SAM H. SCHURR
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Economic Aspects of Atomic Power

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ECONOMIC ASPECTS OF ATOMIC POWER

An Exploratory Study under the Direction of

SAM H. SCHURR and
JACOB MARSCHAK

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PREFACE

THE FUTURE may hold many peaceful economic uses of nuclear processes. The present study is confined to those applications that seem least remote today. Among these applications, we have dealt only with those based on a continually controlled release of energy within a permanent structure (the "reactor") rather than on explosions. The released energy results from the fission (splitting) of heavy atoms such as plutonium. No structural materials are available that could resist the high temperatures obtained when fission energy is released uncontrolled as when a plutonium bomb explodes. This seems to exclude the possibility of constructing reactors for a controlled release of another type of atomic energy, that resulting from the fusion (bringing together) of light atoms such as hydrogen isotopes; for such fusion can start only at very high temperatures and will therefore probably be initiated only by the explosion of a fission bomb. By limiting our study to the controlled release of energy we leave out of consideration the peaceful use of exploding plutonium or hydrogen bombs for, say, the leveling of mountains or (as has been suggested) the melting of the arctic ice-cap. We are also not concerned in this book with the economic consequences of the potential destruction that atomic weapons may bring about or with the economic implications of the defense measures—such as the decentralization of cities—that the existence of such weapons may hasten.

Those applications that today seem likely to become practical first may not, in the long run, be the most important ones. The generation of electricity from the heat created by nuclear fission, while not at present completely worked out, is generally thought feasible; so is the transportation of (relatively) low temperature heat over short distances, as for residential heating. On the other hand, the conversion of fission energy into electric energy without passing through a steam or gas turbine, or the direct use of the high temperature heat of a nuclear reactor (for example, to melt metals) may not be feasible at all. But, if feasible, the economic importance of these applications would overshadow that of merely substituting a nuclear reactor for the coal or oil furnace of an otherwise essentially unchanged power plant. Nor do we know what uses will be made of cheap radioactive elements and compounds, another product of nuclear fission. Perhaps the most important though less immediate applications will be due to the new knowledge of matter, both dead and living, which scientists hope to acquire by using radioactive "tracers." For example: if, helped by these new research tools, we learn to imitate the action of green leaves in absorbing the sun's energy, both uranium and coal may, at some time and for some countries, acquire a formidable competitor, and the effect on food supplies may be even more important.

Even when limited to applications that seem least remote today, the study is still only exploratory. This must be emphasized. The technology of power-making reactors is still in an experimental stage. But even if all the technological data relevant to the production of electricity from nuclear fuel were available, they would not solve the economist's problem but only secure him a better start. The economist has first to estimate, for different areas of the world, the price relation between electricity produced from conventional fuels and water power and electricity produced from the new fuel, whose main virtue is its enormous energy content per unit of weight and hence its cheap transportability over great distances. This price relation helps to evaluate the role of the new source of power in various countries and various industries. Such evaluation is a vast and laborious task, widely ramified by the diversities of geography and of industrial technology. But even if accomplished, this task would still not complete the economist's query. We are interested in the potential sources of demand for atomic energy mainly because we want ultimately to judge the overall effect of the new invention upon the economy of the nation and of the world. This effect works itself out in a sequence of complicated repercussions of one economic sector upon another.

Thus the study is exploratory in a double sense. First, technological data which include future trends in the techniques of generating and using energy are incomplete. One has, therefore, to use a hypothetical range instead of a single figure. This often results in a set of alternatives. The final choice between them must be made later. A very significant figure in this range is the estimated minimum cost for producing atomic power. Working with this figure, which we know to be the lowest conceivable cost for atomic power when produced by techniques now envisaged, we gain a general picture of the scope of the economic changes which could result, at best, from the use of the new energy source. The various determining factors are thus assigned their approximate relative weights. The extremes of optimism and pessimism are put into their proper places.

Second, the book is exploratory also in the sense that it involves a new attempt to formulate an economic theory of the effects of an invention. Since this subject is complicated, its treatment could only be tentative.

What we said above about the economist's task, starting with the technological data of the new invention and ending with the evaluation of its effects upon the economy as a whole, has determined the outline of the book. It begins with the questions of technical feasibility, the availability of raw materials, and the possible cost and other economic characteristics of atomic power (Chapter I). This cost is then compared (in Chapter II), for various areas of the world, with the cost of electricity from conventional sources. This analysis is followed by the study of the potential applicability of atomic power in several industries which are, or could become, important consumers of electricity or heat (Chapters III–XII): the production of aluminum, chlorine and caustic soda, phosphate fertilizer, cement, brick, flat glass, iron and steel, railroad transportation, and residential heating. (We were not able to complete our preliminary studies of the usability of atomic energy in several industries: ferro-alloys, copper, lead, zinc, and pulp and paper; in the production of nitrogen fertilizers; in some phases of agriculture including irrigation; and in ocean transportation.) With the empirical background provided by the regional and industrial analysis, the study proceeds to sketch a theoretical outline for an estimate of the economic effects of atomic power—first, on the economy of a highly industrialized country like the United States (Chapter XIII); then, on the industrialization of so called backward areas of the world (Chapter XIV). But our limited resources did not permit a close analysis by individual countries (which would correspond to the analysis by industries in Chapters III–XII). Such individual country-by-country analyses would be a very useful next step in studying economic implications of atomic power.

The analysis is supported by four maps of the world. Map 1 gives, for various areas, the cost of electric power generated from conventional sources. For thermal electricity, these are cost estimates for power generated in a modern thermal plant on the hypothesis that the construction cost of such a plant relative to that of an atomic power plant is the same as in the United States. Maps 2 and 3 give the world distribution of water power and fuel resources. As explained in Chapter II, these maps help to judge the degree to which the new source of power may compete in a given area with old sources. Obviously this gives only a partial answer to the question of potential markets for atomic power. Even where there is a comparative cost advantage in favor of atomic power, the demand for atomic or for any other kind of power may be small, depending on the density of population and its purchasing power or else on the presence of particular raw materials or markets that may give rise to a demand for electricity if it becomes sufficiently cheap. Accordingly, Map 4 gives the distribution of people over the globe. Population density is a determinant of demand for electricity (given the cost), not only because of the demand of households to run electric lamps and possibly other domestic appliances but also because of the power needs of local transportation and other public services, of retail business, and of other industries serving the local market. A glance at Map 4 reveals its main shortcoming as a demand indicator: a similarly densely populated area in Europe and in Asia would be given equal weight. It is, of course, not the population per square mile but the purchasing power (existing or potential) per square mile that really matters. Unfortunately, a corresponding refinement of Map 4 would require detailed information on the geographical distribution of real income and the potentialities for its growth, by relatively small areas (since electricity cannot be economically transmitted over a large radius). Such data are not available at present even for the existing levels of income except for a few areas of the world. For the United States, the dependence of the electricity demand of private homes upon both price and real income is studied in Chapter XIII.

Another reason why population density, or even the density of "dollars per square mile," is not a sufficient indicator of demand for electricity is the role of industries that produce goods or services for consumers outside of the area served by the power plant in question. Attracted by cheap energy, such industries may in turn draw more people and more buying power into the area. For the United States, some of the major power-consuming industries are studied in Part Two, and the findings may help us in judging for other areas. But, as already stated, the list of industries studied is very incomplete.

In short, if Maps 1 to 3 indicate for a given area a high price for electricity from coal, oil, or water power, and this area appears dark on Map 4, there is a presumption for a potential demand for atomic power—but this presumption must be reconsidered in the light of other information. A dark area on Map 4 may promise little demand for electricity of any kind if it is inhabited by very poor people. Of course, atomic power may contribute to the development of such an area and thereby increase the income of the people; this question is considered in Chapter XIV. On the other hand, a very light area may become a consumer of electricity if it has certain mineral ores, or is located favorably for an airfield, or has potentialities for irrigation, etc.

This study borders on technology and geography. They provide the main data, however incomplete. But still another and even less complete kind of data would have to be known if we should claim to arrive at definitive conclusions. These unknown data are the political decisions of the future.

Political factors have been indicated and weighed in various places of the book. To begin with, atomic power can (though it need not) be obtained as a by-product in the making of nuclear weapons. In this case it can be a subsidized product, military expenses being in general borne by the taxpayer. If the armaments race is mitigated by an international agreement, other economic consequences might arise, as indicated in Appendix B of Chapter I. Therefore a straight comparison of the money cost of energy from new and old sources ceases to be the only guide in determining the extent to which, in a given country, the new source of energy can compete with the old ones. Moreover, this is due not only to diplomatic and military but to other less conspicuous politico-economic decisions as well. As shown in Chapter II, the relative price and availability of the various types of energy can depend on the government subsidies for coal and freight rates (as in Russia) and on the political control of imports and exchange rates, whether undertaken for reasons of security or of domestic economic policy.

The basic comparison, of course, is not that of money costs but of "real costs" in the following sense: To achieve a given level of present and future national consumption, and a given degree of national security, will it take more of a country's resources to produce an additional kilowatt-hour of power from atomic or from conventional sources? To be sure, policy makers, whether democratic or dictatorial, may not always answer or may not even ask this question with complete clarity—because of sectional interests or because they are lacking information or competence. Yet it would be unwise not to press this question of "real cost" when the interest of our own economy and security is discussed. It would be equally unwise to assume that other nations ignore this question and are thus bound to waste their resources foolishly. Now, this question of "real cost" is indeed answered by money-cost comparison—to the extent that private men, and even government agencies, compete in markets and try to avoid losses. To this extent, and this extent only, are money-cost comparisons meaningful.

Many other political variables had to be treated as unknown. In each case an assumption or a set of alternative assumptions had to be explicitly stated and the implications explored. For example, the effects of atomic power upon the national income (in Chapter XIII) were estimated on the assumption that at no time would the government of an industrial country tolerate unemployment due to a fall in effective demand that could be offset by appropriate fiscal and monetary measures. While many political observers have advanced this assumption, they would not be too surprised if it failed. The political science of today does not tell us what determines the business-cycle policy of a government. If instead of making our assumption we had said that governments sometimes do and sometimes don't fight unemployment, we would have given up any possible benchmark for a reasoned evaluation of the effects of the new invention upon national income.

Intangibles of future political history naturally affect also the discussion of the effects of atomic power upon the industrialization of backward countries (Chapter XIV), a process that includes not only the physical construction of mills, roads, harbors, houses, but also its financing by foreign loans or by reducing domestic consumption; it includes a change in birth rates, in sanitary standards, and in the patterns of education; and it presupposes the exercise of policing power. All of this is strongly determined by the domestic policy makers of a country as well as by their partners and opponents in world politics. The economist can but indicate the importance of these variables. He can only ask questions of the anthropologist, the sociologist, and the political scientist.

The fact that the economics of atomic power not only depends on technology but is embedded in general social and political conditions was early recognized by the Social Science Research Council when it appointed a Committee on the Social Aspects of Atomic Energy. This committee represented various social sciences together with physics. Its members were Winfield W. Riefler (Chairman), Bernard Brodie, Rensis Likert, Jacob Marschak, Frank W. Notestein, William F. Ogburn, Isidor I. Rabi, and Henry De W. Smyth. The committee approved the preliminary outline of the present book.

The Rockefeller Foundation undertook to finance the study by awarding a grant to the Cowles Commission for Research in Economics, The University of Chicago. An additional grant by the Life Insurance Association of America helped to complete the study. It is a pleasant duty to thank, on behalf of the study group, the organizations that have initiated the work and provided the necessary funds and facilities.

While the two codirectors of the study share equal responsibility for its shortcomings, Sam H. Schurr had the additional, the major, burden as the author or coauthor of most of Parts One and Two of the book. He wrote Chapters I, III, and IV, and participated in the authorship of Chapter II with Edward Boorstein, of Chapters V–IX and XI with George Perazich, and of Chapter XII with Milton F. Searl, now of Stanolind Oil and Gas Company, Tulsa, Oklahoma. Harold H. Wein, of the U. S. Department of Justice, is the author of Chapter X. The concluding chapters, XIII and XIV, which constitute Part Three, were contributed by Herbert A. Simon, now of the Carnegie Institute of Technology, Pittsburgh. Edward Boorstein and George Perazich, as full-time members of the research staff of the study, contributed in a substantial degree to defining the subject matter and formulating the general approach.

Cartographic advice was given by Robert L. Carmin, now of the Department of Geology and Geography, Michigan State College. He also drew Maps 1 and 3; Map 2 was drawn by Robert E. Stanley. Ruth Frankel Boorstin edited the final copy of the book and, together with Jane Novick, Editorial Secretary of the Cowles Commission, saw the book through the press. Both were assisted by Jean Curtis. William B. Simpson, As-

sistant Research Director of the Cowles Commission, helped in the final arrangements with the publisher. John R. Menke, now of the Nuclear Development Associates, New York, was attached to the study at its beginning and continued later to help with technical advice, as did, at a later stage, Richard L. Meier, now of The University of Chicago.

Each chapter was repeatedly revised by the authors and the codirectors to coordinate the results into a single whole and to take account of suggestions and comments. Some of the preliminary results of the study were published as it progressed, to invite public comment and criticism.[1] All parts of the study were circulated, at different stages of drafting, to specialists in various fields. We have, in fact, drawn heavily on their advice, both in laying out the study (e.g. in selecting those energy-consuming industries that should be analyzed), and in using their detailed critical comments on individual chapters. It is natural that in a field as new as this, conflicting opinions should be expressed. We have tried to weigh them all carefully and to incorporate in this volume the suggestions of these specialists. But they do not share responsibility for the final text, with which indeed they would not always have agreed. We are particularly indebted to A. B. Kinzel, Union Carbide and Carbon Research Laboratories, because of the general guidance he gave us from the very beginning. Various aspects of this study were also discussed to our benefit with H. J. Barnett of the Program Staff, U. S. Department of the Interior, and with Leo Szilard, Professor of Biophysics, The University of Chicago. Ansley J. Coale, Institute for Advanced Study, Princeton University, Mordecai Ezekiel of the Food and Agricultural Organization of the United Nations, and Ward F. Davidson, Consolidated Edison Company of New York, have read and given extensive suggestions on many parts of the book.

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[1] These were: (1) Cowles Commission Special Paper No. 1: "Nuclear Fission as a Source of Power," by John R. Menke (reprinted from *Econometrica,* Vol. 15, October 1947, pp. 314–334); (2) Cowles Commission Special Paper No. 2: "The Economic Aspects of Atomic Power," reprints of papers by Jacob Marschak (from the *Bulletin of the Atomic Scientists,* Vol. 2, September, 1946); and by Sam H. Schurr with comments by Philip Sporn and Jacob Marschak (from *American Economic Review, Proceedings,* Vol. 37, May 1947, pp. 98–117); (3) "Atomic Power in Selected Industries," by Sam H. Schurr (*Harvard Business Review,* Vol. 27, July 1949, pp. 459–479).

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JACOB MARSCHAK

Chicago
March, 1950

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Part One

ECONOMIC COMPARISONS OF ATOMIC AND CONVENTIONAL POWER

CHAPTER I

Economic Characteristics of Atomic Power

CERTAIN information is available today about atomic power which is extremely useful in defining the boundaries within which economic analysis can proceed. The facts which are known consist, in part, of the basic scientific information which has been revealed in such official documents as the report prepared for the War Department by H. D. Smyth,[1] and the various papers submitted to the United Nations Atomic Energy Commission by the government of the United States.[2] There are also the "informed official judgments" on many critical points found mainly in reports of the United States Atomic Energy Commission, and the "informed unofficial judgments" of many scientists who have been associated with the development of atomic energy in the United States and other countries. Such judgments have been of great importance to us in preparing this chapter.

Most of the unanswered important questions in the economic analysis of atomic power remain unanswered not because the information is being kept secret, but simply because it is not yet available, even to the United States Atomic Energy Commission.

Useful atomic power has not yet been produced, except, perhaps, as a by-product of the operation of research reactors, nor has a commercial atomic power plant been designed. The scientists who are attempting to design such a plant are faced with numerous difficult engineering problems, such as the development of new materials able to withstand the unusual operating conditions of nuclear reactors. Clearly, therefore, the most important item of economic information—data on the cost of producing atomic power—cannot be available at the present time. Still, enough appears to be known about the physical characteristics of the process by which atomic power may be produced to indicate at least the broad limits within which the cost, relative to the cost of conventional thermal power, will eventually fall.

[1] *Atomic Energy for Military Purposes,* Princeton University Press, 1946.

[2] *The International Control of Atomic Energy, Scientific Information Transmitted to the United Nations Atomic Energy Commission,* Department of State Publication 2661, Washington, Government Printing Office, 1946, contains the more important papers.

Two known facts have been particularly useful in providing a starting point for our analysis. The first is that while 1 lb. of coal can be transformed into about 1 KWH of electric power, 1 lb. of atomic fuel, fully consumed, would yield about 2½ million KWH of electric power, that is, 1 lb. of nuclear fuel is the equivalent of approximately 1,250 tons of bituminous coal.[3] The economic importance of this fact is clear: by ordinary standards, the cost per unit of energy of transporting the new fuel is negligible. We may say that, in effect, atomic energy will be produced from a weightless fuel, and this in turn suggests that its use could be an important factor in minimizing the wide differences in energy costs throughout the world.

The second important fact is that relatively pure uranium metal, the key mineral in the fission process, cost about $20 per lb. in 1943.[4] As we shall see, there is a reasonable possibility that 1 lb. of uranium can be made into 1 lb. of atomic fuel, which would mean that the energy equivalent of 1,250 tons of coal might cost about $20.[5] This suggests that the new fuel might be available throughout the world at an unusually low cost. This does not mean necessarily, as we shall see, that the conversion to useful power would be cheap; this will depend mainly on the cost of the plant and equipment needed.

These two hypotheses—that this new fuel might be available everywhere in the world at about the same cost, and that this might be a very low cost—indicate at least that this subject warrants further study to fix cost and other economic characteristics more closely. What will it cost to make the energy available in useful form? Will the form in which the energy is made available, and the necessary plant and equipment, limit its use? Will raw materials be available in large enough amounts to constitute a significant addition to the world's stock of energy resources? How great are the developmental problems which must be solved before atomic energy can be used commercially? We will consider these and other questions in this chapter.

We begin in this chapter with a section setting forth certain economic characteristics of atomic power which can largely be inferred from the physical nature of the production process. The second section considers the ore reserves of the source materials of nuclear fuel and inquires whether

[3] This comparison assumes the transformation of heat to electric power at an overall thermal efficiency of about 25% for both coal and nuclear fuel. In our analysis of the cost of ordinary thermal electricity in Chapter II, we will assume a somewhat higher efficiency.

[4] Smyth, *op. cit.*, p. 93, para. 6.14.

[5] The cost of producing metallic uranium may have risen somewhat since; the standard price in New York for metallic uranium, announced in December 1949 by the Atomic Energy Commission, is $50 per lb. We may note, too, that this metal, while highly refined by ordinary standards, would not have the extreme purity required for nuclear reactors (*New York Times*, December 1, 1949, p. 17, col. 2).

these will be sufficient to support a large atomic power industry. The third section discusses the available estimates of the cost of producing atomic power and derives those cost figures which we will use in subsequent chapters. Since the analysis is made without regard to the political factors which may strongly affect the economics of producing and using nuclear power, Appendix B, illustrating how the international control of atomic power may produce economic effects, is included.

A. PHYSICAL AND ECONOMIC FEATURES OF USEFUL ATOMIC POWER

Atomic energy in useful form is released in a completely new type of furnace, at first called an "atomic pile," which has come to be known as a "nuclear reactor." Descriptions setting forth the basic physical characteristics of nuclear reactors and associated facilities have appeared in numerous publications.[6] We select for discussion here only those characteristics which seem to have an important bearing on the economics of producing and using atomic power.

1. The Uses of Atomic Power

Nuclear fission, which is the source of atomic energy, is also the source of intense radioactivity. The only known method for protecting personnel from the deadly effects of the radioactivity and neutrons generated by fission is to surround the reactor with a massive shield which, in current practice, consists mainly of concrete. The necessary shielding at present is reported to be several feet in thickness. This means a weight of at least 100 tons is needed for comparatively small reactors.[7] These dimensions need not hold for all time because new types of alloys and ceramic materials may be developed which will permit the shield to be thinner.[8] But at best the shield will continue to be extremely heavy.

The weight and dimensions of this protective shield, even allowing for improvements, will limit the use of atomic power. Shielding requirements

[6] Leon Svirsky, "The Atomic Energy Commission," *Scientific American*, Vol. 181, July 1949; and "Atomic Energy 1949," *Business Week*, No. 1026, April 30, 1949, contain useful descriptions for the general reader. Additional references, of a more technical nature, are listed under "Electric Power" in *An International Bibliography on Atomic Energy*, Vol. 1, Atomic Energy Commission Group, United Nations, Lake Success, 1949.

[7] Sir Wallace Akers, "Metallurgical Problems Involved in the Generation of Useful Power from Atomic Energy," Thirty-Seventh May Lecture to the Institute of Metals, *Journal of the Institute of Metals*, Vol. 73, July 1947, p. 673. M. C. Leverett, "Some Engineering and Economic Aspects of Nuclear Energy," Declassified Document, United States Atomic Energy Commission, MDDC-1304, December 3, 1948, p. 7. J. A. Wheeler, "The Future of Nuclear Power," *Mechanical Engineering*, Vol. 68, May 1946, p. 403.

[8] F. H. Spedding, "Chemical Aspects of the Atomic Energy Problem," *Bulletin of the Atomic Scientists*, Vol. 5, February 1949, p. 48.