292	614
Oceania	56.0		223	240
Asia (except U. S. S. R. and China)	94.0		376	3,191
China (mainland)	1,070.0	1,760	4,270	
U. S. S. R. and Eastern Europe	1,370.0	2,940	5,490	10,448
World	5,210.0	9,400	21,100	32,172

Source: (1) U. S. Department of the Interior, Impact of the Peaceful Uses of Atomic Energy on the Coal, Oil, and Natural Gas Industries (Jan. 13, 1956), Peaceful Uses of Atomic Energy, vol. II, Joint Committee on Atomic Energy, 84th Cong., 2d sess., pp. 68–89. Department of the Interior figures have been converted from tons of coal, barrels of oil, and cubic feet of gas.

(2) P. C. Putnam, Energy in the Future (1952), ch. 6. Putnam's figures have been converted from British thermal units.

(3) United Nations Department of Economic and Social Affairs, Contribution of Nuclear Energy to Future World Power Needs, Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, vol. I (United Nations, 1956), p. 86, table II.

World totals differ slightly from the sum of the 8 regions as a result of rounding.

Somewhat less regularity is evident in the estimates applying to costs twice or less present costs. Moreover, Putnam's estimates are not subdivided into all eight of the world regions. Nevertheless, one fact is unmistakable: The United States and the Soviet Union have half or more than half the world's solid fuel reserves. China and Western Europe hold second positions of approximately equal amounts, while the rest of the world does not account for any sizable portion of solid fuel reserves. It is noteworthy that in making his estimates for China and the U. S. S. R., Putnam strikes the rather high fraction of three-fourths of the geologically predicted reserves for these regions on grounds of remoteness. With economic growth still ahead, it is possible that these regions may develop in ways that make the reserves less remote from points of consumption.

Again, we shall choose representative figures. For solid fuel reserves recoverable up to twice present costs in the eight regions of the world, they are as follows:

	Kilowatt-hours
North America	$3,000\times10^{12}$
Latin America	30×10^{12}
Western and Southern Europe	$1,500\times10^{12}$
Africa	150×10^{12}
Oceania	140×10^{12}
Asia (except for U. S. S. R. and China)	200×10^{12}
China (mainland)	$2,000\times10^{12}$
U. S. S. R. and Eastern Europe	$3,000\times10^{22}$
World	$10,020\times10^{12}$

In the aggregate, these figures may not be in error by more than a factor of 2. Indeed, a factor of 2 either way would make the spread in the total equal to the spread between the Department of the Interior estimates of reserves at present costs and Interior's estimates at 4 times present costs. But estimates for particular regions may be in somewhat greater error. Note in particular that the relative positions of both China and the Soviet bloc vary considerably for one estimate to another.

TABLE 4.—*Estimates of remaining oil and gas reserves, world*

[In kilowatt-hours times 10^{12} electricity equivalent at full calorific value]

	Recoverable at or near present costs (proved reserves)			Recoverable up to 1.3 times present costs, Putnam [3]	"Ultimate" recovery, U. S. Department of the Interior [4]
	U. S. Department of the Interior [1]	United Nations [2]	Putnam[3]		
North America	112.0	117.0	106.0	[5] 323	990
Latin America	33.0	22.0			241
Western and southern Europe	1.7	.6	5.9	147	37
Africa	.3	.2			[6] 27
Oceania	.3	.2			(7)
Asia (except U. S. S. R. and Middle East)	6.0	133.0	167.0	500	179
Middle East [8]	220.0				[9] 515
U. S. S. R. and East Europe	23.0	26.0	11.7	382	491
World	396.0	300.0	291.0	[5] 1,352	[10] 2,480

[1] Calculated from proved oil reserves as reported for end of 1954, assuming 2,000 cubic feet of natural gas with each barrel of oil, except in North America, where the figure assumed was 6,000 cubic feet of natural gas per barrel of oil.

[2] Oil and natural gas reserves separately tabulated in source.

[3] Putnam assumes 3,000 cubic feet of natural gas per barrel of oil for all deposits including North America.

[4] Including Continental Shelf in United States reserves and calculating all reserves on the assumption that 6,000 cubic feet of natural gas are recovered per barrel of crude oil.

[5] Plus 117 United States oil shale. See table 2, supra.

[6] Excluding Egypt.

[7] Not available.

[8] For countries included, see appendix A.

[9] Including Egypt.

[10] Plus oil shale.

Source: (1) U. S. Department of the Interior, Impact of the Peaceful Uses of Atomic Energy on the Coal, Oil, and Natural Gas Industries (Jan. 13, 1956), Peaceful Uses of Atomic Energy, vol. II, Joint Committee on Atomic Energy, 84th Cong., 2d sess., pp. 68–69. Department of the Interior figures have been converted from tons of coal, barrels of oil, and cubic feet of gas.

(2) P. C. Putnam, Energy in the Future (1952), ch. 6. Putnam's figures have been converted from British thermal units.

(3) United Nations Department of Economic and Social Affairs, Contribution of Nuclear Energy to Future World Power Needs, Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, vol. 1 (United Nations, 1956), p. 86, table II.

World totals differ slightly from the sum of the 8 regions as a result of rounding.

Table 4 extends the world inventory to cover oil and gas reserves. We encounter again the difficult problem of accounting for natural gas on the basis of estimates which give only crude oil figures. Fortunately, the United Nations has reported estimates of proved reserves (not ultimate reserves) which show oil and natural gas separately. These indicate a worldwide average of 2,120 cubic feet of natural gas per barrel of oil.[19] This is considerably below the 6,000 cubic feet per barrel which we found for the United States, and the difference between the United States and world averages becomes even greater when we note that the United Nations overall data included the United States proved reserves. The reason for the marked difference has been attributed to the age of the United States oil industry. With deeper drilling and more thorough exploration, more gas in proportion to oil is found.[20] In view of the uncertainties of the data, we have adopted the round figure of 2,000 cubic feet per barrel for world proved reserves, but in calculating ultimate reserves we use the same figure of 6,000 cubic feet per barrel for the world as for the United States.

Casual examination of table 4 shows the same unevenness in world distribution of oil and gas as in coal. North America, the Middle East, and the Soviet bloc dominate, with Latin America in second position, some oil and gas in Asia, but very little elsewhere. Separate estimates for mainland China are not available, though it appears that China is not destined to become an oil power.

We have no estimates at twice the level of present costs. Putnam chose to cut off his estimates at 1.3 times present costs because he expects (on the basis of a Paley Commission forecast) that a large volume of oil shale can be commercially processed at this point. Oil shales are not included in table 4 except as known to exist in the United States. Putnam reports that half the world supply is in the United States and most of the rest is in Brazil.[21]

It is interesting to note that the ultimate reserves do not exceed Putnam's reserves recoverable up to 1.3 times present costs by very much except in the case of North America. The disparate result here is at least partly accounted for by the inclusion of undiscovered reserves in the Continental Shelf in the United States estimates, but not in other producing regions adjacent to a Continental Shelf.[22]

For purposes of our analysis, we shall take the following rough figures as representative of the oil and gas reserves recoverable at costs on the order of twice those now prevailing:

	Kilowatt-hours
North America [1]	500×10^{12}
Latin America	100×10^{12}
Western and southern Europe	20×10^{12}
Africa	10×10^{12}
Oceania	10×10^{12}
Asia (except U. S. S. R. and Middle East)	100×10^{12}
Middle East	500×10^{12}
U. S. S. R. and East Europe	400×10^{12}
World	$1,540\times10^{12}$

[1] Including oil from shale.

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[19] United Nations Department of Economic and Social Affairs, Contribution of Nuclear Energy to Future World Power Needs, Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, vol. 1 (United Nations, 1956), p. 86, table II.

[20] See discussion by U. S. Department of the Interior, Impact of the Peaceful Uses of Atomic Energy on the Coal, Oil, and Natural Gas Industries (January 13, 1956), in Peaceful Uses of Atomic Energy, vol. 2, Joint Committee on Atomic Energy, 84th Cong., 2d sess., p. 83.

[21] Op. cit., supra, note 4, p. 140.

[22] For rough estimates suggesting that a rather considerable volume of oil and gas may be found in offshore deposits elsewhere, see Putnam, op. cit., supra, note 4, p. 154.

These figures may be in error by a large factor in the "have-not" regions. Table 4 shows little on which to base a rough estimate of reserves in these regions, except that they are small. On the other hand, estimates for the Middle East and the Soviet bloc show a reasonable consistency, suggesting a firmer basis for our corresponding approximations. In the case of North America, the figure is not out of line with our previously chosen value of 270×10^{12} kilowatt-hours for oil and gas reserves in the United States.

Adequacy of coal, oil and gas reserves

Coal, oil and gas are versatile energy sources. All can be and are used in the generation of electricity, which has many special conveniences as a form of energy. All, of course, are well suited for space heating. All can be and are used in their natural physical form as fuel in mobile engines; and where fluid fuels are more convenient, coal can be converted to gas (producer gas), to oil by hydrogenation, or used in powdered form.

The physical substitutability of the three fuels is shown in table 5 for three important end uses. For the same energy content, approximately the same conversion to useful energy forms can be made. Efficiencies are almost identical for residential and commercial heating, which accounted for 25 percent of the coal consumption, 25 percent of the natural gas consumption and 20 percent of the oil consumption in 1950, and for electric power production, which accounted for approximately 20 percent of the coal and 10 percent of the gas.[23]

A significant difference appears in the use of fuels for transportation, where table 5 shows that 1¼ times the conversion to tractive power can be realized from petroleum products as from coal. Moreover, when coal is converted to gasoline and like fluid fuels, approximately half of the energy content of the coal is lost.[24] Transportation accounted for 49 percent of the petroleum and 12 percent of the coal consumption in the United States in 1950.[25]

TABLE 5.—*Average efficiencies of the use of energy in the United States, 1947, in selected applications*

[Efficiencies as percentages energy output/energy input]

	Bituminous coal	Petroleum products	Natural gas
Transportation	4	6	
Generation of electricity	20	20	19
Residential and commercial (97 percent for space heating)	60	60	72

Source: P. C. Putnam, Energy in the Future, (1952), p. 397.

Thus, it appears that for 2 of the 3 most important end uses of coal, oil and gas, contained energy is a good common denominator. For transportation, oil is more efficient by a factor of 1½ to 2, depending upon whether the coal is used directly or converted into synthetic oil. Other end uses cannot be so easily traced. Some may very well manifest the same efficiencies in conversion, while others have special

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[23] Proportions to end uses are from President's Materials Policy Commission, op. cit., supra, note 15, vol. 3, pp. 3, 17–18, and 24.

[24] Putnam, op. cit., supra, note 4, p. 238.

[25] President's Materials Policy Commission, op. cit., supra, note 15, vol. 3, pp. 3, 17–18, and 24.

functions, as in certain metallurgical uses of coal, though even here alternative (but more expensive) techniques, as the electrolytic reduction of steel, would permit the use of energy from all three fuels on an equal basis.[26]

With different degrees of scarcity of coal, oil and gas, it appears that the relative energy convertability of these fuels is sufficiently comparable to permit their substitutability for economic growth, and hence their summation in a balance of world resources and needs. We shall later extend the analysis to consider the solid and fluid fuels separately.

Table 6 is our rough balance sheet of needs and resources. It is limited by all of the approximations that went into the figures presented. Even so, the data permit certain conclusions:

(1) Latin America, Africa and Oceania would probably encounter difficulty in carrying out their projected patterns of growth on the basis of home supplies of conventional mineral fuels, even within the remaining years of the 20th century.

(2) Asia, exclusive of the Soviet Union, China and the Middle East would probably experience the same difficulty.

(3) The four regions, North America, Western and Southern Europe, the Soviet bloc and Mainland China, may be able to continue for the remainder of the 20th century on conventional energy resources without experiencing major economic adjustments, so far as our present data can show.

Table 6.—*Projected energy needs, 1952–2000 A. D., compared with rough estimates of resources of coal, oil, and gas recoverable at costs up to twice present costs*

[In kilowatt-hours$\times 10^{12}$ electricity equivalent at full calorific value]

	Coal reserves (1)	Oil and gas reserves (2)	Total, (1)+(2) (3)	Estimated cumulative energy needs, 1952-2000 A. D.		
				Low (4)	Medium (5)	High (6)
United States	2, 500	270	2, 770	910. 0	1, 060. 0	1, 235
North America	3, 000	500	3, 500	975. 0	1, 140. 0	1, 320
Latin America	30	100	130	159. 0	218. 0	307
Western and Southern Europe	1, 500	20	1, 520	445. 0	512. 0	598
Africa	150	10	160	83. 5	114. 0	156
Oceania	140	10	150	34. 2	46. 6	64
Asia (except U. S. S. R. and China)	200	--------	2, 800	274. 0	372. 0	511
China (mainland)	2, 000	--------		153. 0	208. 0	286
Asia (except U. S. S. R. and Middle East)	--------	100		--------	--------	--------
Middle East	--------	500		--------	--------	--------
U. S. S. R. and Eastern Europe	3, 000	400	3, 400	736. 0	1, 010. 0	1, 420
World	10, 020	1, 640	11, 660	2, 860. 0	3, 620. 0	4, 660

Source: Cols. (1) and (2) are from text. Cols. (4), (5) and (6) are from table 1.

A few additional observations can be made if we consider the relative proportions in which solid and liquid fuels have been consumed in recent years. These are shown in table 7 for the United States, North America, Western and Southern Europe, and for the Soviet bloc plus China.

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[26] Cf. S. H. Schurr and J. Marschak, Economic Aspects of Atomic Power (Princeton University Press, 1950), pp. 165–176.

Table 7 shows that fluid fuels already account for well over half the energy consumed in the United States. Moreover, they are expected to continue to gain percentagewise at least through 1980.[27] But table 6 shows that North American oil and gas reserves (about half the energy content of which is in natural gas) will not be able to satisfy this increasing consumption without increases in real cost over our threshold of twice present levels. Home production will probably be supplemented by increasing reliance upon imports and by producing liquid fuels for coal.[28] Even from a world standpoint, table 6 shows that oil and gas reserves taken together cannot account for a very large fraction of the energy consumed at no more than twice present costs before A. D. 2000.

Changing world trade patterns in mineral fuels are shown in table 8. Data are given in kilowatt-hours$\times 10^9$, a unit one-thousandth the size of our previous kilowatt-hours$\times 10^{12}$, in order to get more convenient figures. Negative signs indicate imports. We note that Europe (except U. S. S. R.) has traditionally provided the coal exports for the world market, but is sending less and less of its coal abroad. The two principal suppliers of international oil are Latin America and the Middle East (responsible for most of the Asian exports). Both have shown rapid increases in their exports, primarily to the United States and Europe, respectively.

TABLE 7.—*Energy resources consumed in 1952*

[In kilowatt-hours$\times 10^{12}$ electricity equivalent at full calorific value]

	Coal and lignite	Petroleum products	Natural gas	All others	Total
United States:					
Kilowatt-hours$\times 10^{12}$	3.27	3.60	2.48	0.40	9.75
Percentage	33.6	36.9	25.4	4.1	100.0
North America:					
Kilowatt-hours$\times 10^{12}$	3.56	3.82	2.52	.54	10.44
Percentage	34.1	36.6	24.1	5.2	100.0
Western and Southern Europe:					
Kilowatt-hours$\times 10^{12}$	4.26	.67	.02	.54	5.49
Percentage	77.9	12.2	.4	9.5	100.0
East Europe, U. S. S. R., and China (mainland):					
Kilowatt-hours$\times 10^{12}$	4.11	.70	.15	1.66	6.62
Percentage	62.1	10.6	2.3	25.0	100.0

Source: United Nations Department of Economic and Social Affairs, World Energy Requirements in 1975 and 2000, and Contribution of Nuclear Energy to Future World Power Needs, Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, vol. I (United Nations, 1956), pp. 17, 86

Western and southern European dependence upon foreign oil is clearly seen in table 6, and the precarious nature of political developments in its principal source of supply, the Middle East, is well known. In addition, Western Europe is now facing difficulties with its major energy source, coal.

Western European coal is mined at almost twice North American costs,[29] and under sufficiently difficult working conditions that produc-

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[27] See U. S. Department of the Interior, op. cit., supra, note 20, pp. 73–74.

[28] Coal hydrogenation results in a gasoline cost estimated at 11, 28.1, and 36.3 cents per gallon by 3 different authorities. These figures are about equal to, twice as high as, and 3 times as high as the cost of gasoline from fuel oil, respectively. The estimate of 11 cents was made by the U. S. Bureau of Mines as a result of pilot-plant studies. The estimate of 28.1 cents was made by Ebasco Services, Inc., and the estimate of 36.3 cents by the National Petroleum Council. See Chemical and Engineering News, vol. 30 (August 11, 1952), p. 3250.

[29] See Putnam, op. cit., supra, note 4, p. 140.

tion is restricted by a lack of available labor.[30] For this reason, and because of the nature of the mines and mining technology, it has been estimated that the probable annual limits on coal extraction in Belgium and the United Kingdom are only 1.22 and 1.32 times the respective annual rates of coal consumption in these countries.[31] Compare table 1 showing expected rates of growth of energy consumption in Western Europe of 1½ to 2 times by 1975 and 2½ to 4 times by 2000. Owing to the same limitations, France is already importing part of her coal.[32]

The world's traditional coal-exporting region appears soon to become a net importer of coal despite the still sizable local reserves. The reserves will last considerably beyond the year 2000, but unless annual rates of output can be improved beyond those now foreseeable, the coal will not be available in sufficient quantity.

TABLE 8.—*Net interregional trade in commercial sources of energy*

[In kilowatt-hours×10⁹ electricity equivalent at full calorific value]

	Year	Solid fuels	Liquid fuels	Total
North America	1929	16.9	0.8	17.7
	1937	−3.4	69.5	66.1
	1950	19.5	−516.0	−494.0
Latin America	1929	−61.8	224.0	162.0
	1937	−52.5	322.0	270.0
	1950	−23.7	722.0	698.0
Europe (except U. S. S. R.)	1929	178.0	−179.0	−1.0
	1937	142.0	−341.0	−199.0
	1950	89.0	−606.0	−517.0
Africa	1929	−41.5	−26.2	−67.7
	1937	−42.3	−66.0	−108.3
	1950	5.9	−124.0	−118.0
Oceania	1929	(1)	−24.6	−24.6
	1937	.8	−38.1	−37.3
	1950	−5.1	−85.5	−90.6
Asia (except U. S. S. R.)	1929	−7.6	24.6	17.0
	1937	−2.5	108.0	105.0
	1950	−11.0	782.0	771.0
Others (including U. S. S. R.)	1929	−83.7	−19.5	−103.2
	1937	−41.5	−54.1	−95.6
	1950	−74.5	−172.0	−246.5

[1] Negative.

Source: Adapted from E. S. Mason & Associates, Energy Requirements and Economic Growth (National Planning Association, 1955), p. 70, table 7.

The Soviet bloc and China taken as a single unit is still coal-based (see table 7), though oil and gas reserves appear to be relatively adequate within the U. S. S. R. (table 6). These regions have not engaged in much foreign trade in energy resources over the past three decades, having been largely undeveloped economically. The rather large proportion which table 7 shows coming from other sources of energy is almost entirely noncommercial, apparently from the combustion of fuel wood, other vegetable matter, and farm wastes. Economic development in this part of the world appears to be relatively free of energy-resource problems, at least for the remainder of the 20th century.

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[30] See U. N. Department of Economic and Social Affairs, op. cit., supra, note 19, p. 89.

[31] Estimates of absolute limits upon rates of coal extraction in these two countries are given by the United Nations Department of Economic and Social Affairs, op. cit., supra, note 19, p. 89; and actual figures for 1952 coal consumption are available from the same authority, op. cit., supra, note 1, p. 20.

[32] United Nations Department of Economic and Social Affairs, op. cit., supra, note 19, p. 89.

Renewable energy resources

Before going on to consider the potential role of nuclear energy in our resource structure, let us note the present and possible future part that might be played by renewable resources. These include waterpower, windpower, solar energy, and various forms of carbon fixed by nature, as in fuel wood, other vegetable matter, and controlled biological photosynthesis. If we could learn to more efficiency use these resources, there would be less need for concern about the exhaustion of conventional fuel supplies.

The United States in 1952 generated approximately 0.112×10^{12} kilowatt-hours of hydroelectric power. In the same year, world hydroelectric output was 0.377×10^{12} kilowatt-hours, exclusive of the U. S. S. R., East Europe, and mainland China, for which estimates are unavailable.[33] These figures are 1.15 and 1.71 percent of the corresponding energy-consumption totals for the United States and the non-Communist world, respectively, in 1952.

There is still a considerable volume of unharnessed waterpower. The Paley Commission foresaw a maximum annual output of 0.314×10^{12} kilowatt-hours of hydroelectric power in the United States by 1975,[34] approximately a threefold increase of existing output. Putnam estimates that hydroelectric capacity can double once again beyond the 1975 Paley Commission level, but this is about the limit of present prospects for hydroelectric power.[35] If we make a rough extension of the rather optimistic Paley Commission rate of growth to year 2000, we get about 0.6×10^{12} kilowatt-hours of hydroelectricity annually, which is 1.85 to 1.15 percent of the projected United States energy consumption in that year, depending upon choice of rate of growth of total energy needs (cf. table 1). And there is very little more hydroelectric capacity in sight.

It is easy to see that hydroelectric power will account for only about the same, or perhaps a slightly higher, proportion of total world energy in year 2000. The proportion of total energy from hydroelectric power in 1952 is not much greater for the world (excluding the Soviet bloc and China) than for the United States. And there is no reason to think that hydroelectric power will develop at a rate very different elsewhere than in the United States.

World "ultimate" reserves of unharnessed hydroelectric power are somewhat greater, however, in relation to present harnessed capacity. We have seen that the United States might ultimately hope to have six times the present hydroelectric output it now has. The world as a whole is thought to have a potential of 17 times its present hydroelectric capacity.[36] This means that world expansion of hydroelectric facilities will probably continue well beyond 200 A. D., though hydroelectric power may never account for more than 1 or 2 percent of the world's energy.

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[33] United Nations Department of Economic and Social Affairs, op. cit., supra, note 1, pp. 19 and 22.

[34] Op. cit., supra, note 15, p. 127.

[35] Putnam's estimate is that there exists about 100 million kilowatts more of unharnessed waterwheel capacity in the United States. Op. cit., supra, note 4, p. 178. To this must be added an installed capacity of about 18 million kilowatts at the time of this writing. We then get a total, harnessed and unharnessed, of 118 million kilowatts of waterpower. Assuming the same use factor, this is twice the 60 million kilowatts capacity corresponding to the annual output foreseen by the Paley Commission for 1975.

[36] Putnam, op. cit., supra, note 4, p. 175–176.

We can rather quickly dispose of the prospects of using windpower. After a careful study of these, Putnam gives windpower a cumulative total contribution of perhaps one-fifth the hydroelectric power in 100 years,[37] but does not hazard a guess for so short a time in the future as A. D. 2000. Even if he is wrong by a factor of 5, it will not materially change our conclusions.

The prospects of using carbon fixed by nature are almost as limited, but in this case presently known technological possibilities have not yet been fully explored. The basic physical phenomenon is the reduction of atmospheric carbon by chlorophyll with the aid of sunlight. Fats, proteins, and carbohydrates are formed which can be burned to recover the energy in useful form. Whether chlorophyll is in a tree or an alga, the process is the same.

As it now operates, nature is relatively inefficient in using sunlight. If all of the carbon fixed in a year in the United States were burned, it would supply only about 1½ times our present national energy needs,[38] and all of the carbon fixed in the world would supply only 4 times present world energy needs.[39] Obviously, we have many other uses for vegetable matter than to support combustion, to say nothing of the costs that would be associated with an attempt to collect and use all such yearly crops of fixed carbon. Some vegetable matter may well be converted to fuel directly (for example, fuel wood) and some may be used to produce alcohol (for example, sugar beets) which can be used itself as fuel or as a starting point in the synthesis of gasoline. We have only to remember that we cannot hope to make a dent upon world energy needs unless we do this with a large fraction of all vegetable matter, assuming present technologies.

Some grounds for hope remain, however, in the use of select strains of alga, which can be made 200 times as efficient as most vegetable matter in fixing carbon. Putnam reports a pilot-plant study indicating that electricity from the burning of today's most promising alga, produced under optimum conditions, would cost 40 to 50 times as much as presently available electricity from coal-fired plants.[40] Many more varieties of alga remain to be studied, however, and there is always the possibility of creating new strains through mutations. Nevertheless, we note that a substantial cost gap must be bridged before this approach offers any reasonable promise.

The most promising continuous source of energy today is the sun. Solar energy reaching continental United States annually is about $14{,}700 \times 10^{12}$ kilowatt-hours; that reaching the land areas of the world, $246{,}000 \times 10^{12}$ kilowatt-hours.[41] If only a fraction of 1 percent of this could be usefully employed, it would satisfy our energy needs as far in advance as we can predict them. (Cf. table 1.)

Solar house heating is already technically feasible and is expected to become economically attractive in the southern United States, so that by 1975 there may be about 13 million houses relying entirely upon the sun for space heating (and space cooling).[42] By year 2000

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[37] Ibid., p. 191.
[38] Ibid., p. 245.
[39] Ibid., p. 199.
[40] Ibid., p. 201.
[41] Ibid., p. 198.
[42] President's Materials Policy Commission, op. cit., supra, note 15, vol. 4, p. 217.

it has been estimated that solar-space heating will have furnished 60×10^{12} kilowatt-hours of the cumulative future energy consumption in the United States, and should eventually level off at about one-fifth of the total comfort-heating load, or 6 to 7 percent of the total United States energy system.[43] One might infer that the prospects are at least as attractive at the same or lower latitudes (north and south) throughout the world.

Certain home uses of solar energy in hot-water heating and cooking are also being found economic. Hot-water heaters are in use in Florida and California. Mass production of inexpensive solar cookers has commenced in India, and many millions of units will probably be sold.[44] But all home uses put together (except space heating) are expected to make a negligible contribution to the world's energy needs.[45]

There is not now a prospect of utilizing solar energy on any significant scale for industrial process heat or power. The great handicap of solar energy is its discontinuous operation. To fill out the need for continuous energy on a small scale for house heating is not difficult, but when large systems are contemplated, economic problems arise. One technique is to store energy by lifting water, which can be allowed to run down again to recover the energy; another is to employ (reversible) chemical phase transitions. On a large scale, the former necessitates great water storage capacity. The possibilities of the latter have not yet been fully explored.[46] Also remaining for further research is the development of photochemical generation of electricity.[47]

To summarize, the prospects of utilizing renewable energy resources are limited at the present time. Hydroelectric and wind power may furnish 1 or 2 percent of our future national energy needs, and not a much higher proportion of world energy needs. The combustion of traditional vegetable matter and/or synthesis of gasoline from the same may make a somewhat greater contribution, depending upon the amount of vegetable matter we can spare from other uses. Solar energy will probably account for another 6 or 7 percent of future energy, as technology now stands.

Remaining needs, somewhere in the neighborhood of 85 to 90 percent of the total, are thrown back on exhaustible fuel resources unless technological development in biological photosynthesis or solar power production can open the way for greater efficiency in capturing the vast quantities of energy available from the sun. Since a large part of the problem lies in the technological unknown, there is ground for hope in what might be learned by future research programs.

THE ATOMIC ENERGY POTENTIAL

The development of low-cost atomic power is in progress today and gives every prospect of eventual success in meeting present cost levels

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[43] Putnam, op. cit., supra, note 4, p. 181.

[44] W. H. Stead, The Sun and Foreign Policy, Bulletin of the Atomic Scientists, vol. 13 (March 1957), p. 88.

[45] Putnam, op. cit., supra, note 4, p. 183.

[46] F. Daniels, Alternate Energy Sources (Unconventional Types), Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, vol. 1 (United Nations, 1956), p. 81.

[47] Some applications of photochemical electricity are already in existence. See Daniels, ibid., pp. 82–83.

for electric-power generation. Other applicants of atomic energy in industrial process and space heating may follow. With the expected future stringency and growing real costs of the fossil fuels, coal, oil, and gas, this appears to open a new horizon in energy resources. We shall attempt to evaluate the extent to which it will do so.

Atomic energy resources

The principal device for the controlled release of atomic energy is the nuclear reactor. Fissionable materials (atomic fuels) in solid or liquid form are inserted in reactors of various designs where they undergo atomic disintegration (fission) into highly radioactive atomic waste materials (fission fragments). In so doing, heat, radiation and neutrons are released. The heat is the desired product; the radiation is a dangerous nuisance except for certain special uses; and the neutrons are potentially valuable for the creation of new fissionable materials as the old are consumed.

There are three principal fissionable materials: uranium 235, uranium 233, and plutonium. Uranium 235 is the only one to occur as such in nature. It constitutes 0.72 percent (approximately one one-hundred fortieth) of natural uranium. The rest of natural uranium is isotope 238, from which plutonium can be produced by the capture of a neutron. Thus, in a natural uranium reactor, disintegration of the uranium 235 produces 2 or 3 neutrons, one of which must be captured by another uranium 235 atom to cause it to fission (and hence to continue the chain reaction). This leaves the remaining 1 or 2 neutrons to be captured by the more abundant uranium 238 to produce plutonium, or perhaps to be absorbed in reactor structural materials, in fission fragments, or to be lost in some other way. Essentially the same process is involved in the creation of uranium 233, except that the free neutrons are captured by another element, thorium, placed in the reactor for that purpose.

Regenerative reactors are designed with a view to manufacturing more fissionable materials as the original charge is consumed. The new fissionable materials, however, are not created in optimum arrangement in the reactor for continuous reconsumption, and the fission fragments, which appear in growing abundance as reactor operation proceeds, steal neutrons so that eventually an economic optimum is reached in which it pays to shut down the reactor and to remove original fuel elements and new fuel (in "fertile" materials) for processing, recovery, and refabrication of fuel elements.[48] Present commercial designs generally strike a balance between the value of energy produced by continuing operation and the value of regenerated fuels, which the United States Atomic Energy Commission (AEC) guarantees to buy back at announced prices.[49] We shall see that these prices are not intended to reflect the fuel values of the new fissionable materials, but to provide, temporarily at least, a means of giving financial aid.

With the coming development of fluid fuel recirculating reactors, the removal of fission fragments will be continuous and regenerated fuel will be fed back into the reactor in which it is created. This will not change the general nature of the requirements of the fuel cycle, but

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[48] For a discussion of considerations determining optimum regeneration, see J. A. Lane, Economics of Nuclear Power, Proceedings of the International Conference on the Peaceful Uses of Atomic Energy (United Nations, 1946), pp. 318–321.

[49] See AEC release No. 930, November 18, 1956.

will eliminate some of the costs, such as fuel fabrication, associated with solid fuels.[50]

The resource potential of atomic energy will be determined by the extent to which we eventually find it economical to create and use regenerated fuels. This will depend upon the relative values of energy and regenerated fuel. In a free market, the two will move together since the latter derives its value (insofar as commercial, as opposed to military, purposes are concerned) from further energy production and further creation of regenerated fuel. But net revenue from regenerated fuel will not necessarily move proportionately with energy revenue in a given reactor or in the same way as between reactors.

Assuming ultimate discontinuance of the Atomic Energy Commission (AEC) price supports, net regenerated fuel values (to their producers) will be separated from energy values by a differential equal to all of the costs of recovering the fuels and producing more energy (and more regenerated fuels) from them. At low energy values, this will discourage recovery in some reactors. At high energy values, recovery will be more attractive and will lead to reactor designs favoring regeneration. Within the limits of capacity for producing virgin fissionable materials of the same concentration, these will set upper limits upon prices of the regenerated fuels.

Other influences will work to retard the feasible regeneration and use of new fissionable materials. These include losses in chemical reprocessing, diversion to military explosives, use of fissionable materials in military powerplants and engines where regeneration is neither convenient nor desired, and finally, there is the physical fact that 7 percent of all uranium 238 cannot be fissioned in the most complete recovery system because it will finally be transformed into the nonfissionable isotope, plutonium 242, at the end of the plutonium neutron-capture chain.[51]

Thus, atomic energy resources are uncertain from the standpoint of degree of usage. They are also uncertain in extent of deposit in the earth's crust.

Table 9 shows announced reserves of atomic energy minerals for five nations. A number of other nations have either stated that they have reserves or are known to have them, but quantitative information is lacking.[52] These nations are: Argentina, Australia, Belgian Congo, Brazil, Czechoslovakia, Portugal, and Russia. There may be others, though AEC descriptions of reserves in the Western World indicate that these, at least, are well known. Without qualification, AEC looks on South Africa, Canada, and the United States as the most important uranium sources in the Western World, and states that France is the major source in Western Europe.[53] Thorium reserves have been

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[50] See remarks prepared by W. Kenneth Davis, Director, Division of Reactor Development, AEC, for presentation at the atomic industrial forum of the International Bank for Reconstruction and Development, Washington, D. C., September 27, 1956, mimeographed release.

[51] See Hearings on Development, Growth and State of the Atomic Energy Industry before the Joint Committee on Atomic Energy, 85th Cong., 1st sess. (February 19, 20, 21, 25, 26, 27, 28, and March 5, 1957), pp. 346–347.

[52] For announcements pertaining to most, but not all, of these nations, see papers presented by their spokesmen in Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, vol. 1 (United Nations, 1956).

[53] Twenty-second Semiannual Report (July 1957), pp. 4–5.

less fully announced, presumably because less well known. The United States, for example, has thorium deposits in Florida, the Carolinas, and Idaho,[54] but these are not shown in our table.

TABLE 9.—*Known atomic energy mineral reserves*

Country	Contained metal, short tons	Concentration average U_3O_8 in ore
		Percent
United States [1]	151,000 uranium	0.27
Canada [2]	200,000 uranium	.10
France [2]	50,000 to 100,000 uranium	(3)
South Africa [2]	308,000 uranium	[3] .025
India [4]	12,000 uranium	(3)
	396,000 thorium	(3)

[1] AEC Release No. 1133, Aug. 22, 1957.

[2] AEC 22d Semiannual Report (July 1957), pp. 4–5. Concentration of South African ores is from Atomic Industrial Forum, Forum Memo (January 1957), p. 11.

[3] Not available.

[4] Atomic Industrial Forum, Forum Memo (July 1957), p. 30.

The table 9 data are given in contained tons of pure metal at the specified ore concentrations. The average grade of domestic uranium ores fed to process during the first 6 months of 1957 was 0.28 percent U_3O_8 (uranium oxide).[55] At lower concentrations, ore-refining costs will be higher, but this will not have an appreciable effect on fissionable materials costs.

The energy content of fissionable materials is so high (approximately 9.7 million kilowatt-hours equivalent per pound of uranium or thorium) that at the present price level of $18.10 a pound of pure uranium metal,[56] costs of metal production would be a very small part of costs of energy. Assuming a thermal efficiency of 30 percent in power generation [57] and that fuel regeneration permits recovery of one-third of all fissionable material,[58] metal production will account for 0.0187 mill per kilowatt-hour, which is insignificant as compared with total costs of atomic-power production. We shall see that the latter will fall in the range of 7 to 10 mills per kilowatt-hour. If uranium-metal production costs increase 10 or even 100 times over today's levels, they will not seriously impair the economic prospects of atomic power.

As the demand for uranium metal is now forecasted, 200,000 to 300,000 tons may be required for commercial uses in the United States by 1975.[59] This estimate is based on optimistic assumptions about the rate of growth of the atomic-power industry, but at least gives us a basis for thinking that reserves shown in table 9 will not serve for very long, especially in view of the fact that they must also provide fissionable materials for military needs.

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[54] F. D. Lamb, Rare Earth Metals in U. S. Bureau of Mines, Minerals Facts and Figures (Washington 1956), pp. 735–743.

[55] AEC Release No. 1133, August 22, 1957.

[56] AEC Release No. 675, August 8, 1955.

[57] Thermal efficiencies in modern steam-generating plants are usually 30 percent or higher. See Federal Power Commission, Steam-Electric Plant Construction Cost and Annual Production Expenses (published yearly).

[58] One-third conversion to fissionable materials is assumed by Putnam, op. cit., supra, note 4, p. 214.

[59] See AEC, Uranium Ore Requirement for Nuclear Power in the United States, in Peaceful Uses of Atomic Energy, vol. 2, op. cit., supra, note 20, pp. 113–123.

Putnam refers to a number of low-grade sources, apparently of considerably lower concentration than those shown in table 9, and estimates that world reserves may account for 25 million tons of uranium and 1 million tons of thorium.[60] Since he made this estimate while acting as a consultant for AEC, we must assume that it was based upon the most complete information available at the time (1953). There is no evidence of any disproportionate incidence of uranium behind the Iron Curtain;[61] therefore, we will assume that the non-Communist world has available a proportional share of this total.

Again making the assumption that fuel regeneration will lead to conversion of perhaps one-third the uranium and thorium into fissionable materials, a total of 26 million tons of metal containing 9.7 million kilowatt-hours per pound will give 168,000 times 10^{12} kilowatt-hours electrical energy equivalent at full calorific value. This is 36 times our highest estimate of future cumulative world energy requirements by year 2000 (cf. table 1), about 17 times estimated coal reserves recoverable at costs up to twice the present levels and about 110 times estimated oil and gas reserves recoverable at twice present costs.

Previous discussion has described the problems of making an estimate of the extent to which we can rely upon fuel regeneration and has indicated something of the vagueness associated with estimates of reserves. If the combined error from these resources has lead to estimates which are five times too high, the potential of atomic energy will still exceed by many times the potential of all other energy resources put together.

Commercial uses of nuclear fuels in the United States

Unlike the fossil fuels, fissionable materials do not provide a versatile energy source. The physical requirements of a controlled chain reaction and the various devices that are necessary to protect personnel from intense radioactivity necessarily make a nuclear furnace very large and cumbersome.

In order for a chain reaction to be self-sustaining, it is necessary that at least one neutron from each fission be captured by another fissionable atom. Whether this is achieved depends upon the concentration of fissionable materials in a given mass, the size of the mass (which affects the ratio of volume to surface from which neutrons may escape), and the presence of other materials that will moderate the speed of the neutrons to increase the chances of their being captured by the unburned fuel. Flexibility in the critical mass (minimum-size mass) can be achieved by varying the concentration of nuclear fuel and by the use of moderating materials, but high concentrations and efficient moderators increase costs, and in any event, there is a limit on the size of the critical mass. A reactor can be designed for any power level, but these considerations make reactors very costly in units small enough, say, for the normal family dwelling.

In addition are the limitations due to the intense radioactivity which is a part of the fission process. The only known method of protecting personnel from radioactivity is by massive shielding, which may be a thickness of several feet of concrete for even a small reactor.[62]

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[60] Op. cit., supra, note 4, p. 214.

[61] See, for example, H. Schwartz' discussion of Soviet uranium reserves, Russia's Soviet Economy, 2d edition (1954), pp. 24–25.

[62] Schurr and Marschak, op. cit., supra, note 25, p. 5. See also AEC, Twenty-first Semiannual Report (January 1957), pp. 109–115.

For the same reason, reactor control and maintenance requires complicated gadgetry, very often two-stage heat removal systems, and special arrangements for fuel insertion and removal. These facts eliminate the prospect of directly using atomic power for transportation in self-propelled small vehicles, though we shall see that atomic energy can in many other ways carry part of the future energy load.

Electric powerplants.—The most promising commercial application of atomic energy today is in large central station electric powerplants, i. e., plants having a rated capacity on the order of 100,000 kilowatts or more. Small nuclear powerplants (of approximately one-tenth this size) are not as well developed economically, but appear to have costs per kilowatt-hour 2 or 3 times those of the large.[63]

Nuclear powerplants are similar to conventional powerplants except that steam is generated in the nuclear reactor, or in a heat exchanged heated by a fluid which has in turn received its heat from the reactor. After the steam has been delivered to a turbogenerator, electrical generation, transmission, and distribution proceed as before.

Projected trends in the cost of atomic power in large central sections in the United States, 1955–80, are shown in figure 1. The atomic power trends were projected by W. Kenneth Davis, Director, and Louis H. Roddis, Deputy Director, Division of Reactor Development, AEC. They are compared with the author's interpretation of costs of new conventional powerplants.

In their original chart, Messrs. Davis and Roddis gave projections of conventional power costs in the United States, but showed them to have an upward drift. Since no explanation accompanied their conventional cost projections, the latter were replaced by others thought to have substantial justification. Briefly, it is true that conconventional cost projections, the latter were replaced by others the same time improvements in conventional steam-plant effciency appear likely to at least offset their effect in the time period before 1980.[64]

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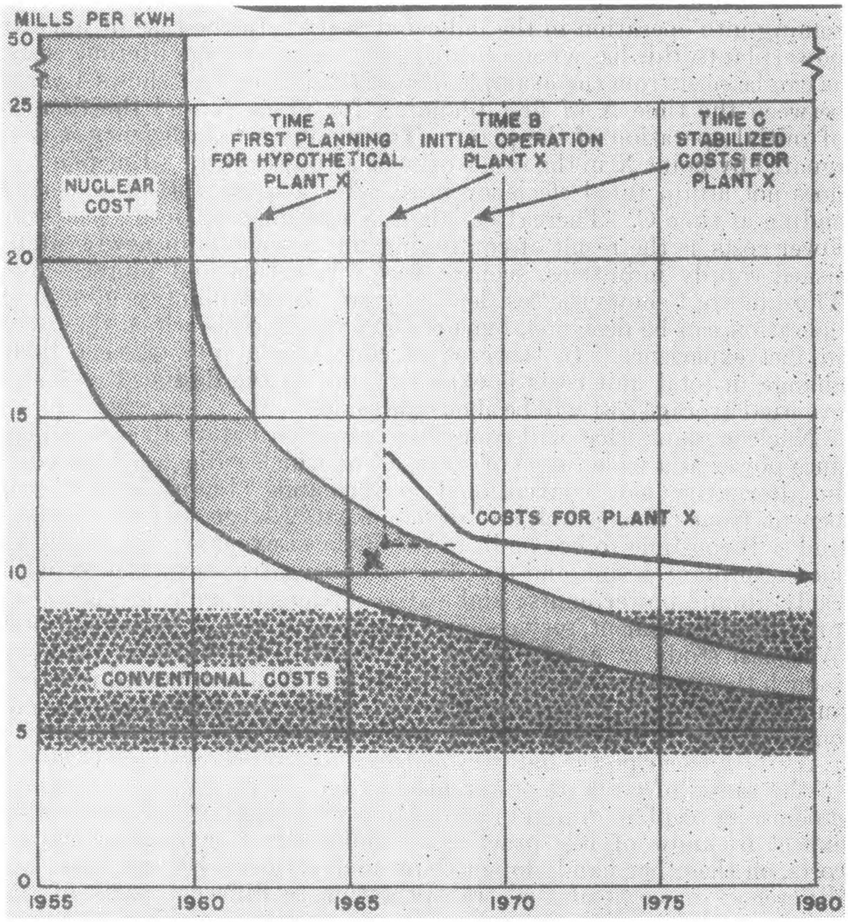
[63] See discussion by S. H. Robock, Nuclear Power and Economic Development in Brazil (National Planning Association, 1957), pp. 57–61. Robock's data for small plants in the United States were obtained from manufacturer's estimates, except in one case, which was based upon operation of a test facility.

[64] R. A. Tybout, The Economics of Nuclear Power, The American Economic Review (May 1957), pp. 352–353, 357.

FIGURE 1. ESTIMATED TOTAL UNIT COSTS OF POWER FROM LARGE NUCLEAR AND CONVENTIONAL POWERPLANTS GOING INTO SERVICE EACH YEAR

[Assumed load factors: For nuclear plants, 70–80 percent; for conventional plants, 50 percent]

[Figures are in 1957 dollars]



Source: Nuclear power projections are from paper prepared jointly by W. Kenneth Davis, Director, and Louis H. Roddis, Jr., Deputy Director, Division of Reactor Development, U. S. Atomic Energy Commission, for presentation at 5th Atomic-Energy-in-Industry Conference of National Industrial Conference Board, March 14, 1957, mimeographed AEC release, chart A. Conventional power projections are from R. A. Tybout, The Economics of Nuclear Power, American Economic Review (May 1957), pp. 352, 353, 357.

The Davis-Roddis projections use load factors of 70 to 80 percent, which is normal for the first few years of plant operation, but tends to understate fixed costs over plant lifetime.[65] Since nuclear powerplants will have fixed costs in the range of half to two-thirds their total costs,[66] this understatement can be significant. For example, if the lifetime load factor is 55 percent, as it may well turn out to be, total unit costs will be in the neighborhood of 20 percent higher than

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[65] Ibid., p. 354.
[66] Ibid., p. 352.

figure 1 shows for nuclear plants.[67] Conventional powerplant projections in figure 1 assume a 50-percent load factor. Davis and Roddis do not indicate their assumed annual rates for investment costs, but total unit costs are not sensitive to variations in these, within a reasonable range.[68]

The projections of power costs shown in figure 1 are for plants coming into operation in the indicated years. In the case of nuclear powerplants, this has a complicated relation to average lifetime costs, as can be seen from the example of plant X. Figure 1 shows 4 years between the time A of first planning for plant X and the time B of initial operation of the plant. The plant's rated efficiency is designated by point X in the range of nuclear power costs. But plant X does not attain rated efficiency until after a 3-year break-in period ending at time C. Thereafter, plant X continues to produce at ever lower costs as the result of continuing improvements in newly established supply industries, such as fuel fabrication and reprocessing. Thus, figure 1 shows the cost levels for which new plants coming into operation can be designed, but not the average costs which they will in fact experience. In the case of conventional plants, very little change in total unit costs is expected, and so the designed cost and eventual average cost will be about the same.

Nuclear plants that will come into operation before 1960 will produce power at a wide range of costs, all of which will exceed the costs in alternative new conventional powerplants. Later designs will benefit from (1) research and development, a large part of which is and will continue to be conducted at Federal expense; (2) improvements in plant design and operation resulting from experiences with early atomic powerplants; and (3) economies of scale in industries providing equipment, services, and supplies for atomic power stations. We shall study at a later point the Federal expenditures made to launch the atomic power industry, including AEC-supported research and development. Expected improvements in plant design and economies in supply industries are tangential to our present interests.[69]

As the nuclear power industry matures, figure 1 shows a convergence in the range of costs of power production. This reflects increasing uniformity of plant design in accordance with what we can reasonably expect to know of best-practice technologies. Conventional power costs, on the other hand, do not show a convergence because there are differences in costs of fuel transportation to different parts of the country. Among other things, this reflects one important economic aspect of atomic power—that nuclear fuels are almost weightless and sizeless for their energy content.[70] Atomic power will become economic first in those regions where conventional costs are high as a result of fuel transportation expenses. These include especially New England, Florida, and the Dakotas.

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[67] Calculated on the basis of data in Tybout, ibid., p. 352.

[68] For a tabulation of components of investment costs relevant to a comparison of atomic and conventional powerplants, see Tybout, ibid., p. 353.

[69] These have been discussed by the author, ibid., pp. 355–357.

[70] Using energy contents of 7,680 kilowatt-hours per ton of bituminous coal and 9.7 million kilowatt-hours per pound of fissionable uranium (as indicated elsewhere in this article), we find that 1 pound of uranium has a heat content equal to that of 1,260 tons of coal.

TABLE 10.—*Forecasts of nuclear additions each year as percent of total additions to electric generating capacity*

	1960	1965	1970	1975	1980
Davis (1955)[1]	4	8	38	60	70
Davis-Roddis (1957)[2]	4	8	26	53	67
McKinney Panel (1956)[3]	*4	*7	14	44	63
B. R. Prentice (1956)[4]	6	6	12½	41	62

*Obtained by graphical extrapolation.

[1] Remarks prepared by W. Kenneth Davis, Director, Division of Reactor Development, AEC, for presentation at the 17th Annual Meeting of the American Power Conference, Chicago, Ill., AEC release, Apr. 1, 1955.

[2] Paper prepared jointly by W. Kenneth Davis, Director, and Louis H. Roddis, Jr., Deputy Director Division of Reactor Development, U. S. Atomic Energy Commission, for presentation at 5th Atomic Energy in Industry Conference of National Industrial Conference Board, Philadelphia, Pa., AEC release, Mar. 14, 1957.

[3] Panel on the Impact of the Peaceful Uses of Atomic Energy (McKinney Panel), Peaceful Uses of Atomic Energy, vol. 2, Joint Committee on Atomic Energy, 84th Cong., 2d sess., (January 1956) p. 23.

[4] B. R. Prentice, A Forecast of the Growth of the Nuclear Fueled Electric Generating Industry, reprinted in part in Hearings on Development, Growth, and State of the Atomic Energy Industry before the Joint Committee on Atomic Energy, 84th Cong., 2d sess. (Feb. 7, 8, 15, 16, 23, 29, Mar. 1, 5, and 6, 1956), p. 578.

As a combined result of public aids and the eventual economic merits of atomic power itself, installed nuclear capacity will account for an increasing proportion of total electric power generated. Table 10 shows the range of expert opinion forcasting nuclear additions each year as a proportion of new electric generating capacity installed. The first two lines reflect AEC opinion, expressed first by W. Kenneth Davis, Director, Division of Reactor Development, and, second, By Mssrs. Davis and Roddis jointly at the same time that they provided the figure 1 forecast of costs. The last two lines express expert opinion from outside AEC.

In Mr. Davis' 1955 forecast, he made it clear that his predictions were based upon a bandwagon psychology assumed to motivate electric utilities to adopt atomic technologies.[71] In his 1957 forecasts with Mr. Roddis, the projections were simply presented as their "best judgment."

The McKinney panel (Panel on the Impact of the Peaceful Uses of Atomic Energy) and B. R. Prentice estimates are related in that Mr. Prentice (General Electric Co.) prepared his estimates for the use of the panel. The panel then revised them slightly to take account of special considerations.

The forecasts were made by a comparison of predicted future atomic power and conventional steam power costs in large plants in each of the eight regions into which the Federal Power Commission divides the Nation.[72] Lower costs of atomic power were used than have since been reported by Davis and Roddis (fig. 1), but conventional power costs were the same as there reported. The forecasts also took account of the fact that, perhaps for psychological reasons, some nuclear power is being installed before costs compare favorably with conventional power. In view of the body of opinion brought to bear upon the problem by the panel (representing private electric utilities, public power systems, electrical equipment manufacturers, AEC, Federal Power Commission, and the Department of the

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[71] See discussion by R. A. Tybout, The Public Investment in Atomic Power Development, Law and Contemporary Problems, vol. 21 (winter 1956) pp. 71, 72.

[72] See Panel on the Impact of the Peaceful Uses of Atomic Energy, Peaceful Uses of Atomic Energy, vol. 2, Joint Committee on Atomic Energy, 84th Cong., 2d sess, (January 1956), pp. 8–29.

Interior) and the systematic approach taken, we shall use the McKinney forecasts as a basis for estimating the toal volume of energy from atomic power in 1975.

The next step in estimating the future energy potential of atomic electricity is to determine the most likely rate of growth for national electric power production.

The average rate of expansion of electric power production for the Nation as a whole from 1920 to 1950 was approximately 7 percent per annum, continuously compounded.[73] This corresponds to an approximate doubling of electric power every 10 years. In view of our annual average increase of 3 percent in the first half of the 20th century,[74] this has meant an increasing substitution of electric power for other forms of energy. The electric motor has replaced the stationary steam engine with its power-delivery system of shafts and pulleys. In 1950, electric-power consumption was eight times the 1920 level. Use of petroleum in 1950 was more than 2½ times the 1925 level, water power was 4 times, and natural gas 5 times.[75] Only coal consumption stood at about the same level as in 1925.[76]

The question is whether electricity will continue to grow at the expense of other forms of energy. The Paley Commission felt that it would, but assumed only a 5 percent average (continuously compounded) rate of increase through 1975.[77] The Federal Power Commission uses a percentage rate declining from 7.2 annually for the 5 years 1955–60 to 3.8 annually for the 5 years 1975–80.[78] Contributors to the McKinney panel have given the weight of their authority to a growth rate of 6½ percent annually from 1955 to 1980.[79] The Edison Electric Institute proposes a range of rates from 5.4 to 6.8 percent a year from 1950 to 1975,[80] while Electrical World uses 7.0 percent to 1970.[81]

As a rough compromise and while recognizing the uncertainties implied by the differences in expert opinion, we shall use a 6 percent rate of growth per annum, continuously compounded to 1975. The resulting projection of nuclear-power production in 1975 will appear in table 11, following discussion of the prospects for nuclear fuels in other applications.

Beyond 1975, the probable rates of growth of both electrical power and its atomic-energy component are most speculative. We shall make no independent projection for this period, but will note Putnam's forecast for year 2000.

Process and space heat.—Large stationary heat sources, such as provided by nuclear reactors, offer some prospect of utilization for industrial process heating and can be adapted to large central-space heating almost as readily as to electric-power generation. The first application is limited by technological developments, the second by the nature of the market for space heating.

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[73] President's Materials Policy Commission, op. cit., supra, note 15, p. 103.
[74] Ibid., p. 105.
[75] Ibid., p. 103.
[76] Ibid.
[77] Ibid., p. 119.
[78] Estimated Future Power Requirements of the United States by Regions, 1955–80 (Washington, 1956).
[79] Op. cit., supra, note 72, p. 25.
[80] Looking Ahead to the Last Quarter of the First Century of Electric Power in the United States (June 1954).
[81] Electrical World, September 17, 1956.

Industrial process heat requires higher temperatures than electric-power generation.[82] The problem of obtaining structural and other reactor materials that will withstand the combined effects of temperature and high radioactivity, a difficult problem for electric-power reactors, becomes a limiting factor in the development of industrial process heat reactors. It has been predicted by AEC that perhaps 15 years (from 1955) of research and development will be needed before we can utilize nuclear energy for industrial process heat.[83] Thereafter, adoptions will take place first in large installations locate in areas of high cost alternative energy sources.

Space-heating applications will also be limited by the requirements of bulk consumption. A typical family dwelling housing 5 persons requires a heat plant with capacity on the order of 25 kilowatts. This is far below the level at which it is economic to generate atomic power.[84] Similarly, a large hotel or apartment house with a heat plant of 1,000 kilowatt capacity is less than one hundredth the size now judged most promising for electric-power production. In the absence of unforeseen technological changes, nuclear power for space heating will be limited to central-district plants.

Schurr and Marschak have found that to be economically promising, central-district heating requires very high population densities (of the order of 10,000 per square mile) and long cold winters.[85] There are districts in Chicago, Milwaukee, Buffalo, Boston, and the New York area which fit these requirements and, in fact, account for a significant part of the space-heating load.[86] With the trend to urbanization, the potential for nuclear-space heating should further improve.

Adequate information has not been developed to make forecasts of nuclear-power consumption in industrial process and space heating, but Putnam has offered informed guesses, which we shall note below.

Atomic propulsion.—Congress has authorized the construction of a nuclear-powered merchant ship jointly by AEC and the United States Maritime Administration.[87] The powerplant will be a pressurized water reactor of the type already in use in the Navy's submarine, *Nautilus.*

Some indication of the prospects for economic application is merchant-ship propulsion has been provided in a survey report by Rear Adm. H. G. Rickover, Chief, Naval Reactors Branch, AEC. Admiral Rickover indicates that capital costs of the reactor in the *Nautilus* are about seven times as great as those for an equivalent horsepower oil-fired plant, and that for a commercial surface vessel nuclear fuel costs would be about 50 times the cost of fuel oil for equal shaft-power generation.[88] Within 5 years, Admiral Rickover

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[82] Panel on the Impact of the Peaceful Uses of Atomic Energy, op. cit., supra, note 72, p. 316.

[83] Ibid.

[84] Ibid.

[85] Op. cit., supra, note 25, p. 211.

[86] Ibid., p. 212.

[87] Public Law 848, 84th Cong., approved July 30, 1956.

[88] Panel on the Impact of the Peaceful Uses of Atomic Energy, op. cit., supra, note 72, p. 241.

expects nuclear-fuel costs can be reduced to 15 or 20 times those of fuel oil.[89]

Nuclear powerplants offer the special advantage of ability to travel long distances without refueling, a matter of some importance in many military situations. This explains the Navy's interest in nuclear-powered submarines and an analogous interest by the Air Force in nuclear-powered aircraft. But there is no immediate prospect that atomic power can stand on its own economic feet in commercial vehicles, even when installed in vessels as large as merchant ships.

Nuclear fuel potential.—Table 11 shows plausible contributions of nuclear fuels in the United States in 1975 and 2000. Previous discussion has established the basis for our estimate for 1975, viz., that total electric-power generation will grow at a rate of 6 percent annually and nuclear capacity will be installed in accordance with the McKinney growth-rate schedule.

Putnam bases his estimate of nuclear power upon an annual rate of growth of total electric generating capacity of 4¼ percent compounded from 1950 to 2000 A. D. and assumes that 70 percent of all electric power generated in year 2000 is nuclear. His estimate of space heat is based upon one-sixth of the Nation's estimated needs and for process heat, upon one-tenth of estimated needs. Further details are not given.

Comparing the table 11 figures with table 1 estimates, we find that somewhere in the neighborhod of 5 percent of total national energy consumption will be nuclear in 1975 and somewhere from 10 to 20 percent in 2000.

TABLE 11.—*Plausible energy supplied by nuclear fuels in the United States in years 1975 and 2000*

[In kilowatt hour × 10^{12} at full calorific value]

	1975 [1]	(Putnam) 2000 [2]
Electricity	1.0	5.15
Industrial process heat	(?)	0.53
Space heat	(?)	1.32
Total		7.00

[1] Calculated in accordance with assumptions indicated in text and applied as shown in appendix B.
[2] P. C. Putnam, Energy in the Future (Van Nostrand, 1953), p. 209.

The difficulties of radically extending our consumption of atomic fuels are implicit in previous discussion. Transportation accounted for 30 percent of all end uses of energy in the United States in 1947 and the Paley Commission expects it to hold approximately the same position through 1975.[90] The possibilities of using nuclear energy for transportation appear limited except through the medium of electric power, which would necessitate radical modifications in economic and social relationships. The fluid fuel problem is more likely to be solved, in the 20th century at least, by use of oil shales, conversion of coal.

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[89] Ibid., p. 242.
[90] Op. cit., supra, note 15, p. 125.

Similarly, in comfort heating, which accounts for about a third of energy consumption in the United States,[91] the applications of nuclear heat are limited to central district heating in the absence of a technological breakthrough, unforeseeable at the present time. For industrial process heat, which accounts for 11 percent of present energy consumption,[92] nuclear fuels offer a potential, though it tends to be especially related to bulk uses and, for example, cannot serve the same chemical function as coke in steelmaking. Primary metals consumption of coke accounts for 4.2 percent of all energy consumed in 1947.[93]

Nuclear energy finds its greatest potential in the applications of electrical energy. All in all, it would seem generous to conclude that with existing and foreseeable technologies, nuclear energy will provide any more than a quarter to a third of our future energy needs in the absence of far-reaching social and economic changes. Such changes, for example, might take the form of overhead electrification on main highways for cars, buses, and trucks, with reliance on storage batteries or remaining fluid fuels elsewhere, and more community life in high population density areas than can be served by central district heating.

Whether we actually move in either of these directions will depend upon a variety of factors, not the least of which is technological advance in developing other energy sources. Ample opportunities for research remain, for example, in improving upon nature's efficiency in fixing carbon. It is not immediately obvious that the prospects are very much less attractive than for commercial atomic propulsion.

The nuclear potential abroad

Most regions of the world will face more pressing energy resource problems before the end of the 20th century than will the United States. The underdeveloped countries are, by and large, also the "have not" nations for fossil fuels. The mature economies of Western Europe are in a precarious position with respect to fluid fuels and appear constrained in the extent to which they can exploit home coal reserves. In between are Japan, Brazil, Israel, and certain other nations with a demonstrated understanding of economic progress, but long-term energy resource problems.

In a general way, we shall note the promises and problems of industrial atomic energy for underdeveloped and developed economies abroad. American nuclear power policy is, at one and the same time, an aspect of international development and a form of rivalry with the Soviet Union in demonstrating economic prowess and cementing technological ties with other world regions.

Underdeveloped countries.—Underdeveloped countries face a general problem of capital shortage. Overland transportation is limited and costly, which tends to force local self-sufficiency and low productivity. Equipment for productive techniques, power generation, and energy consumption tends to be concentrated in large cities with access to water transportation. Other areas, even when thickly populated, have substantially no access to energy and no tools with which

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[91] Putnam, op. cit., supra, note 4, p. 102.

[92] Ibid.

[93] Putnam, ibid., p. 391, reports coke consumption by end uses, while the President's Materials Policy Commission, op. cit., supra, note 15, p. 125, gives coke consumption as a proportion of all energy consumption.

to use it. Electrification and local access to high energy consuming methods of production is only one part of a far-reaching capital-consuming process, and is dependent upon simultaneous progress with the other parts.

In this context, the capital intensive requirements of nuclear power production appear at a disadvantage. Table 12 shows the capital needs of nuclear compared with those of other electric power generating systems. All figures are for the United States and assume the availability of a standard industrial complex for the production and transportation of cement, steel, and other products.

Nuclear power estimates for large plants are given for the present and expected future levels of capital costs. In both cases, the nuclear figures include all the special supporting industrial process equipment for fuel preparation, fuel enrichment, waste disposal and the production of certain other special materials. Between $50 and $100 of these capital costs could be turned into operating expenses by a nation that was willing to buy its enriched fuel abroad.[94]

Assuming the availability of foreign loans, the implied drain upon foreign exchange would appear to be serious but for the fact that many underdeveloped countries must already import coal and oil at high delivered prices. These countries already face a foreign exchange problem as a result of transportation costs for the long distances fuels must be carried. Although nuclear power requires a high capital investment, annual costs of nuclear fuel transportation would be negligible.

Even in underdeveloped countries where coal is mined cheaply, available rail transport usually sets an upper limit of 300 to 400 miles on the distance for economic overland transportation.[95] Hydroelectric power, where available, cannot be transmitted economically over 400 to 500 miles with present technologies.[96] Again, transportation costs may work to the advantage of nuclear fuels in economically isolated (though perhaps heavily populated) areas. A qualification is that there must be enough heavy transport available to permit the initial construction of the atomic powerplant.

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[94] W. Kenneth Davis, Capital Investment Required for Atomic Energy, Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, vol. 1 (United Nations, 1956), p. 299.

[95] United Nations Department of Economic and Social Affairs, Some Economic Implications of Nuclear Power for Underdeveloped Countries, Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, vol. 1 (United Nations, 1956), p. 343.

[96] Ibid.

TABLE 12.—*Investment costs of electric generating stations with special supply facilities* [1]

[Dollars per installed kilowatt]

	100,000 kilowatts capacity	10,000 kilowatts capacity	1,000 kilowatts capacity
Nuclear	[2] 350 [3] 250	[2] 600–700	(?)
Conventional steam	135	155	(?)
Internal combustion	(?)	138	162
Hydroelectric	120	170	240

[1] The only plants requiring special supply facilities are the nuclear plants.
[2] Now.
[3] Estimated future.

Source: W. Kenneth Davis, Capital Investment Required for Nuclear Energy, Proceedings of the International Conference on the Peaceful Uses of Atomic Energy (United Nations, 1956), pp. 299–300, except for the estimate of per kilowatt cost for nuclear plants of 10,000 kilowatts capacity. This was obtained by combining the per kilowatt cost of special supply facilities from W. K. Davis, op. cit., with the per kilowatt electric plant cost from S. H. Robock, Nuclear Power and Economic Development in Brazil (National Planning Association, 1957), p. 122, table 2.

A final point works to the disadvantage of nuclear power. Table 12 points to the fact, which we have already noted, that nuclear power is not economical in small plants. Yet, a large part of the market in underdeveloped countries is for small power units. The first Indian 5-year plan is reported to provide for an 800-percent increase in diesel engines used for electric water pumping in agriculture although the fuel must be imported.[97] The dispersion of power needs which this implies is characteristic of the early stages of economic development. There are only limited opportunities in underdeveloped countries for power consumption on the scale most economic for nuclear plants.

The net result of these various influences is, of course, different in each specific situation, but we may observe that in general atomic power might be attractive for some underdeveloped countries as a result of transportation costs of conventional fuels.

It is worth noting in passing that the underdeveloped countries should have a special interest in solar energy. Solar energy collectors are well adapted to small power outputs and present no problems of importing fuels of any kind. Moreover, most underdeveloped countries lies in the more sunlit regions of the world. The technologies of solar energy collection and storage are relatively unexplored, but even at their present primitive level find a market for cooking in India and space heating in the United States. One can only speculate as to what might result from a national effort to develop solar energy comparable to the effort we are making to develop atomic power.

Developing economies.—In the advanced stages of economic development, nuclear power is more likely to find useful applications in the foreseeable future.

Developing economies are concerned especially with heavy manufacturing production, which tends to make disproportionate energy demands. In a worldwide correlation, Robinson and Daniel found twice the rate of energy consumption with manufacturing production as with real national income.[98] It follows that in the rapidly developing regions of the world, including the Soviet Union and a number

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[97] Ibid., note.
[98] Op. cit., supra, note 5, pp. 38–41.

of South American countries, large markets are opening for energy-intensive uses. Where fossil fuel shortages appear, nuclear power may offer the best solution.

Comparing our previous discussion of energy resources, South American countries would seem to be in the position to first adopt atomic power among the developing economies, and there is some direct evidence that this is the case. Spokesmen for Brazil, Argentina, and Uruguay delivered papers at the Geneva Conference describing plans for energy development.[99] Of these, Brazil and Argentina indicated clear possibilities for early introduction of nuclear power. In a study of Brazil alone, Robock found economic benefit from nuclear power (despite foreign exchange problems) by 1965 and increasing advantage in the years thereafter.[100]

Mature economies.—Mature economies abroad have, if anything, more immediate grounds for economic interest in atomic power than has the United States.

Fuel shortages appear to be not far in the future for the western European countries as a whole and indeed, are present today in the sense that coal production involves costs almost twice those of the United States.[101] Japanese electricity is produced 60 percent from hydro power, but suitable hydro sites are almost all in use and delivered coal prices are approximately twice as high per contained kilowatt-hours of energy as in the United States.[102] Both regions also differ from the United States in that they are less heavily committed than are we to a transportation system based on liquid fuels, a fact which would make for less difficult adjustments through electrification.

AEC has indicated that Japan expects to need 500,000 kilowatts of nuclear electric capacity by 1965,[103] while Britain has announced a program of construction of nuclear power plants which will bring 5 to 6 million kilowatts of nuclear capacity into operation by 1965.[104] Assuming a 3 percent rate of growth of energy consumption in Britain, that the nuclear electric facilities are used at a load factor of 85 percent in 1965, and an average thermal efficiency of 30 percent in the nuclear plants, this means that about 6 percent of all energy consumed by Britain in 1965 will be nuclear.[105]

On the continent, the Community of Six (Belgium, France, Western Germany, Italy, Luxembourg, and the Netherlands) through its creation, the European Atomic Energy Community, has drawn up a scheme of cooperative endeavor commonly known as Euratom. This involves supranational authority having certain regulatory functions to protect public health and to prevent diversion of nuclear materials

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[99] See Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, vol. 1 (United Nations, 1956).

[100] Op. cit., supra, note 63.

[101] Op. cit., supra, note 4, pp. 137–139.

[102] Delivered coal prices for Japan and the United States, respectively, are from M. Sapir and S. J. Van Hyning, The Outlook for Nuclear Power in Japan (National Planning Association, 1957), p. 64, and Federal Power Commission, Steam-Electric Plant Construction Cost and Annual Production Expenses, Eighth Annual Supplement (Washington, 1956). Information on Japanese hydro sites is from Sapir and Van Hyning, op. cit., pp. 25–27.

[103] Prepared statement submitted in hearings on development, growth, and state of the atomic energy industry before the Joint Committee on Atomic Energy, 85th Cong., 1st sess. (February 19, 20, 21, 25, 26, 27, 28, and March 5, 1957), p. 156.

[104] Atomic Industrial Forum, Forum Memo (September 1957), pp. 22–25.

[105] Based on 1952 energy consumption, as reported by United Nations Department of Social and Economic Affairs, op. cit., supra, note 1, p. 20.

to armaments and having advisory functions with respect to power generation and coordination of national program.[106] Euratom has announced that it will need a capacity of 3 million installed kilowatts of atomic electricity by 1963 and 15 million by 1967.[107] On the basis of the same assumptions as made for Britain, this will mean that approximately 9½ percent of all energy consumed in the six participating countries in 1967 will be nuclear.[108]

If they carry out their plans, both Britain and Euratom will have exceeded the United States in nuclear capacity by 1965 and 1967. The comparable figures for the United States are 2.8 million and 5.4 million kilowatts of installed nuclear power in these respective years.[109] Our previously derived estimate of nuclear consumption as a proportion of the United States total energy consumption is approximately 5 percent in 1975.

Lane reports reactors planned or announced in other countries as follows: Austria, one 10,000-kilowatt powerplant; Canada, a 20,000-kilowatt electric powerplant; Norway, a 20,000-kilowatt process heat plant; Sweden, 3 process heat plants totaling 236,000-kilowatt capacity and 3 electric powerplants totaling 75,000 to 300,000 kilowatts; and the Soviet Union, looking toward a total of 2 to 2.5 million kilowatts.[110] In all cases, the plants are to be in operation by the early 1960's.

Foreign assistance.—The United States is giving assistance to friendly nations in their efforts to develop and utilize atomic power. This is generally referred to under the global term "atoms-for-peace," stemming from the President's historic announcement before the eighth session of the United Nations General Assembly, December 8, 1953. In keeping with his proposals, the President subsequently announced that 20,000 kilograms of enriched uranium fuel would be available for lease or sale to friendly nations at $25 a gram, a price intended to cover AEC's total unit costs of production, but not to yield AEC a profit.[111] Various other steps have been taken, too numerous to catalog here, but including especially the promotion of the Geneva Atoms-for-Peace Conference and the International Atomic Energy Agency.

For its part in atoms-for-peace work, AEC requested a budget authorization of approximately $7.7 million, about $3 million for expenses of international conferences and about $2.5 million for construction of a training center in Puerto Rico.[112] The remainder was for relatively stabilized aspects of AEC foreign aid, as shown in table 13.

Table 13 shows the assisted nations by world region, and for each region, totals are indicated. Four types of assistance are shown. Columns (1) and (2) refer to student training. Columns (3) and (4)

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[106] See K. E. Knorr, Nuclear Energy in Western Europe and United States Policy Princeton, 1956).

[107] AEC prepared statement, op. cit., supra, note 103, pp. 155–156.

[108] Based on 1952 Energy consumption for the six Euratom nations, as reported by United Nations Department of Social and Economic Affairs, op. cit., supra, note 1, p. 20.

[109] Calculated from schedule of nuclear capacity installed each year in the United States, appendix B, table B–1, col. (6).

[110] J. A. Lane, Where Reactor Development Stands Today, Nucleonics (August 1956).

[111] White House press release, February 22, 1956. An additional allocation of 29,800 kilograms was subsequently made available for foreign governments. White House press release, July 3, 1957.

[112] Hearings before the Subcommittee on Appropriations on Atomic Energy Appropriations for 1958, 85th Cong., 1st sess. (July 10, 1957), p. 140.

show assistance in actually getting reactors. Column (3) shows licenses issued for export of reactors. In most cases the export is paid for through a grant shown in column (4), but this is not always the case. Canada and Italy are importing reactors not covered by grants. Column (5) shows depository libraries, distinguished by C if classified, by U if unclassified. Columns (6) and (7) show bilateral agreements in effect, and in process of negotiation, respectively. The bilateral agreements provide for exchange of information, classified or unclassified, as indicated, and often include provision for shipment of nuclear fuels under terms noted above.

The general impression given by table 13 is that Europe is receiving by far the greatest assistance in developing atomic energy. Asia comes next, at least in student training, but is matched by the Americas in all other respects. Very little aid goes to other world regions.

TABLE 13.—*Selected foreign atomic energy assistance*

Country	Students trained at ISNSF [1]		Research reactors licensed for export		Technical library [2]	Bilateral agreement	
	Number (1)	Cost to United States (2)	Number (3)	Grant by United States (4)	(5)	In effect [3] (6)	Pending or in negotiation [2] (7)
The Americas, total	29	$174,000	2	$700,000	1C, 13U	1C, 9U	5C, 5U
Argentina	4	24,000			U	U	C
Brazil	9	54,000	1	350,000	U	U	C
Canada			1		C	C	
Chile	4	24,000			U	U	
Colombia					U	U	
Costa Rica					U		U
Cuba	2	12,000			U		C, U
Dominican Republic					U	U	
Ecuador	1	6,000					U
Guatemala	1	6,000			U	U	
Haiti					U		U
Mexico	3	18,000			U		
Nicaragua							U
Peru	1	6,000			U	U	C
Uruguay	2	12,000			U	U	C
Venezuela	2	12,000		350,000	U	U	
Europe, total	132	792,000	10	2,620,000	2C, 17U	5C, 10U	5C, 2U
Austria	5	30,000			U	U	
Belgium	8	48,000		[3] 350,000	C	C	
Denmark	4	24,000	2	350,000	U	U	
Finland	2	12,000			U		
France	13	78,000			U	C	
Germany, Federal Republic of	20	120,000	4	[3] 350,000	U	U	C
Greece	8	48,000		[3] 350,000	U	U	
Iceland					U		
Ireland					U		U
Italy	21	126,000	1		U	U	C
Luxembourg					U		
Netherlands	4	24,000	1	350,000	U	U	C
Norway	4	24,000			U	C	
Portugal	3	18,000	1	350,000	U	U	
Spain	22	132,000	1	350,000	U	U	C
Sweden	5	30,000			U	U	C
Switzerland	9	54,000		[4] 170,000	U	C, U	
United Kingdom					C	C	
Yugoslavia	4	24,000			U		U
Africa, total	9	54,000			2U		2C, 2U

See footnotes at end of table.

TABLE 13.—*Selected foreign atomic energy assistance*—Continued

Country	Students trained at ISNSF [1]		Research reactors licensed for export		Technical library [2]	Bilateral agreements	
	Number (1)	Cost to United States (2)	Number (3)	Grant by United States (4)	(5)	In effect [3] (6)	Pending or in negotiation [2] (7)
Egypt	8	48,000	-----	-----	U	-----	-----
Liberia	-----	-----	-----	-----	-----	-----	U
Southern Rhodesia	1	6,000	-----	-----	-----	-----	C
Tunisia	-----	-----	-----	-----	-----	-----	U
Union of South Africa	-----	-----	-----	-----	U	-----	C
Asia, total	102	612,000	1	700,000	13U	9U	6C, 3U
Afghanistan	1	6,000	-----	-----	-----	-----	-----
Burma	5	30,000	-----	-----	U	-----	-----
Ceylon	1	6,000	-----	-----	U	-----	U
China (Taiwan)	7	42,000	-----	-----	U	U	C
India	8	48,000	-----	-----	U	-----	-----
Indonesia	3	18,000	-----	-----	-----	-----	-----
Iran	2	12,000	-----	-----	-----	-----	U
Iraq	5	30,000	-----	-----	U	-----	U
Israel	4	24,000	-----	[3] 350,000	U	U	C
Japan	18	108,000	1	350,000	U	U	C
Korea, Republic of	12	72,000	-----	-----	U	U	-----
Lebanon	1	6,000	-----	-----	U	U	-----
Pakistan	14	84,000	-----	-----	U	U	C
Philippines	5	30,000	-----	-----	U	U	C
Thailand	7	42,000	-----	-----	U	U	C
Turkey	9	54,000	-----	-----	U	U	-----
Oceania, total	2	12,000	-----	-----	-----	1C, 1U	-----
Australia	2	12,000	-----	-----	-----	C	-----
New Zealand	-----	-----	-----	-----	-----	U	-----
World, total	274	1,644,000	13	4,020,000	[5] 3C, 45U	7C, 29U	18C, 12U

NOTES

[1] Authorized enrollment at the International School of Nuclear Science and Engineering (ISNSE), 1st 6 sessions commencing from March 1955 to September 1957.

[2] By "U" is meant an exchange of unclassified information related to research reactors; by "C" is meant an exchange of classified information related to power reactors.

[3] Tentative grants; complete plans not submitted by applicants.

[4] This is the Geneva Convention Reactor which was sold to Switzerland at approximately 50 percent of cost.

[5] Does not include 4 technical libraries awarded to international organizations.

Sources: Cols. (1), (3), (4), (5), (6), (7) compiled from AEC Releases through Sept. 18, 1957; col. (2) calculated on the basis of costs announced by AEC in hearings before the subcommittee of the Committee on Appropriations on Atomic Energy Appropriations for 1958, House of Representatives, 85th Cong., 1st sess. (July 10, 1957), p. 120. Exact pro rata figure per student is $5,916.67.

PUBLIC AIDS

The development of civil atomic power is one phase of a predominantly military atomic energy program which from its inception in 1940 to the end of fiscal year 1956 resulted in public appropriations of $15.2 billion,[113] at least several billion dollars of which would have been necessitated by a single-purpose civil power effort.

Military objectives have already led to the conduct of much of the necessary basic research, have stimulated exploration for uranium ores, and have created the refining, fuel enrichment and fuel reprocessing facilities that give the nuclear power industry a supply base upon

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[113] AEC 21st Semiannual Report (January 1957), p. 379.

which to build. The facilities for fuel enrichment and reprocessing even today are publicly owned, though there is every reason to think that as the atomic power industry grows, these traditional industry-type activities will be conducted in the private sector. Until that time, nuclear power will continue to benefit from its base in the public sector, if for no other reason, because the atomic power industry, if based only in the private sector, could not have supported in its early years the scale of fuel enrichment and reprocessing operations that would have kept costs down to their present levels.

These benefits are real, but are unintended byproducts of military preparedness. In principle, we cannot charge them against atomic power, and in practice, information is not available and could not be obtained with any exactitude as to their extent, based upon what might have been the situation in their absence.

The public aids with which we shall be concerned are those explicitly intended to bring atomic power costs down to present levels of steam electric power, plus certain other public expenditures for the joint purpose of furthering both military and civil atomic power, but no expenditures incurred in whole or in part for military explosives.

AEC has undertaken three major programs of financial assistance for low cost civil atomic power. First, the Atomic Energy Commission is conducting research and development on promising reactor concepts. This is generally limited to pilot-plant (experimental small scale) models. Second, the Commission is covering part of the cost of particular full-scale nuclear power stations which will be privately operated under arrangements referred to as the power reactor demonstration program (demonstration program). Assistance of this type is negotiated separately for each project. Third, AEC has adopted a sliding scale of price supports for purchase of regenerated fissionable materials produced in private atomic powerplants, whether or not the plants are operating under demonstration program arrangements.

Other forms of financial assistance are made available by the Federal Government. First, rapid tax amortization is available for civil atomic powerplants, though not for other electric utilities. Second, the civil atomic power industry is indemnified by law against public claims of damages from nuclear accidents over certain levels.

Finally, at the State level, established practices in electric utility regulation have been interpreted to permit atomic power station operators to charge the higher costs of atomic electricity to consumers in higher rates than would have resulted had conventional facilities been installed.

AEC civil-power research

Table 14 shows cumulative AEC expenditures for civil-power research through 1957, plus related projects and cost projections.

Twelve projects appear under the title "Civil-Power Reactors." The first five were AEC's 5-year power reactor development program started in 1954, but since swallowed up in the present expanded (and unnamed) program of civil-power research. The rest of the projects were adopted as they showed technological promise, very often as the result of stimulation by the congressional Joint Committee on Atomic Energy. For example, column (6) shows that appropriations for fiscal year 1958 included sums that had not been requested by AEC. These originated in the Joint Committee on Atomic Energy.[114] The natural uranium (graphite-moderated, gas-cooled) reactor had not been represented before among the civil-power projects.

The pressurized water project, listed first among the civil-power reactors, is a full-scale electric powerplant of 60,000 kilowatts capacity located at Shippingport, Pa. (in the Pittsburgh area) and scheduled to begin operation in December 1957. The plant is owned by AEC, but will be operated by the Duquesne Light & Power Co. under arrangements that will result in Duquesne's paying about 32 percent of all electric power generating costs over the plant lifetime.[115] Operating costs shown in column (1) of table 14 for this plant refer only to research and development operations, since the plant is not yet generating power.

TABLE 14.—*Atomic Energy Commission reactor development costs*

[In millions of dollars]

	Costs through fiscal year 1957			Projected costs		
	Operating (1)	Construction (2)	Total (3)	Operating, fiscal year 1958 (4)	Construction, at completion (5)	Added by Congress, fiscal year 1958 (6)
Civil power reactors:						
Pressurized water	47.0	43.9	90.9	21.0	64.5	----------
Boiling water	18.7	1.8	20.5	5.0	10.3	----------
Homogeneous	42.7	1.0	43.7	11.8	4.7	----------
Fast power breeder	20.2	5.7	25.9	13.6	29.1	----------
Sodium graphite	16.5	0	16.5	7.9	6.0	----------
Liquid metal fuel	5.1	0	5.1	8.0	(?)	----------
Organic moderated	3.9	0	3.9	5.5	.8	----------
Plutonium recycle	1.0	0	1.0	4.0	(?)	15.0
Pressurized heavy water	.5	0	.5	4.0	(?)	----------
Advanced design	.5	0	.5	2.0	(?)	----------
Natural uranium	----------	----------	----------	----------	----------	3.0
Other	5.9	1.1	7.0	0	(?)	----------
Total	162.0	53.5	215.5	82.8	115.4+	18.0
Military and classified projects	483.1	174.1	657.2	180.6	----------	----------
General development, operation of supporting facilities, etc	222.2	212.9	435.1	51.9	----------	3.0

Source: Cols. (1), (2), and (3), unpublished data from U. S. Atomic Energy Commission.

Col. (4), AEC budget request, hearings before the Subcommittee on Appropriations on Atomic Energy Appropriations for 1958, House of Representatives, 85th Cong., 1st sess. (July 10, 1957), p. 217. The AEC budget request of $2,377,600,000 for operations was granted in the amount of $2,215,470,000 in Public Law 715, 85th Cong., approved Aug. 28, 1957, without restriction upon reactor development.

Col. (5), AEC prepared statement in hearings before the Joint Committee on Atomic Energy on Development, Growth, and State of the Atomic Energy Industry, 85th Cong., 1st sess. (Feb. 19, 20, 21, 26, 27, 28, and Mar. 5, 1957), pp. 690, 691, and J. A. Lane, Where Reactor Development Stands Today, Nucleonics (August 1956).

Col. (6), Public Law 162, 85th Cong., approved Aug. 21. 1957. No distinction is made between plant and operating expenditures in these appropriations.

Costs are given on the basis of obligations incurred and not for cash disbursed in cols. (1) through (4).

All of the other projects listed as civil power reactors are experimental units, and a number of such units may be included in a given project. For example, the first homogeneous reactor was started in March 1951 at the Oak Ridge National Laboratory, but was shut

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[114] See S. Rept. 791, 85th Cong., 1st sess. (August 2, 1957).

[115] Calculated on the basis of a $30 million expenditure by Duquesne Light Co. over plant life (see Tybout, op. cit., supra, note 71, pp. 65–66), as compared with AEC's investment of $64.5 million shown in table 14, column (5), which will substantially complete the AEC expenditure for power generation at Shippingport.

down and dismantled in early 1954. The present homogeneous reactor is also being constructed at Oak Ridge; present plans call for initial operation in December 1957. The costs of both homogeneous reactors are included in columns (1), (2), and (3). The same principle is followed for other civil power projects, except that military and general research precursors are not included with the civil power reactors. The cost of earlier reactor research was assigned in Commission accounts, which were the source of data in columns (1), (2), and (3), to civil atomic power only in cases were this was the clear intention at the beginning of the research.[116]

Table 14 shows a total cost of civil power reactors of $215.5 million through fiscal year 1957. In addition, AEC spent $657.2 million on military reactor development (principally for propulsion) and $435.1 on general reactor development, including operation of supporting facilities. The general expenditures were intended to further both military and civil goals. At least some part of them should be assigned to civil power development.

Two procedures for allocation of general reactor development expenses between civil and military programs have been described elsewhere by the author.[117] The first treats all general expenses in the same way as overhead burden in many industrial cost accounting systems. Applied to the data in table 14, it results in the assignment of $109.7 million of the general expenses to civil power, bringing the civil power total to $325.2 million by the end of fiscal year 1957.

The second apportions all general expenses in the same way as common costs are allocated in the most satisfactory of the techniques for our large multipurpose river and regional development projects, such as the Tennessee Valley Authority. This method assigns $217.6 million of general expenses to civil power, resulting in a total civil power cost of $433.1 million through fiscal year 1957.

Columns (4), (5), and (6) of table 14 show projected costs as far ahead as these can be foreseen with reasonable assurance. The column (5) figures include the construction costs shown in column (2), except for minor plant costs which are no longer used in reactor projects. An example would be the previously mentioned first homegeneous reactor, now dismantled. This is included in column (2), but not column (5).

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[116] Physical descriptions of the civil power reactors may be found in AEC semiannual reports of recent years.

[117] See Tybout, op. cit., supra, note 71, pp. 65, 66.

A rough total of funds spent and committed to civil power can be calculated by adding the projected costs (sum of cols. (4), (5), and (6)) to civil power costs through fiscal year 1957, and subtracting the column (2) costs so as to avoid double counting with column (5). This, of course, will understate total costs even as implied by present projects to the extent that civil power reactor projects already undertaken will necessitate further (specific and general) expenditures before completion. Recognizing this limitation, the indicated calculations give 487.9 to 595.8 million dollars for civil atomic power, depending upon the method used for allocating general expenses cumulated to the end of fiscal year 1957. For future reference, we shall round this to 500 to 600 million dollars.

There is no immediate prospect of abatement of AEC's civil power reactor research program. Only 1 of the first 5 projects (the boiling water reactor) has all of its projected research facilities in operation.[118] Facilities for the rest are scheduled to begin operation at various dates in 1957, or as late as June 1959 in the case of the fast power breeder reactor.[119] It may also be significant, as a commentary upon the embryonic state of our technological knowledge, that presently estimated costs of the five reactor plants vary from 36 percent to 89 percent above their original estimated costs.[120] The rest of the projects are in the study stage, and if carried forward might go considerably beyond the costs shown for them in table 14.

Power demonstration reactor program

Power demonstration projects in prospect at the beginning of August 1957 are summarized in table 15. Projects are identified by the name of proposers, or powerplant operators. The operators are groups of private electric utilities and other business firms in the case of Yankee Atomic Electric Co., Power Reactor Development Co., Florida Nuclear Power Group, and Northern States Power Co., with membership as shown in appendix C. The other five organizations shown in table 15 are public or cooperative bodies. The operators are grouped according to whether the proposals were made in response to AEC's first, second, or third round invitations, directed to American industry and offering different kinds of aid for different classes of atomic powerplants which the latter might propose to build and operate.

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[118] See hearings, supra, note 103, pp. 690–691.

[119] Ibid.

[120] Ibid.

TABLE 15.—*Atomic Energy Commission assistance in power reactor demonstration program*

[In millions of dollars]

PART A—ASSISTANCE REQUESTED BY PRIVATE PROJECT PROPOSERS

Operators and plant capacity for each	(1) Preconstruction research and development	(2) Reactor construction	(3) Postconstruction research and development	(4) Total cols. (1)+(2)+(3)	(5) Waiver of interest charges on fuel	(6) Total value of assistance, cols. (4)+(5)
FIRST ROUND PROPOSALS						
Yankee Atomic Electric Co. (134,000 kilowatts)	5.000			5.000	2.980	7.980
Power Reactor Development Co. (100,000 kilowatts)	4.450			4.450	3.703	8.153
Consumer Public Power District (75,000 kilowatts)	18.165	24.013	8.000	50.178	1.325	51.503
Total				59.628		
SECOND ROUND PROPOSALS						
Shugach Electric Association (10,000 kilowatts)	9.880	6.729	2.500	19.109	0.620	19.729
Rural Cooperative Power Association (22,000 kilowatts)	2.760	5.686	1.640	10.086	0.125	10.211
Wolverine Electric Cooperative Association (10,000 kilowatts)	1.635	3.837		5.472		5.472
City of Piqua, Ohio (12,500 kilowatts)	3.500	4.010	3.600	11.110	0.625	11.735
Total				45.777		
THIRD ROUND PROPOSALS						
Florida Nuclear Power Group (136,000 kilowatts)	9.300		(1)	9.300	[2] 7.500	16.800
Northern States Power Co. (66,000 kilowatts)	5.500		0.500	6.000	1.000	7.000
Total				15.300		
Grand total	60.190	44.275	16.250	120.705	17.878	138.583

PART B—ASSISTANCE AUTHORIZED AND APPROPRIATED

	Amount
Authorized by Joint Committee on Atomic Energy:	
1st round proposals	$59.628
2d round proposals	48.237
3d round proposals	30.000
Research and development on fast breeder technology	1.500
Subtotal	139.365
Waiver of fuel use charges	20.000
Total	159.365
Appropriated:	
Previous	9.450
Fiscal year 1958	129.915
Total	139.365

[1] Undetermined.

[2] Includes waiver of heavy water use charges of $5 million.

Source: S. Rept. 791, Authorizing Appropriations for the Atomic Energy Commission, 85th Cong., 1st sess. (Aug. 2, 1957), except for fiscal year 1958 appropriations, which are in Public Law 162, 85th Cong., approved Aug. 21, 1957, without restriction upon the power reactor demonstration program projects.

The projects represent types of reactors appearing in table 14, but do not give complete coverage of the table 14 reactors. The Yankee proposal shown in table 15 is for a pressurized-water reactor. Rural

Cooperative Power and Northern States have both proposed boiling-water reactors. Wolverine Electric's is an aqueous homogeneous reactor. Power Reactor Development Co. proposed a fast-breeder reactor; Consumers Public Power, a sodium-graphite reactor; Chugach, a sodium heavy-water reactor; Piqua, an organic-moderated reactor; and the Florida Nuclear Power Group, a natural uranium, gas-cooled, heavy-water-moderated reactor. The last draws from the pressurized heavy water and natural uranium concepts shown in table 14, so that there are only the liquid metal fuel and plutonium recycle reactors not represented among the table 15 projects.

All of the table 15 projects are full-scale (large, medium, or small) electric-generating installations. Plant sizes are indicated under the name of each operator in kilowatts of electric power capacity. The plants are being designed with the benefit of information developed in AEC research projects noted in table 14, and will be expected in turn to contribute information of value for the next generation of atomic powerplants.

The dollar values of AEC assistance shown in table 15 are those requested by the proposers of the projects, indirectly approved by AEC in requesting funds in approximately the same amounts, and made possible by Congress in authorizing the necessary appropriations, which are shown in part B of the table. Appropriations authorized by the Joint Committee on Atomic Energy are shown separately in part B for the first-, second-, and third-round proposals, plus a miscellaneous item, research on fast-breeder technology. Compare the subtotals in column (4) showing the requested amounts of demonstration program assistance.

The first round, in which negotiations are still being conducted with respect only to the Consumers Public Power District project (contracts have been signed with Yankee and Power Reactor Development), is completely covered. Close to $3 million is authorized in excess of the financial assistance requested by participants in the second round and almost $15 million more is approved for the third round, which is still open and in which we can expect more proposals to be submitted. The waiver ofthe fuel-use charge requires no appropriations, but has received Joint Atomic Energy Committee authorization with a cushion of $2 million over amounts requested. Part B also shows that the necessary appropriations have been approved in appropriations legislation.

In its first-round invitations, announced on January 10, 1955, and with an April 1, 1955, deadline for submission of projects, the Commission offered: (1) to waive interest charges (which AEC had set at 4 percent) for the loan of source and special nuclear materials (but not to waive charges for the consumption of these materials); (2) to perform in AEC facilities without charge to the participating firms certain mutually agreed-upon research and development work; and (3) to enter into research and development contracts with participating firms, the resulting information to become AEC property available for public use.[121] The Commission indicated that it would employ the following criteria in evaluating proposals: (1) the probable contribution of the proposed project toward achieving economically competitive power; (2) the cost to AEC in funds and materials; (3) the risk

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[121] AEC Release No. 589, January 10, 1955.

to be assumed by the maker of the proposal; (4) the competence and responsibility of the maker of the proposal; and (5) assurances given by the maker of the proposal against abandonment of the project.[122]

In subsequent negotiations, the terms of AEC assistance were further liberalized. First, the fuel use charge waiver was to expire July 1, 1962 (7 years after July 1, 1955).[123] Instead, the use charge negotiated in all 3 of the first round projects involves a waiver for the first 5 years of plant operation,[124] which will extend at least to 1965 since none of the plants will be in operation before 1960.[125] The values of the waiver, shown in column (5) reflect the interesting fact that interest on fuel inventory, an inconsequential item in conventional plants, looms large in nuclear plant costs. This is the combined result of the high value of the fuel per pound and the large critical mass needed for nuclear fission, as a result of which only one one-thousandth of the fuel in the reactor may be consumed daily.[126]

Research and development, as envisaged in the first round included funds for reactor "fabrication and experimental operation." [127] This concept is highly specific for given reactor designs, and, in fact, was further extended to include, in the Consumer's Public Power project an AEC contribution of $8 million to costs of operation (for "unusual maintenance"),[128] shown in column (3). AEC reactor construction and ownership was not considered at all in the first-round invitation, but has become a part of the Consumer's Public Power project, as shown in column (2).

AEC announced its second-round invitation September 21, 1955, with a deadline of February 1, 1956 for submission of proposals.[129] This round was limited to medium and small powerplants (in the range of 5,000 to 40,000 kilowatts capacity), suitable for rural and perhaps foreign applications.

Essentially the same kind of assistance was offered as in the first round, but with liberalizations and additions. Waiver of the fuel use charge was extended to 5 years after the start of plant operations, foreshadowing the de facto practice later to appear in the negotiation of first-round proposals. Postconstruction research and development assistance was more explicity offered. And a new offer was made—that AEC would consider financing and retaining title to all or part of a reactor system.

The Commission set forth essentially the same criteria as in the first round, with two exceptions. Projects utilizing a low degree of enrichment of nuclear fuel were to be favored. And no mention was made of the necessity of the proposers giving assurances against abandonment. AEC was subsequently to be criticized by the Comptroller General for an absence of safeguards against abandonment in its (first round) contract with Yankee Atomic Electric Co.[130] Similarly, the

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[122] Ibid.

[123] Ibid.

[124] S. Rept. 791, supra, note 114, pp. 9–10.

[125] Paper prepared jointly by W. Kenneth Davis, Director, and Louis H. Roddis, Jr., Deputy Director, Division of Reactor Development, U. S. Atomic Energy Commission, for Presentation at 5th Atomic Energy Industry Conference of National Industrial Conference Board, Philadelphia, Pa., AEC release, March 14, 1957.

[126] D. M. Leppke, The Facts of Atomic Power Development: Some Aspects of Nuclear Power Economics, Law and Contemporary Problems, vol. 21 (winter 1956), p. 3.

[127] AEC Release No. 589, January 10, 1955.

[128] S. Rept. 791, supra, note 114, p. 10.

[129] AEC Release No. 695, September 21, 1955.

[130] Report on Review of Atomic Energy Commission Contract No. AT(30–3)–222 with Yankee Atomic Electric Co., November 1956, by the Comptroller General of the United States, p. 6.

Joint Committee on Atomic Energy has noted the lack of control by AEC under second-round projects in the absence of safeguards against abandonment.[131]

Seven second-round proposals were received, three of which AEC found unacceptable on the basis of announced criteria.[132] The remaining four were accepted as a basis for negotiation, as shown in table 15. All of the proposals were made by public groups or cooperatives, apparently reflecting the special interest of these groups in small plants. The four acceptable proposals took advantage of the AEC offer to finance the reactor system and retain title to the reactor portion of the powerplants, thereby reducing greatly the ultimate cost of atomic electricity to consumers. Table 15, column (6) shows that although the second-round proposals are almost one-fifth to one-tenth the size of the other powerplants, they account for AEC assistance in roughly the same or higher amounts. This is probably the result of two facts: (1) the cost of power generation is high per kilowatt-hour in small plants; and (2) local consumers tend to participate in the ratemaking policies of municipalities and cooperatives, and would wish to shift a maximum of expenses to AEC.[133]

AEC's third-round invitation, announced in January 1957 set no deadline on the receipt of proposals except that they should be for plants capable of completion by June 30, 1962, or June 30, 1963, depending upon their design.[134] No limits were set on the size of the powerplants to be considered, though the Commission indicated a preference for the aqueous fluid fuel systems and for natural (rather than enriched) uranium fuels in heavy water moderated reactors. A number of atomic energy experts have pointed out that natural uranium fuels might well be better suited for foreign reactors, primarily because this is a way of avoiding the large investment required for fuel enrichment facilities.[135] The effects upon total unit costs of power production remain to be seen.

AEC assistance was offered in the same way as for the second-round invitation, with two exceptions. First, the Commission offered the loan of heavy water on the same terms as nuclear fuel. Second, the offer of AEC to finance and retain title to parts of the reactor system was not repeated.

Table 15 describes the two proposals that had been made by the beginning of August 1957 in response to the third-round invitation. As of that time, AEC had not announced whether it would consider these as accepable bases for negotiation.

The total financial value of AEC assistance in its demonstration program is only about one-quarter of that or research and development now underway (cf. table 14), but for the particular projects involved, it often amounts to a large part of total costs. The extent

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[131] S. Rept. 791, supra, note 114, p. 16.

[132] AEC Release No. 777, February 7, 1956. The three rejected proposals were made by University of Florida; city of Orlando, Fla.; and city of Hoyloke, Mass.

[133] The Atomic Energy Act of 1954 prohibits the Commission from engaging in the commercial sale of electricity (see sec. 44, 68 Stat. 954, 42 U. S. C. 2064, 1957 supplement), though it is not prevented from building experimental power reactors and selling the electricity which they produce. (See sec. 31 (a) (4), 68 Stat. 954, 42 U. S. C. 2051, 1957 supplement.) Consistent with these provisions, AEC regards the 5 power reactors which it will own—4 second-round projects plus Consumers Public Power District—as experimental facilities.

[134] AEC Release No. 953 and 1077, January 7 and June 10, 1957, respectively. The 1963 date was made available for fluid fuel aqueous solution reactors in order to permit more time for the development of research results by AEC on this type of reactor.

[135] See discussion of fuel enrichment plant costs, supra.

of public assistance may be gaged from the fact that AEC is planning to build 5 of the reactors, as shown in column (2), table 15. As benchmarks in judging the costs of the large reactors, we note that the Yankee plant is expected to cost $34.5 million and the Power Reactor Development plant, $47.3 million.[136]

Preconstruction and postconstruction research and development is probably best viewed as design and operation assistance, respectively, with special reference to the novel problems introduced by nuclear technology. The fuel waiver is worth a little over 1 mill per kilowatt-hour generated in the case of Power Reactor Development Co. over the 5 years of the waiver, assuming an average load factor of 75 percent, and a fraction of a mill for most of the other projects.[137]

AEC charges and price supports

Until 1954, the Commission was the only authorized manufacturer of fissionable materials and continues today as their only legal owner. The long period of government proprietorship was the result of the importance of fissionables for national security and the primitive state of technology for commercial utilization. In consequence of both, AEC now finds itself the principal determiner of the price of many materials and services essential for reactor operation.

AEC charges for nuclear fuel are established in two parts: (1) The use charge, or interest on fuel inventory leased to reactor operators; and (2) the charge for consumption and loss of fissionable materials. We have seen that the use charge is set at 4 percent, but waived for the first 5 years of operation of demonstration program projects, where requested by the proposers. Firms not participating in the demonstration program pay the use charge.

Consumption and loss charges were publicly announced by AEC in November 1956,[138] superseding a previous schedule of prices in which fissionable materials were made available in another (more expensive) chemical form. Present AEC policy is to encourage private firms to undertake all chemical processing and fabrication of fissionable materials necessary to prepare them for the requirements of different reactors, though the Commission stands ready to do this part of the job to the extent that private industry does not provide the services [139] Consumption and loss charges are designed to recover full AEC cost of production of the fissionable materials, following established accounting practices and including direct and indirect operating expenses, depreciation, prorated overhead, interest on government investment, special handling, and other intangible expenses.[140] The prices are not indefinitely guaranteed, but AEC intends to keep them as stable as possible, with changes due only to rather significant cost changes.[141] Such stability as can be achieved is intended to implement private planning for reactor operation.

Other materials, including natural uranium, thorium and heavy water are purchased by the Commission at prices guaranteed for the

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[136] Hearings, supra, note 103, p. 692.
[137] Calculated from data given in table 15.
[138] AEC Release No. 930, November 18, 1956.
[139] See hearings, supra, note 103, pp. 107–108, 681–685.
[140] Ibid.
[141] Ibid.

7 years ending June 30, 1963.[142] These materials that can be, and are being produced commercially. AEC is interested in building healthy industries for all of them, and in guaranteeing prices is at the same time providing cost benchmarks for reactor designers. The Commission cannot offer subsidies to private nuclear reactor operators by underpricing as long as it desires to have these materials produced by private industry, and, eventually, to depend upon free market processes for price determination.

AEC charges and price supports again affect reactor operators in reprocessing spent fuel elements. Charges for the services of separation of fission fragments, recoverable fuel, and new fissionable materials (either plutonium or uranium 233) follow the pattern of other AEC charges, discussed above, for full cost recovery.[143] Moreover, the Commission intends to discontinue offering its reprocessing services when private industry can furnish them at prices on the order of 15 percent or so above AEC prices,[144] thus throwing the market in the lap of private suppliers. Presumably the latter would then be expected to expand and reduce costs at least to the AEC level.

Special interest attaches to the prices for which AEC will buy back the fissionable materials, plutonium and uranium 233, produced in the course of reactor operation. Present commercial designs do not include any considerable consumption of these new fissionables as they are produced in a reactor, though they will support a controlled chain reaction and can be used in military weapons. Future technologies, now in the experimental stage, are expected to make possible the continuous recycling of plutonium and uranium 233, and hence their utilization as principal reactor fuels. Until that time, AEC purchases of these materials is a stockpiling operation.

The Commission's "buy back" policy for plutonium and uranium 233 has never been entirely clear. Classified prices were first made available to private operators at the time of announcement of the first round of the demonstration program.[145] These were to hold for the period from July 1, 1955, to June 30, 1962, in accordance with the statutory authorization permitting AEC to guarantee prices for not more than 7 years.[146] The Commission's statement of considerations explaining the determination of prices could be interpreted to have either one of two meanings: (1) Prices were intended to reflect the market values which plutonium and uranium 233 would ultimately have as fuels for power generation (and further creation of replacement fuels), as nearly as these could be estimated; or (2) prices reflected the values of these fissionable materials for military uses.[147]

In November 1956, AEC announced unclassified "buy back" prices of $12 a gram for plutonium and $15 a gram for uranium 233 that it would pay during the single year July 1, 1962, to June 30, 1963.[148]

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[142] Ibid.
[143] Ibid.
[144] See comments of Lewis L. Strauss, Chairman, Atomic Energy Commission, K. E. Fields, General Manager, and W. Kenneth Davis, Director, Division of Reactor Development, Atomic Energy Commission in AEC press conference, April 1, 1957, mimeographed release. pp. 27–28.
[145] AEC release No. 590, January 10, 1955.
[146] 68 Stat. 931, 42 U. S. C. A. par. 2076 (1957 supplement).
[147] See Tybout, op. cit., supra, note 71, pp. 74–75.
[148] AEC release No. 930, November 18, 1956.

This action was taken so as to keep reactor operators informed of the guaranteed prices for a moving 7 years in advance. These prices, the Commission subsequently indicated, were based upon estimated fuel value for electric power generation and would result in revenues on the order of 1 mill per kilowatt-hour for typical reactors now being designed for electric power generation.[149] Nothing was said to clarify the basis for the (still classified) "buy back" prices applicable until June 30, 1962.

Then, on May 18, 1957, AEC announced that purchases between that date and June 30, 1962, would be made at $30 to $45 a gram of plutonium, depending upon fissionable materials content, and for the year July 1, 1962, to June 30, 1963, the guaranteed price of plutonium would be $30 a gram.[150] These prices superseded all previous guaranteed prices of plutonium. Nothing further was said about the price of uranium 233 and, indeed, only a few of the reactors now contemplated will produce it, while the great majority will product plutonium.

AEC did not directly explain its action, but indicated that in its future yearly extensions—

> * * * the guaranteed fair price of plutonium will be reduced, as dictated by consideration of the value of the material for its intended use by the United States and giving such weight to the actual cost of producing it as the Commission finds to be equitable, to a level based upon the fuel value of plutonium in commercial power reactors.[151]

Military value may enter when plutonium is priced according to "its intended use by the United States," but ultimately AEC hopes to price it at the fuel value level.

It is not difficult to infer that AEC's action constitutes a subsidy of atomic power reactors. If $12 a gram is the Commission's best estimate of the future fuel value of plutonium, then $30 to $45 a gram is almost 3 or 4 times this value. If $12 a gram provides a revenue of 1 mill per kilowatt-hour, then $30 to $45 a gram will provide a revenue of 2.5 to 3.75 mills per kilowatt-hour for reactor operators.

Tax treatment of atomic powerplant expenditures

Atomic powerplant owners and operators, like business firms in other industries, will be able to take advantage of loss offsets (carry-forward and carry-back provisions) useful in reducing tax liabilities of new enterprises, corporate surtax exemptions important to small-growing businesses, insofar as these are involved, and other general provisions of the Internal Revenue Code. In addition, and especially relevant for the atomic-power industry, are provisions dealing with accelerated amortization and research and development expenses.

Defense Mobilization Order VII–6 summarized all categories of electric power related expansion goals as of April 23, 1955, showing goal No. 255 (power facilities for military, atomic energy, and defense-related needs) as well as goal No. 55 (electric power) to be open, entitling affected firms to accelerated amortization treatment.[152]

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[149] See hearings, supra, note 29, p. 108.

[150] AEC release No. 1060, May 18, 1957.

[151] Ibid.

[152] C. F. R., title 32A—National Defense, appendix (revised Dec. 31, 1956).

Goal No. 55 (electric power) was subsequently closed in January 1956[153] and had not been reopened as of the middle of August 1957. Goal No. 255 remained open, leaving atomic-power facilities in a preferred position as compared with conventional-power facilities.

Whereas accelerated amortization permits amortizing over a period of 5 years, it may be possible to reduce the amortization to an annual writeoff by charging atomic powerplants as research and development. W. K. Cisler, president of Power Reactor Development Co. has indicated that his atomic powerplant does not have a capital account, but that all contributions of the members are charged as research and development although they go for the construction of the physical plant.[154] Accordingly, Power Reactor Development Co. has applied for a ruling from the Bureau of Internal Revenue that would permit it to charge these contributions against income as current research and development expenses at the time of making the contributions.[155] This is permitted by the Internal Revenue Code if we are dealing with research and development.[156] The question is whether full-scale atomic powerplants should be classified as such. If so, there will be no reason why the precedent cannot be applied to other atomic powerplants.

There is some precedent for a ruling favorable to Power Reactor Development Co. AEC is classifying as experimental facilities the five reactors which it will own in its demonstration program.[157] We shall see, in future discussion of rate regulation, that a number of State commissions have approved the contributions by members of Power Reactor Development Co. as properly charged to research and development as operating expenditures for purposes of ratemaking. Finally, AEC has indicated that it considers private projects in the demonstration program to be research and development projects, at least in their initial stages of operation.[158]

The net effect of either 5-year (rapid) amortization or annual writeoff of contributions to plant costs will be to provide tax-free income to the atomic-plant owners (contributors), which they can use for investment in the earlier years. Income taxes normally payable are postponed to later years when depreciation allowances are correspondingly less and taxable income is increased. This amounts to an interest-free loan from the Treasury, which will be of no small importance in view of the magnitude of the capital investment required for atomic powerplants.

Government indemnification

Perhaps the most difficult problems for public policy are posed by the potential dangers of a runaway atomic power reactor. Damages,

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[153] 21 F. R. 460, Jan. 21, 1956.

[154] Testimony in hearings before the Joint Committee on Atomic Energy on Government Indemnity, 84th Cong., 2d sess. (May 15, 16, 17, 18, 21, and June 14, 1956), p. 134. For contributions of members, see appendix C.

[155] Ibid., p. 128. Although the application had been pending for well over a year, no ruling had been issued by July 31, 1957.

[156] Internal Revenue Code of 1954, 26 U. S. C. par. 174 (1957 supplement).

[157] See note 133, supra.

[158] Testimony of K. D. Nichols, General Manager, AEC, in hearings before the Joint Committee on Atomic Energy on Development, Growth, and State of the Atomic Energy Industry, 84th Cong., 1st sess. (January 31; February 1, 3, 4, 7, 8, 9, 10, 28; and March 1, 2, and 3, 1955), p. 155.

if and when they occur, would come principally from radioactive fission fragments injected into the atmosphere in various ways.[159] Comparing atomic power waste materials with bomb-test fallout, Representative Holifield, chairman of the Special Radiation Subcommittee investigating the latter, stated:

> We are on the threshold of an era of nuclear power. This new power source, if it is to play any significant role in filling the energy needs of the world, will unleash amounts of radioactivity even more staggering than those involved in nuclear weaponry.[160]

Experts have placed property damage (largely from contamination) in the range of half a million to seven billion dollars for a hypothetical large (approximately 150,000 kilowatts capacity) reactor in a characteristic location and after 180 days of operation, by which time essentially full fission fragment inventory would have been built up.[161] These are lower and upper limits, respectively, for different kinds of accidents, the most serious of which would involve failure of various automatic control and retention devices.[162] Personal damages from the same accidents would range from a lower limit of no deaths or injuries to an upper limit of 3,400 killed and 43,000 injured.[163]

When faced with the question of estimating the probabilities of atomic powerplant accidents, some of the experts responsible for the above data were unwilling to quantify their valuations of the risks in view of the lack of experience with major accidents in AEC facilities. Others ventured their opinions, though recognizing the uncertainties. Their estimates ranged from 1 chance in 100,000 per year to 1 in a billion per year for a major accident for each single large reactor as previously described.[164]

We cannot adequately represent in dollars the cost to human life and health, but can compare the above estimates with accident experiences elsewhere. Using the most pessimistic probability estimate and the most serious accident estimate, plus the additional assumption that there are 100 large nuclear power reactors in the United States, there would be 1 chance in 50 million of getting killed in any year in a reactor accident and 1 chance in 4 million of sustaining injury. For comparative purposes, we note that there is presently about 1 chance in 5,000 of getting killed in any year by a motor-vehicle accident and about 1 chance in 130 of incurring a disabling injury.[165]

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[159] The technological aspects of an atomic power reactor out of control are described by Dr. C. R. McCullough, Director for Reactor Safeguards, Atomic Energy Commission, in his testimony in hearings before the Joint Committee on Atomic Energy on Government Indemnity for Private Licenses and AEC Contractors Against Reactor Hazards, 84th Cong., 2d sess. (May 15, 16, 17, 18, 21, and June 14, 1956), pp. 46–50.

[160] Representative C. H. Holifield, Who Should Judge the Atom, Saturday Review of Literature (August 3, 1957), p. 37.

[161] Excerpts from a report by a group of engineers and scientists to the Atomic Energy Commission, requested by the Congressional Joint Committee on Atomic Energy and read into the record by Lewis L. Strauss, Chairman, Atomic Energy Commission in hearings before the Joint Committee on Atomic Energy on Government Indemnity and Reacto Safety, 85th Cong., 1st sess. (March 25, 26, and 27, 1957), pp. 10–12.

[162] Built-in safeguards in reactor design are discussed in Atomic Energy Commission, 21st semiannual report (January 1957), pp. 137-143.

[163] See note 161, supra.

[164] Ibid.

[165] Calculated from National Safety Council, Accident Facts. A disabling injury is one which causes total incapacity to engage in one's normal pursuits for at least 1 calendar day.

In view of the extent of possible third-party liability, private operators have been unable to get adequate insurance from private sources. The latter can make available about $60 million for third-party liability and at least as much for property damage from a single major atomic powerplant disaster.[166] By recent legislation, Congress has therefore authorized AEC to extend the indemnification up to $500 million damages, public and private.[167] AEC will require reactor operators to purchase different amounts of private insurance, depending upon reactor size, location, and other factors influencing risk, and will levy an annual charge of $30 per thousand thermal kilowatts (approximately $100 per thousand electric kilowatts, depending upon the efficiency with which thermal energy is converted to electrical energy in a particular plant) in commercial atomic powerplants, but may waive the charge where the plants are classed as research and development projects.[168]

It is not clear whether the annual charge is intended to build up a reserve or merely to cover administration of the program. The Joint Committee on Atomic Energy report favorably recommending the bill merely notes the difficulties of foretelling what might be an adequate reserve, and expresses concern that insurance charges not be too high lest they add too much to the costs of atomic power.[169]

The effect of insurance costs upon a specific atomic powerplant is shown in table 16. This is a pressurized water reactor of approximately the size used in previous discussion of reactor hazards and fully contained within an explosion chamber, as is now judged necessary for safety protection. The plant operates at 28 percent thermal efficiency. It is located, however, in a sparsely settled area rather than in a relatively populus agricultural area such as would characterize most of the reactors now in the process of design and construction. Nevertheless, it is the only reactor for which different insurance spokesmen have quoted comparable estimates of rates.

Table 16 shows costs attributable to each type of insurance. Conventional insurance refers to all insurance generally carried by conventional electric powerplants, including conventional fire damage, vandalism, extended coverage, auto insurance, workmen's compensation, and all other types of insurance except as applied to the special nuclear hazard. Some of the conventional insurance, for example, workmen's compensation, might be higher in nuclear powerplants, and for this reason the use of the average cost of conventional insurance may tend to understate even this part of the costs shown in table 16. Insurance for nuclear hazards is shown separately for property damage (to the reactor powerplant itself) and for third party liability.

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[166] Third party liability insurance of as much as $50 million can be made available through the pooled resources of stock companies and $10 million more through the pooled resources of mutuals working in collaboration with the stock companies. See hearings, supra, note 161, testimony of C. J. Haugh, Nuclear Energy Liability Insurance Association, and H. W. Yount, Mutual Atomic Energy Reinsurance Pool and the American Mutual Insurance Alliance, pp. 91 and 129, respectively. Property damage insurance of approximately $60 million can be made available by another stock company group and $30 million can be written by another mutual group, but there is no evidence that these two are working in collaboration to make the sum total available. See testimony of K. E. Black, chairman, Governing Committee, Nuclear Energy Property Insurance Association, and A. Kelly, general counsel, Associated Factory Mutual Fire Insurance Cos., pp. 130 and 214, respectively.

[167] Public Law 256, 85th Cong., 1st sess., approved September 2, 1957.

[168] Ibid.

[169] H. Rept. 435, 85th Cong., 1st sess. (May 9, 1957), p. 9.

The latter is divided between private and public indemnification. Total insurance costs to the private operator are divided by an average annual lifetime rate of power production to show their effect upon power costs per kilowatt-hour, and, for the sake of comparison, the same calculation is made for conventional costs alone. The results show that insurance costs will be about 3½ times as high in the nuclear plant as compared with the conventional plant, but will not make much difference in total power costs in the range of 7 to 10 mills per kilowatt-hour.

TABLE 16.—*Annual insurance cost of a 134,000 electric kilowatt pressurized water reactor powerplant full contained*

[Assumed plant value, $30 million]

All conventional insurance (0.003×$30,000,000)	[1] $90,000
Property damage from nuclear hazard, including radioactive containment ($0.30 per $100 of insurance)	[2] 81,000
3d party liability:	
Private coverage of $50,000,000	130,000
Public coverage of additional $500,000,000 ($108 per electrical kilowatt)	[3] 14,500
Total annual insurance cost	315,500
Total annual insurance cost per kilowatt-hour generated, assuming 50 percent load factor ... mill	0.54
Annual insurance cost per kilowatt-hour generated for all conventional insurance alone, assuming 50 percent load factor ... mill	0.15

[1] Assumes 0.3 percent on plant value for all conventional insurance charges in accordance with established Federal Power Commission practice for conventional steam plants.

[2] Assumes 90 percent insurable value of the $30 million plant.

[3] Assumes 28 percent thermal efficiency.

Source: Nuclear insurance charges are from hearings before the Joint Committee on Atomic Energy on Government Indemnity and Reactor Safety, 85th Cong., 1st sess. (March 25, 26, and 27, 1957). The property damage rate of $0.30 per $100 of insurance was provided by W. H. Berry, vice president, American Fire Insurance Group and chairman, executive committee, Nuclear Insurance Rating Bureau, p. 142. The annual premium for $50 million of third party liability insurance was estimated by C. J. Haugh representing Nuclear Energy Liability Insurance Association, p. 88. The rate of $108 per thousand electric kilowatts of installed capacity was derived from the statutory rate of $30 per thousand thermal kilowatts of installed capacity and the assumed thermal efficiency of 28 percent for the plant here involved.

It is possible that the social costs of reactor hazards will be different from those charged the plant operators, depending upon whether AEC's annual charge for Government indemnification, plus private insurance premiums, provide adequate or inadequate reserves in the light of experience. If there is any bias in the charges, it would seem from the Joint Committee on Atomic Energy's concern for low insurance costs to reactor operators that public levies, at least, will not be too high. Moreover, we note that AEC has the option to reduce the insurance charges in "research and development" plants, which is interpreted by the Commission, we have noted, to include demonstration program plants.

A different kind of social cost may follow from the genetic consequences of radiation exposure. Traditional concepts of compensation are hardly relevant for this problem. One must make his choice between the welfare of succeeding generations and the costs of atomic power today, as affected by additional protection and safety devices.

The genetic effects of atomic powerplant accidents were not within the scope of AEC's team of experts for evaluation of atomic hazards, noted above, but expert opinion has been directed to the problem of radiation standards for atomic powerplant workers. The United

States National Academy of Sciences and the United Kingdom's Medical Research Council have both recommended, on genetic grounds, a schedule of lifetime maximum radiation dosages that could well be exceeded by private firms complying with present (August 1957) AEC regulations.[170] In its own facilities, AEC has maintained a margin of safety adequate to conform easily to the geneticists' recommendations.[171] The Commission noted in January 1957 that it had these recommendations under consideration.[172] If adopted for atomic powerplants, it would seem that the added safety could be largely handled by rotation of work force without any significant effect on costs.

Electric utility rate regulations

Previous discussion has shown that atomic power costs in the near future will exceed those of conventional power (cf. fig. 1). To some extent, the higher costs of atomic electricity will be offset by AEC demonstration program expenditures (cf. table 15), though these expenditures wil not affect two atomic powerplants being constructed by private electric power companies outside the demonstration program: Consolidated Edison of New York, building a 236,000-kilowatt plant, 140,000 kilowatts of which will be nuclear; and Commonwealth Edison of Illinois, building a 180,000-kilowatt nuclear powerplant.[173] Probably more important as offsets to high-cost atomic power will be the subsidies in AEC buy-back prices for plutonium and thorium. These apply to all plants, whether or not in the demonstration program, and will probably continue further into the future than demonstration program assistance.

The combined effect of demonstration program assistance and buy-back subsidies will be to reduce the impact of higher atomic power costs for electric utility rate regulation. It is not likely that the other Federal aids, favorable tax treatment and Government indemnification, will have the same effect. In the absence of State commission regulation of net earnings in electric utilities, regulatory tax treatment need not lead to a reduction of power rates as a result of rapid amortization.[174] The present costs of Government indemnification to the atomic powerplant owners are very small, and were included in the Davis-Roddis estimates used in figure 1.

To envisage the possible burden remaining to be absorbed by electric power consumers (or electric utility stockholders), we note first that

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[170] Atomic Energy Commission, 21st semiannual report (January 1957), p. 183. The National Academy of Sciences report is reprinted in New York Times, June 13, 1956, p. 1, col. 8.

Both groups recommended that tolerance (maximum exposure) levels for radiation be established at a cumulative total of 50 roentgens for the first 30 years of an individual's life, a total of 50 roentgens more between ages 30 and 40, and (presumably though not explicitly so states) for each of the next 2 decades. Of these cumulative total exposures, at least part is received from nonatomic sources. The National Academy of Sciences estimated that background radiation, present everywhere in normal living, accounts for about 4.3 roentgens and X-radiation for another 3 roentgens on the average in a 30-year period. The X-radiation, of course, is received in very different amounts by different individuals.

Present AEC regulations applicable to atomic powerplant operators permit a maximum exposure of 15 roentgens per year to all persons regardless of age, except that they be older than 18 years. Code of Federal Regulations, title 10, pt. 20, Standards for Protection Against Radiation (January 25, 1957). See also AEC 21st semiannual report (January 1957), pp. 183, 252–254.

[171] Cf., AEC 21st Semiannual Report (January 1957), p. 183.

[172] Ibid.

[173] The Commonwealth Edison plant is being financed with the assistance of other electric utilities combined to form the nuclear power group, as shown in appendix C.

[174] A. J. G. Priest, What Should Commissions Regulating Public Utilities Do About Accelerated Amortization, Virginia Law Review, vol. 39 (June 1953).

the relevant nuclear costs are almost entirely those shown for years after 1960 in figure 1. Messrs. Davis and Roddis calculated large plant costs for installations that could have been designed to come into operation before 1960, but were not designed and will not come into operation except for the Shippingport plant, which we have noted is about 70 percent financed by AEC. Second, we shall imagine the Davis-Roddis curve in figure 1 to be dropped about 2 mills per kilowatt-hour to at least mid-1963, the latest date for which AEC has announced buy-back prices. Two mills represents approximately the amount of the AEC subsidy, as previously noted, over the expected fuel value of plutonium, and, in fact, will bring the lowest nuclear power costs down to the highest conventional power costs by 1962 or 1963.

The remaining burden is thus represented partly by differences in the technically possible lower costs of nuclear electricity (to the private electric utilities) and the upper costs of conventional power. It will undoubtedly also be affected by the fact that nuclear powerplants may not be installed where conventional costs are highest. For example, the Commonwealth Edison atomic powerplant is to be installed 44 miles southwest of Chicago and the Power Reactor Development Co. plant is being constructed in the Detroit area. The average cost of electricity generated in new conventional steam plants in Illinois of over 100,000 kilowatts capacity coming into operation in 1951 to 1955 inclusive was 7.20 mills per kilowatt-hour.[175] In Michigan, the figure is 6.25 mills per kilowatt-hour.[176] Compare the range of conventional costs shown in figure 1.

An approach to coverage of the higher costs of atomic power in electric utility rates is illustrated by certain electric utility members of Power Reactor Development Co., who have obtained specific approval of their respective State regulatory commissions for accounting treatment of their contributions as research and development expenses, and hence, as reimbursable from operating revenue obtained by the sale of electricity. These contributions, we recall, are to cover the costs of construction of Power Reactor Development Co.'s plant at Monroe, Mich.

The Detroit Edison Co., for example, obtained an accounting order from the Michigan Public Service Commission authorizing it to reflect a $5 million contribution in the utility's account 801, "Miscellaneous general expenses." [177] This means that in the normal course of events, the $5 million will be charged to the company's power cost pool, along with the cost of other electrical generation or power purchases and that the total amount in this pool will be spread over all consumers. In the hearing preceding the order, Detroit Edison made clear that the $5 million, considered at a yearly rate of $1¼ million and with allowances for income taxes, would not affect net revenue sufficiently in itself to bring an application for rate increases, but would, nevertheless, remain an element of value in general support

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[175] Calculated from data reported in Federal Power Commission, Steam-Electric Plant Construction Costs and Annual Construction Expenses (annual supplements 1951 through 1955).

[176] Ibid.

[177] Michigan Public Service Commission Accounting Order D-1282A-55.1, March 23, 1955.

of future rate increases.[178] By an amendment, the Michigan Commission later extended the order to apply to Detroit Edison's present commitment of $8.75 million.[179]

This is not to be confused with the pricing of power that will actually be generated in the Power Reactor Development Co.'s plant, to be operated by Detroit Edison. Such power will be priced by a formula based on the costs of operation of a conventional steam plant and using as a criterion Detroit Edison's most efficient conventional plant.[180] The nuclear costs will not all be covered by a price so calculated, but by means of charging the plant costs tc research and development, the sponsoring companies can pass on additional costs to consumers in their nonatomic power rates.

Other members of Power Reactor Development Co. have received similar orders for accounting treatment of research and development, as shown in table 17, based upon a mail survey conducted by the author. Column (3) indicates utilities that have received specific regulatory approval for charging their part of the plant costs to research and development by the word "approved." The word "allowable" means that State regulatory authorities have indicated that such contributions should be so charged, and in many cases, that they are being so charged. In 2 cases, information was not available and in 2 other cases, the proper State regulatory commission lacked jurisdiction over expense accounting for electric power.

In the course of correspondence with the author regarding the charging of the contributions to research and development, some regulatory bodies indicated that they would be disposed to question any large amount of such charges in support of rate increases. Others took for granted that if the charges were properly made, as we note they were in all cases where information could be obtained, they would be includible in support of rate increases.

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[178] See testimony of C. R. Landrigan, vice president, Detroit Edison Co., in hearings before the Michigan Public Service Commission in the matter of the application of the Detroit Edison Co. for directions as to accounting treatment for disbursements made or expenses incurred in the design, construction, and operation of a developmental atomic power reactor (March 14, 1955), pp. 35, 39–42.

[179] Accounting order D–1282A–56.1, November 9, 1956.

[180] Steam agreement between the Detroit Edison Co. and Power Reactor Development Co., October 20, 1956.

TABLE 17.—*Regulatory accounting for contributions to power reactor development company*

Electric utility members (1)	Commitment (millions of dollars) (2)	Regulatory accounting for commitment as operating expense (3)
Alabama Power Co	$0.800	Allowable.
Central Hudson Gas & Electric Co	.200	Do.
Cincinnati Gas & Electric Co	.250	Do.
Columbus & Southern Ohio Electric Co	.250	Do.
Consumers Power Co	2.500	Approved.
Deleware Power & Light Co	.300	Not allowable.
Detroit Edison Co	8.750	Approved.
Georgia Power Co	.800	Allowable.
Gulf Power Co	.200	Not allowable.
Iowa-Illinois Gas & Electric Co	.120	No jurisdiction.
Long Island Lighting Co	.620	Allowable.
Mississippi Power Co	.200	No jurisdiction.
Philadelphia Electric Co	2.500	Allowable.
Potomac Electric Power Co	.800	Approved.
Rochester Gas & Electric Co	.450	Allowable.
Toledo Edison Co	.500	Do.
Wisconsin Electric Co	.300	Do.
Total	19.540	
Nonutility members	4.000	
Total	23.540	

Source: Cols. (1) and (2) are from appendix C. Col. (3) shows orders approving charge to operating expenses:

Consumers Power Co.: Michigan Public Service Commission Accounting Order D-875-A-56.1, Nov. 14, 1956.

Detroit Edison Co.: Michigan Public Service Commission Accounting Order D-1282A-55.1, Mar. 23, 1955, as amended Nov. 9, 1956.

Potomac Electric Power Co.: Public Utilities Commission of the District of Columbia Order No. 4362, Mar. 19, 1957.

All other information was obtained by personal correspondence with State regulatory bodies in June and July 1957.

Essentially the same situation is found in the nuclear power group, where three Illinois electric power companies, Commonwealth Edison Co., Illinois Power Co., and Central Illinois Light Co. obtained an accounting order permitting them to charge their contributions to the Commonwealth Edison plant as research and development, a miscellaneous general operating expense.[181]

Manifestly, the practice of calling electric generating plant costs research and development is something of an extension of usual concepts. Yet, we have seen that the research and development concept is taken to include design and operating assistance in AEC's demonstration program, has been used as a basis for Power Reactor Development Co.'s application for special tax treatment, and is invoked to give AEC authority to waive charges for Government indemnification. The practice calls for more general discussion than is appropriate here; hence we shall postpone this matter for later evaluation, except to note that it seems to provide a means of reflecting the higher costs of atomic power in consumer rates.

To be sure, the burden is spread broadly in the Power Reactor Development Co. so that the effect upon electric-power rates of its utility members will be negligible. Nevertheless, if the practice should become widespread (despite criticism by some State bodies)

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[181] Illinois Commerce Commission Order No. 42638, July 19, 1955. The nuclear power group is a vehicle for financing $15 million of the $45 million price of the Dresden nuclear powerplant. The remaining $30 million is being furnished by Commonwealth Edison Co. and will be capitalized by that organization. See appendix C.

throughout the precompetitive period of atomic power, it would not have negligible results.

A more direct method of handling atomic-power costs is simply to treat them as any other costs of electric-power generation. The public-utility concept, unless modified, will then lead to the necessary rate adjustments so that full costs of atomic power (including a return on the value of the powerplant) are paid by consumers. This appears to be the approach taken by Yankee Atomic Electric Co. for its plant in Rowe, Mass., and by Consolidated Edison Co. for its plant at Indian Point, N. Y., to serve the New York City area.

In Massachusetts, an electric utility does not have to come before the State department of public utilities to obtain a certificate of public convenience and necessity. The only requirement is for approval of its financing, and this is being received piecemeal in actions of the Massachusetts department.[182]

The first formal order of the Massachusetts department reported that contracts for the pricing of electric power sold by Yankee to sponsoring companies (for delivery and resale to consumers) could not be worked out until more cost information was available.[183] The Federal Securities and Exchange Commission later indicated that in hearings relative to Yankee's holding company status, the applicant submitted estimates showing expected average charges for power to sponsoring companies of 7.8 mills per kilowatt-hour.[184] On this basis, Yankee representatives estimated that the company would lose possibly $1.5 million during the first 5 years of operation, which is an annual average loss of about 2.1 percent on the $14 million equity (see appendix C) and that they expected earnings thereafter ranging from 0 to 6 percent return on the equity.[185]

These expectations are more optimistic than the Davis-Roddis estimates shown in figure 1, but are not out of line with the McKinney panel estimates issued in January 1956 [186] a few months after the Securities and Exchange Commission hearing. The most authoritative estimate previous to the McKinney panel's showed atomic power costs approximately three times those of competitive conventional power,[187] and it was during 1954 and 1955, while this estimate prevailed, that most important actions were taken to organize the Yankee and other projects with which we are here concerned.[188]

In New York, there is no preliminary action required of the Public Service Commission in approving the Consolidated Edison plant, since it is within the area already franchised to this company.

In Illinois, a certificate of convenience and necessity has been issued to the Commonwealth Edison Co. for construction of the Dresden nuclear power station.[189] Among its findings, the Illinois Commis-

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[182] The latest order, DPU 11957, November 26, 1956, approved an issue of $500,000 common stock in addition to $500,000 already approved. Sales of the securities were to sponsoring companies as shown in appendix A, where the total eventual financial arrangement is reported. Also approved was $1 million of short-term borrowing from sponsoring companies.

[183] 8 PUR 3d 116 (1955).

[184] Securities and Exchange Commission, Holding Company Act Release No. 13048 (November 25. 1955). Calculated from data reported on pp. 8–9.

[185] Ibid., p. 9.

[186] See Tybout, op. cit., supra, note 64.

[187] See remarks prepared by W. Kenneth Davis, Deputy Director, Division of Reactor Development, AEC, for presentation at the National Industrial Conference Board, New York, N. Y., AEC release, October 13, 1954.

[188] See Tybout, op. cit., supra, note 71, pp. 75–84.

[189] Illinois Commerce Commission Order No. 43336, September 24, 1956.

sion referred to its previous action authorizing certain Illinois utilities to contribute to the cost of the plant through the nuclear power group,[190] in taking which action (in 1955) the Illinois Commission had found that Commonwealth Edison—

> * * * believes that the plant can produce electricity at a per kilowatt-hour cost reasonably competitive with present costs of power produced from conventional new generating facilities located in Edison's service area and using coal as a fuel.[191]

Traditional public-utility regulation hesitates to pass upon the merits of a technology embodied in a new investment. The matter is usually regarded as a proper concern of management alone. This approach has been supported by the popular assumption that new investments will follow least-cost techniques of production. Now we find the assumption fallacious.

In the face of uncertainty and official estimates of high costs of nuclear power, there was no sure mechanism for review and evaluation of the public interest in experimental electric-generating facilities, the power from which can be sold to the public at fully allocated costs.

EVALUATION

Energy consumption is correlated with economic growth over a thirty- to forty-fold range of per capita national income. Underdeveloped countries eager for improved standards of living, developing economies which have tasted the fruits of economic progress, and mature economies determined to preserve and enhance their material blessings are alike concerned with access to adequate energy supplies. The more important these become when account is taken of present and expected future rates of population growth.

We have drawn world energy need and resource balances for the second half of the 20th century. There are approximations on both sides of the data. Estimates of needs are based on ranges of rates of growth. Estimates of energy resources are taken from as many experts as appear to have made careful independent studies. The general pattern of the results is unmistakable.

The fossil fuels, coal, oil, and gas are distributed unevenly. Solid fuel reserves are best in North America, the Soviet Union, and China. These regions will not experience adjustments as a result of coal shortages in the 20th century. Western Europe, the world's historic coal-exporting region is facing increasing difficulties in keeping coal production abreast of needs.

Fluid fuel reserves are concentrated in the Americas, the Middle East, and the Soviet bloc. Western Europe is completely deficient and China is thought to have little fluid fuel. World reserves are unlikely to meet projected needs for the remainder of the 20th century. North America will be affected more than other regions because of its greater consumption of fluid fuels in relation to total energy, but economic adjustments will be ameliorated and postponed beyond the end of the century by the use of oil shales and coal hydrogenation.

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[190] See supra, note 181.

[191] Ibid., pp. 7–8.

The underdeveloped regions of the world tend also to be the fossil fuel have-not regions. These are Asia, except for the Soviet Union, China, and the Middle East; Africa; South America (after exhaustion of oil reserves) ; and Oceania.

Replaceable energy resources, falling water, vegetable matter, solar energy, and others account for about 20 percent of world energy consumption today, but most of this is in the form of fuel wood and farm wastes. In the United States, they account for only 3 percent today, but this may be expanded to 10 percent or more by increased use of solar energy for space heating, and other developments, by year 2000. There are unexplored avenues of technological development which seem worth further study. Some contribution may be made by improvements (great improvements are required) on the carbon-fixing processes of nature, while improved collection and storage devices for solar energy could be important, especially to underdeveloped nations.

Atomic energy offers a new avenue for at least a partial solution of the world's energy needs. If we find that fissionable fuel regeneration can be economically achieved, world fuel reserves will be multiplied 10 or 20 times beyond present economically recoverable estimates of fossil fuels. This allows for the fact that uranium and thorium "ores" of such low grade that the uranium and thorium metal may cost 100 times present costs will not substantially affect the price of atomic energy, due to the high energy content per pound of metal.

Despite the high promise of these findings, it appears that atomic energy is destined to serve only large bulk energy consumers, except in military applications, where cost is not a deterrent. The most promising commercial applications are in electric power generation, particularly in large plants, in certain industrial process heating uses, and in central district space heating. None of these have costs as low as their conventionally fueled counterparts today, but are expected to become economic within the next decade or two. Mobile units, even as large as in merchant ships, appear to be hopelessly expensive in the foreseeable future. In small, independently driven vehicles such as the automobile, atomic energy is ruled out as a result of the massive shielding necessary to contain radiation, if for no other reason.

Taking into account the market for electricity, certain applications of industrial process heat, and central district space heating, it appears that nuclear power can satisfy only about a quarter of our energy needs without adjustment in consumption patterns. Such adjustment might take the form of more consolidated living in urban centers, where central district heating can be economically utilized, more reliance upon electrification for transportation, and perhaps other changes. These are not likely to be important within the 20th century.

The mature economies of Western Europe and Japan seem most likely to use nuclear power profitably within the next decade or two. These regions are already facing delivered fuel costs twice or more those of the United States. Certain developing economies like Brazil, and perhaps underdeveloped countries as well, facing high costs of conventional fuels due to their transportation over long distances may find economic applications of nuclear power, but these will be limited, especially in the underdeveloped countries, by the number of markets in which large or even moderately large outputs of power can be consumed.

The United States is the center for the development of civil atomic power technologies. A number of programs for training, dissemination of technological information and foreign aid in reactor development have been instituted as an integral part of United States foreign policy. These are backed by programs of research and development organized by the United States Atomic Energy Commission and cooperating industry groups.

AEC finances and directs basic programs of scientific research. These are important for both military and civil progress in the uses of atomic energy. At a more specific level, the Commission performs the same functions for particular reactor concepts holding promise for civil atomic power. Expenditures in this last area through fiscal year 1958, including some plant facilities to which AEC is committed but which may not be completed by the end of June 1958, are estimated at $500 to $600 million.

The next stage of development envisages the construction of full-scale atomic electric power generating stations. Two programs of financial assistance are available for these stations. In its power reactor demonstration program, $159 million is currently available for AEC's share of cooperative public-private atomic power plant financing. Second, through supports in its "buy-back" prices for plutonium and uranium 233, not limited to demonstration program plants, AEC will cover about 3 mills of the per kilowatt-hour cost of atomic power generated to the middle of 1963, the most distant date for which prices have been announced. This is approximately 2 mills over the estimated fuel value of plutonium and uranium 233. The 2-mill subsidy will account for 10 to 25 percent of the cost of generating atomic electricity at the cost levels estimated for this period by AEC spokesmen.

Private investment in atomic power stations is also being aided by non-AEC policies. These include the award of rapid amortization tax treatment for atomic powerplants, public indemnification of reactor owners, and rate making policies for full recovery of atomic electric power costs, though higher than those of conventionally generated power.

We may wonder whether all of these aids are necessary. From a domestic standpoint, there is the basic question of energy needs. Granted the long-term importance of nuclear power, it will not solve the fluid fuels problem, and electricity generation from coal seems safe enough for the remainder of the present century. At least we could have taken a decade or several decades to perfect the commercial application of nuclear power from technologies already delineated as a result of military applications.

From the standpoint of foreign policy, different conclusions may follow. This aspect of atomic energy policy is beyond the scope of the present study, though we note that the peaceful atom is a powerful symbol and the United States technological leadership, a valuable national asset for its own sake.

Another aspect of the question of the necessity of public aids is whether in their specific form they seem conceptualized to provide a useful, natural division of labor between business and government and whether they are easily intergrated within existing American institutions.

Public policy in atomic energy seeks to cull from a defense technology such commercial and peaceful applications as hold reasonable promise of improving the standard of living. Apart from the desirability of supporting basic science, there are public advantages in doing this. In reactor development, an important part of the large public investment in plant facilities can be made to serve a commercial as well as a military purpose. Economies of scale are available in supporting facilities which would not accrue to a private-based atomic power industry until years after its establishment. It is likely that similar situations can be found elsewhere in our defense program, that other civil developments might gain from a base already established at public expense if similar public programs were undertaken by other defense agencies.

At the applied level of research, there are advantages in the cooperative business-government approach wherein research projects are conceived and conducted by the users of the results, as in the demonstration program. Continuous exchange of information between laboratory, pilot plant and production facility increases the potential utility of applied research (and indirectly the utility of the principles discovered in basic research). At the same time, it makes for improved production management insofar as operating officials are made more aware of the possibilities inherent in a given design or functional relationship.

Beyond this point, an appraisal of public assistance is affected by the priority (on foreign policy grounds) which we wish to give civil atomic power. In reviewing the demonstration program, we noted that electric power producers do not suffer from a lack of Federal assistance in a wide variety of financial arrangements, provided that their projects satisfy AEC's concept of technological promise. A high priority for atomic power might justify the present extent of demonstration program aid for the relatively small participating group. On the other hand, a gradual development of atomic power might look toward the training of a larger number of participating firms at less cost for each, and with more time to cultivate competitive relationships among powerplant designers and suppliers. Similarly, in AEC's own civil power research, a more leisurely approach, exploring one technological finding after another might lead to the same end results at lower total costs than the present multifront attack.

A similar interpretation is in order for rapid amortization and price supports for regenerated fissionable materials. Both will stimulate the group of the atomic power industry beyond the rate which it would experience in their absence. The price supports will have the additional effect of stimulating the technology of fuel regeneration, which will extend the utilization of uranium and thorium ores. Over the long run, however, the price supports will have to be removed or AEC will have to sell at a lower price to users of plutonium and uranium 233; otherwise uranium 235 will be used in preference to the regenerated fuels.

Special treatment of atomic-power-station expenses is accorded through their classification as research and development. This includes demonstration program assistance in design and operation, waiver of charges for Government indemnification at AEC discretion, possible tax advantages (over those already available), and a method of charging the higher costs of atomic power to consumers.

The operation of full-scale electric-generating facilities is not within the usual meaning given to research and development. It is doubtless true that valuable lessons will be learned in the operation of atomic-power stations, but in unregulated private businesses a new technology must lead to costs no higher than competing technologies before it can be introduced. Then, such advances as result from full-scale operation lead to further cost reductions for the unregulated firm. If an unregulated firm should introduce a high-cost technology before it was competitive, that firm would never attain the volume of sales necessary to permit economies to be realized from full-scale operation.

If we are to define research and devlopment in terms of activities leading to cost reduction from plant operations in new fields of technology, there is no easy stopping point in what might be included. Merely by virtue of the growth of an industry, service and supply facilities become more specialized and lead to economies (external economies) which have nothing directly to do with the operation of plants in the industry, but nevertheless lead to cost reductions in those plants. The concept eventually devolves into the familiar "infant industry" case, wherein public aids are sought simply for the purpose of assisting an industry to grow, with the expectation that increased size will be accompanied by increased profitability.

Another problem presented by atomic power for rate regulation in the immediate future arises from the direct adoption of higher cost designs for electric generation. If public-utility regulation cannot assume that least cost technologies will be followed, the only obvious remedy is to suggest more extensive regulatory inquiry into production technologies as a preliminary to their adoption. Electric utilities are not organized for, nor are they intended to represent the public interest in the same way that regulatory commissions or the AEC are. If the public interest requires atomic-power generation financed through consumer rates as a means of reducing nuclear costs, this would best be decided through effective participation in the public agencies responsible for rate regulation.

Appendix A. Countries and Areas Within World Regions in Table I

- North America:
  - Canada
  - Greenland
  - Alaska
  - United States
- Latin America:
  - Central America:
    - Bahama Islands
    - Barbados
    - Bermuda
    - British Honduras
    - Costa Rica
    - Cuba
    - Dominican Republic
    - El Salvador
    - Guadeloupe
    - Guatemala
    - Haiti
    - Honduras
    - Jamaica
- Latin America—Continued:
  - Central America—Continued:
    - Martinique
    - Mexico
    - Netherlands Antilles
    - Nicaragua
    - Panama
    - Panama Canal Zone
    - Puerto Rico
    - Trinidad and Tobago
    - Virgin Islands
  - South America:
    - Argentina
    - Bolivia
    - Brazil
    - British Guiana
    - Chile
    - Colombia
    - Ecuador
    - French Guiana

Latin America—Continued:
  South America—Continued:
    Paraguay
    Peru
    Surinam
    Uruguay
    Venezuela
Western and Southern Europe:
  Austria
  Belgium-Luxembourg
  Denmark
  Finland
  France and Saar
  Germany, Western
  Greece
  Iceland
  Ireland
  Italy
  Malta
  Netherlands
  Norway
  Portugal
  Spain
  Sweden
  Switzerland
  United Kingdom
  Yugoslavia
Africa:
  Algeria
  Anglo-Egyptian Sudan
  Angola
  Belgian Congo
  British Somaliland
  British Togoland
  Canary Islands
  Cape Verde Islands
  Egypt
  Ethiopia
  French Cameroons
  French Equatorial Africa
  French Somaliland
  French Togoland
  French West Africa
  Gambia
  Gold Coast
  Italian Somaliland
  Kenya
  Liberia
  Libya
  Madagascar
  Mauritius
  Morocco (French)
  Mozambique
  Nigeria
  Northern Rhodesia
  Nyasaland
  Portuguese Guinea
  Reunion
  Ruanda-Urundi
  St. Thomas and Prince Island
  Seychelles
  Sierra Leone
  Southern Rhodesia
Africa—Continued:
  Spanish North Africa
  Tanganyika
  Tunisia
  Uganda
  Union of South Africa
  Zanzibar
Oceania:
  Australia
  British Solomon Islands
  Fiji Islands
  French Oceania
  Hawaii
  New Caledonia
  New Guinea (Australia)
  New Hebrides
  New Zealand
Asia (except U. S. S. R., China)
  Aden
  Afghanistan
  Bahrein
  Brunei
  Burma
  Ceylon
  China: Taiwan
  Cyprus
  Hong Kong
  India
  Indochina
  Indonesia
  Iran
  Iraq
  Israel
  Japan
  Jordan
  Korea (South)
  Kuwait
  Malaya and Singapore
  North Borneo
  Pakistan
  Philippines
  Sarawak
  Saudi Arabia
  Syria and Lebanon
  Thailand
  Turkey
East Europe:
  Bulgaria
  Czechoslovakia
  German Democratic Republic
  Hungary
  Poland
  Rumania
Middle East (in table 5):
  Bahrein
  Iran
  Iraq
  Kuwait
  Qatar
  Saudi Arabia
  Neutral Zone
  Turkey

APPENDIX B

Table B–1 shows the derivation of installed nuclear capacity in each year to 1975. In the period through year 1962, nuclear capacity is obtained by direct AEC estimates based on a knowledge of projects planned or underway. From 1963 through 1975, the estimates are derived by applying the McKenney growth rates of nuclear power to the kilowatts of capacity of total electric power installed in each year. Total electric-power capacity is assumed to grow at a 6-percent annual rate, as described in the text. The results appear in column (6).

Column (7) indicates load factors which could reasonably be expected to correspond to usage of the various yearly additions of nuclear capacity in 1975. The load factors are graduated evenly for an assumed plant life of 34 years. Outputs are shown in column (8). The total output is shown at 0.3159×10^{12} kilowatt-hours. Assuming a thermal efficiency of 30 percent or slightly over, we find a nuclear-energy input of approximately 1.0×10^{12} kilowatt-hours in 1975.

TABLE B–1.—*Derivation of estimates of nuclear-electric power produced in 1975*

[Cols. (1) through (6) in millions of kilowatts]

	Total capacity	Net added	Retired	Gross added (2)+(3)	Nuclear added		Load factor, percent	Kilowatt-hours $\times 10^9$ 1975
	(1)	(2)	(3)	(4)	Percent of total (5)	Kilowatts (6)	(7)	(8)
1955	116.3							
1956								
1957						0.08	40	0.3
1958								
1959						.05	45	.2
1960						.67	50	3.0
1961						.1	50	.4
1962						.4	55	1.9
1963	188.0	11	1.4	12.4	6	.7	55	3.4
1964	199.0	11	1.5	12.5	6½	.8	60	4.2
1965	211.0	12	1.6	13.6	7	1.0	60	5.2
1966	224.0	13	1.7	14.7	8	1.2	65	6.3
1967	238.0	14	1.8	15.8	9	1.4	65	8.0
1968	252.0	14	1.9	15.9	10	1.6	70	9.8
1969	267.0	15	2.0	17.0	12	2.0	70	12.3
1970	282.0	15	2.1	17.1	14	2.4	75	14.7
1971	299.0	17	2.2	19.2	20	3.8	75	25.0
1972	317.0	18	2.4	20.4	25	5.1	80	35.7
1973	336.0	19	2.5	21.5	30	6.4	80	44.8
1974	356.0	20	2.7	22.7	37	8.4	85	62.5
1975	377.0	21	2.8	23.8	44	10.5	85	78.2
Total								315.9

Source: Col. (1): Calculated on the basis of a 6-percent rate of growth compounded yearly, starting with observed capacity of class I systems in 1955 from Electrical World, Sept. 17, 1956. Col. (3): 1955–70 total, Electrical World. 1970 figure, Electrical World. Intervening years and extrapolation to 1975 by author. Col. (5): Growth rates forecasts by McKinney panel, supra, table 10, as extrapolated to 2000 A. D. by the author. Col. (6), 1955–62: Presently planned projects reported in paper prepared jointly by W. Kenneth Davis, Director, and Louis H. Roddis, Jr., Deputy Director, Division of Reactor Development, U. S. Atomic Energy Commission for presentation at 5th Atomic Energy in Industry Conference of National Industrial Conference Board, Philadelphia, Pa., AEC release, March 14, 1957. Cols. (2), (4), and (6) 1963–75: Derived from other columns.

APPENDIX C. ORGANIZATION OF PRIVATE ATOMIC POWER GROUPS

I. Financial structure of Yankee Atomic Electric Co.

Yankee sponsors and percentage of stockownership:	*Percent*
New England Power Co	30.0
Connecticut Light & Power Co	15.0
Boston Edison Co	9.5
Central Maine Power Co	9.5
Hartford Electric Light Co	9.0
Western Massachusetts Electric Co	7.0
Power Service Company of New Hampshire	7.0
Montaup Electric Co	4.5
Central Vermant Public Service Corp	3.5
New Bedford Gas & Edison Light Co	2.5
Cambridge Electric Light Co	2.0
Connecticut Power Co	.5
Total	100.0

Financial arrangements announced at hearings before Securities and Exchange Commission, concluded in November 1955:

	Million
Common stock of sponsors	$14
Funded debt	19
Total	33
Total plant cost appearing in Yankee contract with the Atomic Energy Commission; June 1956	33.4

Source: Report on Review of Atomic Energy Commission Contract No. AT (30–3)–222 With Yankee Atomic Electric Co., November 1956, by the Comptroller General of the United States.

II. Membership and contributions of members of Power Reactor Development Co. (nonprofit organization)

	Commitment
Alabama Power Co	$800,000
Allis-Chalmers Manufacturing Co	500,000
The Babcock & Wilcox Co	1,000,000
Burroughs Corp	250,000
Central Hudson Gas & Electric Corp	200,000
The Cincinnati Gas & Electric Co	250,000
Columbus & Southern Ohio Electric Co	250,000
Combustion Engineering, Inc	1,000,000
Consumers Power Co	2,500,000
Delaware Power & Light Co	300,000
The Detroit Edison Co	8,750,000
Georgia Power Co	800,000
Gulf Power Co	200,000
Holley Carburetor Co	250,000
Iowa-Illinois Gas & Electric Co	120,000
Long Island Lighting Co	620,000
Mississippi Power Co	200,000
Philadelphia Electric Co	2,500,000
Potomac Electric Power Co	800,000
Rochester Gas & Electric Corp	450,000
The Toledo Edison Co	500,000
Westinghouse Electric Corp	1,000,000
Wisconsin Electric Power Co	300,000
Total of contributions	23,540,000
Funded debt	15,000,000
Total	48,540,000
Total plant cost	47,300,000

Source: Personal communication, AEC, letter dated July 3, 1957.

III. Membership and contributions of members of nuclear power group (nonprofit organization)

	Commitment
American Gas & Electric Service Corp	$2,833,333
Bechtel Corp	1,000,000
Commonwealth Edison Co	2,833,334
Central Illinois Light Co	500,000
Illinois Power Co	1,500,000
Kansas City Power & Light Co	1,500,000
Pacific Gas & Electric Co	2,833,333
Union Electric Co	2,000,000
Total	15,000,000

Commonwealth Edison Co., as an organization separate from the nuclear power group, will pay an additional $30 million and will receive title to the plant. Total plant cost: $45 million.

Source: Personal communication, AEC, letter dated July 24, 1957.

IV. Membership of Florida nuclear power group (financial structure not announced)

Florida Power Corp.
Florida Power & Light Co.
Tampa Electric Co.
Total estimated plant cost: $40 million.

Source: AEC Release No. 1051, May 13, 1957.

V. Membership of Northern States Power Co. (nonprofit organization, contributions not announced)

Mississippi Valley Public Service Co.
Otter Tail Power Co.
Interstate Power Co.
Iowa Power & Light Co.
Iowa Southern Utilities Co.
Wisconsin Public Service Corp.
Madison Gas & Electric Co.
Northwestern Public Service Co.
St. Joseph Power & Light Co.
Central Electric & Gas Co.
Total estimated plant cost: $21 million.

Source: AEC Release No. 1122, August 2, 1957.