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RESEARCH IN ELECTRIC POWER

by

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To MICHAEL and SARAH

TOMMY and PAUL

Foreword

DURING the past decade and a half it has been the national policy of the United States to support strongly research and advanced study in those areas of electrical engineering deemed critical in our defense and space efforts, notably electronics, communications, and control. As a result, research in these areas has grown while comparable growth has not occurred in the field of power. Since, in modern engineering education research and advanced study is the apex of a rather broad pyramid extending through the faculty members at the top to increasing numbers of research associates, graduate students and interested undergraduates, one effect of the relative lack of such research is decreased interest in power at all levels.

At a meeting of the Edison Electric Institute held two years ago and devoted to the subject of education in power, invited academic representatives emphasized their opinion that more research was required. At roughly the same time the Chairman of the Federal Power Commission voiced similar opinions. And various analyses seem to indicate that a relatively small research effort is being made in the power field, small at least in comparison with the size of the industry and the obvious needs evidenced by its forecast growth. All of these factors point toward the need for thoroughgoing discussion and consideration of the topic of these lectures.

Over fifteen years ago I had the pleasure of hearing Dr. Sporn speak to a small group about technological problems of the power industry. At the time I was impressed by the cogency of his reasoning and subsequently was amazed by the accuracy of his predictions. It was with great alacrity, therefore, during one of our discussions concerning research in power that I seized upon his offer to put together his ideas on the subject in the form of a series of lectures. This volume is the result and presents three invited lectures in the Cornell University Lecture series of 1965.

The time is now past when the electric utilities can rely on the well-developed techniques of an earlier day to promote the knowledge and skills that will be required to implement the future that Mr. Sporn projects for the power industry. Equipment and appliance oriented manufacturers are evidently increasingly reluctant to undertake open-ended investigations for the utilities industry unless they can foresee a relatively immediate market application.

There is a sound alternative for research and development. It is to encourage the university research structure to spark new ideas and investigate the basic sciences and engineering so that prototypes may be developed and the commercial research laboratory may bring new conceptions to fruition. Mr. Sporn has issued a clear call for the required research. And the breadth of concern in the industry is such that it is anticipated that significant action will result.

A word or two about the lecturer himself is appropriate at this point. Mr. Sporn came to this country from Austria with his parents and received his education here. He is a graduate of the Columbia University School of Engineering and subsequently did postgraduate work there. Since 1920 he has been associated with the American Electric Power Company, becoming its chief executive officer in 1947. Throughout his career he has been a willing and highly effective participant in governmental, industrial, and national groups concerned with power and energy. He maintains close relationships with many colleges and universities and continues a personal, substantive involvement in new developments in all phases of power. There are few men with the breadth and depth of interest brought to the subject by Dr. Sporn, and he speaks with both knowledge and dedication.

15 October, 1965 ANDREW SCHULTZ, JR.

Acknowledgment

I AM GLAD to acknowledge and to express my appreciation for the help I received from my colleagues, Messrs. A. Gerber and P. Dragoumis, in connection with the editing of the material and the reading of proofs.

Introduction

IN THE introduction to an earlier book on energy* I pointed out that few subjects of such vital concern and interest to modern societies are more misunderstood than energy. In that book I tried to describe the role of energy resources in our society, their function and application, and to visualize the likely course of development of energy use for the balance of this century.

I particularly stressed the great advances in the technology for the production and utilization of electric energy, the economic development of the electric utility industry and its dynamic growth since its origin in 1882, when the historic Pearl Street Electric Station in New York first demonstrated the vistas opened by electric energy.

Exciting as the past development has been, the potential for growth and development in the future is even greater. Looking ahead to the end of this century, growth in electric energy generation in the United States to a level of 6000 billion kWh is clearly indicated. The implication of sixfold expansion over present levels in electric energy use are: capital resource requirements amounting to perhaps $300 billion; a build-up in annual primary energy needs to a level of 1600 billion tons of bituminous coal equivalent; and the numerous complex technological problems created in de-

**Energy : Its Production, Conversion and Use in the Service of Man,* Pergamon Press, 1963.

signing, building and operating the generation, transmission and distribution facilities of the yet not fully grasped much larger power systems that will necessarily evolve. These constitute an almost impossible to overemphasize challenge.

But they are also sobering prospects. Contemplating them one cannot help but wonder whether the electric power industry, including both its manufacturing and utility segments, is alert enough to visualize not only all these problems involved in creating these systems, but whether it has the vision to see all the difficulties which that act of creation will pose in so short a time. One wonders whether the imaginative, high-quality men who must face this task of technological creation are available in sufficient numbers and trained in proper depth and breadth and with proper appreciation of the social responsibility they will be called upon to discharge.

One cannot help but be apprehensive when one considers the failure of the guardians of our educational resources to perceive the social importance of educating enough high-grade young people in these areas and the self-imposed limits placed on their creativity (and their profits) by our great manufacturing organizations by putting a coin-in-the-slot repayment meter on Pegasus. And one wonders at the state of underexcitement among the managers and directors of our electric manufacturing and of our electric energy producing and distributing organizations—both public and private.

The present state of the United States electric power industry as the most advanced in the world, and its position as a great dynamic force in our society, came about only because of its technological boldness. It did not come from the complacency expressed by some, that after all there is nothing new in electricity—the kilowatt and the kilowatt-hour are the same today as they have been from the beginning.

Nothing new? What a terrible misreading of the industry's technological history this is! In the last 60 years alone the industry has gone from Corliss engines of several hundred horsepower to 1 million h.p. turbines on a single shaft; from steam pressures of several atmospheres to supercritical pressures of 250 and 300 atmospheres; from thermal efficiencies of conversion of 3% to 40%.

In transmission and distribution have there not been similar histories of almost unbelievable progress? To cite only one example: from Edison's three-wire 220 V d.c. grid to alternating current of first 11,000 V, then progressively to 69,000, 138,000, 220,000, 345,000 and now 500,000 V? The technological developments and inventions involved in insulating, protecting and controlling circuits handling up to 1 million kW with only three conductors are in themselves the culmination of a history of venturesome exploration into new and untried areas that have yielded great scientific, technological and economic rewards.

How but for all these technological advances could our electric networks have covered the 3 million square miles of the United States, making electric energy available everywhere, in whatever quantities from fractions of a watt to millions of kilowatts at a single point of application and at competitive costs?

It was because of my deepening concern that the comprehension of the vital role that advancing technology has played in the past and will play in the future of the electric industry was being lost that I grasped the opportunity offered by Dean Andrew Schultz, Jr., of the Cornell College of Engineering, to discuss this so vital subject of technology and research in electric power at Cornell in the spring of 1965. In the three lectures published here, I have tried to discuss in depth the great—indeed indispensable—need of a broad program of research in electric power to bring into being the fabulous growth attainable in that area in the next third of a century; the many areas and the many specific problems in these areas that call for research; and, finally, the danger of centralizing research efforts as well as the alternative forms of organization that might be employed to carry out that research effectively.

I have also tried to outline the areas in which the colleges and universities, the manufacturing organizations, the electric utilities, and government each can function. And while all these discussions are directed mainly at the situation in the United States, I hope that the basic ideas and mechanisms have a universality so as to find applicability in any technologically and economically advanced society, and might even be helpful to those planning and working toward creating such a society.

I hope these lectures will contribute to a broader and more deeply based recognition of the challenges and opportunities in energy, and particularly electric energy, technology, research and development. I hope they will stimulate not only greater, but better organized and more effectively directed efforts without which our society's rapidly growing energy needs cannot satisfactorily be met.

September 1965 PHILIP SPORN

I. Research as an Indispensable Element in Inventing the Future

THIS is the first of three lectures on research in electric power. In these lectures I am going to discuss three questions: Why Research?; What Research?; and How Research?

The title of this first lecture reveals the answer to the first question: Why Research? Research, I submit, is an indispensable element in inventing the future. This lecture will attempt to elaborate and explain that answer.

In order to understand the importance of research in electric power it is necessary to find out something about the role research has played in the past, what it is doing today, and, finally, what kind of future is visualized for electric power and the function of research in achieving that future.

The development of commercially supplied electric energy originated as the result of a brilliantly conceived systematic program of research and development by Edison. It has been advanced by numerous important technological achievements ever since. Edison invented not only the incandescent lamp, but also the central station for electric generation. Indeed, he invented the electric utility industry. These inventions did not come about by mere accident.

Edison, having brought forth a series of startling inventions of great ingenuity—the quadruplex system of telegraphy, the telephone transmitter which is in use to this day, the phonograph—finally responded to the urging of what had been in his mind for years, reinforced by the prompting of a number of his friends, to try to develop an improvement on gas lighting, which by then had become a major industry in the United States and in other industrially advanced countries.

Edison stated the problem for himself, putting it down in his notebook as follows:

> Electricity versus gas as general illuminant. Object: electricity to effect exact imitation of all done by gas, to replace lighting by gas by lighting by electricity, to improve the illumination to such an extent as to meet all requirements of natural, artificial and commercial conditions.

He started the work on his light on 8 September, 1878. By October, 1879 Edison had invented and perfected the electric light. He was then ready to start work on the power plant required to provide the lamp with its energy.

The concept of the subdivided light and of a centrally located power plant to serve an entire surrounding area had been clearly formulated by Edison as early as 1878, but he had laid the power plant aside while he did his work on the lamp. Incidentally, when he started work on the power plant, Edison had a clear idea that it was going to furnish power and heat as well as light. And indeed many of the early Edison companies featured the slogan "Light, Heat, and Power". He went to work in earnest on the power plant in 1879 and in 3 years invented and developed the central station system and the entire concept of an electric utility operation. On 4 September, 1882, almost 4 years from the day on which Edison began his work on the electric light, the switch was thrown at the Pearl Street Station in New York to inaugurate the first central station electric service. From this has grown what is today one of the great social–economic forces in the world—the generation, transmission and distribution of electric energy.

In the course of that work Edison encountered hundreds of problems that had never even been imagined before, and he had to make hundreds of inventions to solve them. Included among them were speed governors for engines, the dynamo itself, voltage regulators, indicating meters, watt-hour meters—on meters alone Edison was granted twenty-two United States patents—fuses, cutouts, switches, insulating tapes for underground cables, underground tube systems, the electric grid, the screw socket and lamp base, the socket snap switch—the total number ran into several hundreds.

But the point is, having established his objective, electric illumination, he then conceived—that is, invented—the grand design of central station electric service in which universal electric lighting would play a prominent part, and proceeded to invent and develop the vast array of indispensable components necessary to achieve his objective and to make a success of his two basic inventions, the lamp and the central station.

This solid background of technological accomplishment and scientifically oriented thinking has remained the continuing heritage of the electric power industry. Starting with a total load of 30 kW in September, 1882, the utility industry has had one of the most amazingly consistent histories of growth. The record of a compound rate of growth of about 7.2%—doubling every 10 years—is particularly amazing when one considers that the industry is now in the middle of its ninth decade.

This remarkably consistent growth in electric energy consumption has occurred at almost all levels of consumer use. It has taken place in the home, on the farm, in commerce and in industry. In every area of human activity in modern, economically advanced societies, electric energy use has had this continuous and consistent growth over a period of more than 80 years.

The reasons for this are many. Essentially, this growth has resulted from a series of social–economic and ecological developments which have brought about, contrary to the expectations of many sociologists and economists, growth in population and in family units, the extension of electric service to every family in the United States and an increase in national production and productivity, with accompanying growth in total and per capita income. A very significant contribution to this growth in electric energy use has been the consistent reduction in the price of electricity to the consumer made possible by the industry's continuing technological progress.

Let us more carefully analyze the cause of growth from the standpoint of the areas of application or utilization.

In 1882 electricity began to replace other lighting sources with the incandescent lamp, but it took 20 years to convert the first million customers from kerosene and gas lighting and another 5 years to convert the second million.

Electric irons were introduced in 1893 and the appliance industry was born. This was the beginning of a host of other inventions and developments designed to replace human and fossil fuel energy in the home that has culminated in the present concept of electric energy as the total or universal energy source in the all-electric home using electric energy to satisfy all energy needs, including space conditioning.

In addition to its role as a substitute for other forms of energy for lighting and heat, electric energy made possible the development of a group of labor-saving appliances—washers, ironers, dishwashers—which substituted electric energy for human energy in the home.

Although early growth of the industry could be almost entirely attributed to substitution, there evolved new uses for power which were unique to electricity. New processes and products hitherto unobtainable, such as entertainment, were developed and even in those cases where substitution was the initial purpose, growth took place to the point where the magnitudes really amounted to new use.

Thus, as an example, mechanical refrigeration in the home went far beyond the replacement for 50 lb. of ice per day because the electric refrigerator, which replaced the icebox, produced the equivalent of 200 lb. of ice per day; so that electrifying the customer had in many cases a creative effect by making more abundant the necessities and comforts in the home.

Radio, introduced in 1920, is an example of a totally new energy use. Although it took Americans 20 years to buy their first million water heaters, radio, which came on the market at about the same time, exceeded a million users in just 4 years. The growth of the radio industry illustrated just how much more rapidly a new use or product could achieve acceptance than can a substitute use or product.

Design improvement in an existing product often gives it the dramatic appeal of a new use. To cite an example, the electric toaster was introduced in 1893, but it took 30 years to sell the first million; the "pop-up" automatic toaster, introduced about 1926, became so popular that by 1928 a million were sold in 1 year.

The introduction of television in 1939 was hampered by the start of World War II, but a million sets were sold by 1948.

An analysis of the development of electric energy applications in the home leads to several important conclusions:

1. Appliances that represent substitutions, unless they have a particularly dramatic appeal, expand at a relatively slow rate.
2. Rapid progress can generally be expected in anything new or exciting in domestic entertainment.
3. No new home appliance of major significance has been introduced in the last 25 years.

These conclusions have a particularly important bearing on requirements for future research.

On the farm, mechanization has brought about some substitution of electrical use for human labor. A trend toward fewer and larger farms accelerated electric applications to such chores as milking, grain handling, stock feeding, and watering. New uses include environmental control for cattle, swine, and poultry (including electric space conditioning), hydroponic grass growing, electric grain drying and, of course, the electrification of the farm home itself which has resulted in bringing the farm population into closer contact with the rest of society by means of radio and television, and so has served to place the farm home on a more equal footing with the urban home in terms of the educational and entertainment opportunities now available to both.

In commerce merchants found that light was a selling tool and the dramatic new uses, including accent and color discrimination, far exceeded the needs for it as an aid to sight.

More recently there has been the large-scale introduction of electronic computers. While one might say that computers and data processing equipment are merely replacement of manual labor and manual computers, it actually is more true to say they represent a new use of electric energy which is an important source of growth for the power industry. Users are learning that, although in theory at least armies of clerks can be allowed to perspire, the new computers will not tolerate such abuse. They require environmental control including temperature, humidity and dust, and electric energy is the most effective means to this end.

In industry new uses contributing to growth have been many. The industrial user early became familiar with applications of electric power when he substituted it for his other prime movers, manual material handling processes and many of his gas or steam heat applications. In addition there developed processes uniquely electric: electroplating, resistance welding, metal refining, the reduction of such modern metals as aluminium, magnesium and titanium, and the production of alloys and alloy steels possible only in electric vacuum furnaces. Still another class of uniquely electric processes was developed in the chemical field, involving either electrolysis or compression. Illustrative of these is the production of ammonia, chlorine and oxygen.

Dielectric and induction heating made possible application of heat for new techniques such as molding products that would be impractical with conventional heating methods.

One of the important factors contributing to the expansion of electric use by all consumers has been the decline in price of the product made possible by the electric power industry's continuous search for, and effective support of, technological progress. This feedback relationship, with lower price making possible additional expansion and the introduction of new technology making possible still further reduction in price, has been and will continue to be an essential—indeed an indispensable—factor to sustain the growth of electric energy consumption.

Technology has been the key to growth. Technology and growth have both moved together and they have been closely interrelated. In the main it was the technological advances that brought about the rapid growth. But really this was a closed cycle. The rapid growth also made possible many of the technological advances. Particularly has this been so in the last quarter-century when rapidly growing use of electric energy and substantial technological advances have made possible a decline in the average price per kilowatt-hour in the face of major increases in the general price level.

During the last 40 years electric utility generation increased almost twentyfold while gross national product less than quadrupled. This growth in the past quarter-century has involved a change in the character of a considerable part of the electric utility industry from relatively small, more or less isolated, systems into large integrated systems. Many of these large systems in turn have been interconnected in major pools to exploit the advantages of mass production and transmission of electric power at costs lower than could be achieved by the smaller systems. This phase of the industry's development has been made possible in large part by a number of important technological developments and the large systems themselves in turn have made possible the incorporation of cost-saving technological developments which would otherwise have not been made.

For example, the savings in construction cost per kilowatt of capacity by building larger units would not have been possible without the large systems able to absorb large-sized units, and the savings in fuel costs now being achieved through the use of larger, more efficient units and the transmission of larger blocks of power from plants, strategically located with respect to load centers and the sources of fuel and condensing water, would not have been possible without the need for large blocks of power in single systems.

Important forward strides in technology have taken place in every phase of the industry's operations. The expansion of electric utility generating capacity from 34 million kW in 1934 to the present (1964) 221 million kW was much more than a simple multiplication in kind. Units of recent installation can hardly be classified as of the same species as those of 25 or 30 years ago. The size of units, the steam pressures and temperatures were all almost undreamed of or considered impossible a quarter of a century ago.

The developments in steam generation are reflected in the comparison of thermal efficiency. In 1934 the average heat rate of the industry was 17,950 B.t.u. By 1963 it had fallen to 10,200 B.t.u., a decline of over 43%. For one large system, American Electric Power System, the average heat rate in 1963 had fallen to 9457 B.t.u. kWh.

The improvements in thermal efficiency resulting from increases in temperature, pressure and reheat have been, in part, made possible by the great increase in unit size. The typical large turbo-generator in 1935 was 40,000–50,000 kW—today we have 600,000 kW units in operation and several much larger units are now under construction, including one of 1 million kW.

These larger sizes and higher pressures and temperatures have resulted in construction cost savings and operating manpower savings which have helped to offset part of the higher construction and labor prices, thus holding down the cost per kilowatt-hour.

Enumeration of other phases of the electric power industry in which, as in steam generation, great progress has been made is impressive. There have been significant advances in hydroelectric dam design and construction, advances in transformers in keeping with growth in generation, and dramatic progress in transmission at high voltage.

In the field of system control and protection an outstanding example is the successful ultra-high-speed reclosing of transmission lines by which a faulted line is opened at both ends simultaneously to clear the fault and reclosed for normal operations, all in a fraction of a second so that the net effect on service is as if there never had been any interruption.

The immense growth of systems and pools has required reliable communication at all times, a requirement that is being met most effectively by microwave communication which provides high-quality voice transmission and a large number of channels. Application of digital computers to power system planning problems, to certain operating problems and to commercial and accounting phases of the utility industry has made rapid strides. In distribution, as in transmission, significant progress has been made in the technology and in its application. The pervasive utilization of electric power in itself has suggested new concepts of distribution economics and reliability to match the new concepts of utilization—the all-electric home, for example.

It is not possible in this lecture to submit the history of progress in any great detail, but I should like merely to record a list of eight major utilization inventions which have had an enormous influence on the usefulness of electrification and its service to man and a list of some twenty-seven other major inventions and developments which have influenced enormously the technology and eventually the economics of electric power generation, transmission, and distribution to the utilization devices.

Among the utilization devices that have been invented or developed since 1882 for the home, the following stand out: the electric lamp, the electric iron, the toaster, the refrigerator, the automatic washer, radio broadcasting and radio receiver, and television. All these devices have over a period of years received universal acceptance so that in a relatively short period after their first introduction all of them could be found in more than 80% of American homes, and in some cases, such as the refrigerator, in close to 100%.

In the non-residential area two devices cannot be omitted because of the enormous influence they had on the development of electric energy utilization and the usefulness of electric energy. The first is the direct-current (d.c.) motor in all its various forms and the second is the alternating-current (a.c.), and particularly the a.c. polyphase, motor. The latter became the great work-horse of industry the world over.

In the field of electric energy generation, the following inventions or developments stand out:

1. The Edison d.c. system of generation, including the dynamo and all its concomitant parts, involving regulators, switches, cutouts, etc.

2. The steam turbine as the principal converter of thermal energy into the electric form.
3. The high-pressure, high-temperature, reheat turbine and cycle.
4. The hydrogen cooling of turbo-alternators and other large electric machines.
5. The liquid cooling of stators, first through oil and and later through water circulating through hollow conductors.
6. The pulverized fuel boiler.
7. The water-cooled boiler, including walls, roof and floor.
8. The supercritical pressure once-through boiler.
9. The tall stack, rising to levels approaching 1000 ft to bring about diffusion of the waste products of combustion into the upper atmosphere.
10. The modern cooling tower to reduce the limitation of condensing water availability on the location of steam–electric generating plants.
11. The thermal or converter nuclear reactor.

In transmission, the following major inventions or developments stand out:

12. The a.c. transformer.
13. The suspension insulator.
14. The transil oil switch.
15. The high-voltage lightning arrester.
16. The high-voltage transmission grid.
17. The high-speed, high-voltage circuit breaker, currently developed for an opening speed of 2 cycles.
18. The high-speed 1 cycle relay system.
19. The ultrarapid reclosure of extra-high-voltage lines.
20. The design of the insulation of the entire transmission system on the basis of the principle of insulation co-ordination.

The outstanding developments in distribution are:

21. The Edison d.c. grid.
22. The a.c. network.
23. The development of economical high-voltage distribution, currently in voltages up to 34.5 kV.

In systems development the following inventions or developments stand out:

24. The development of the principle of interconnection.
25. The development of the integrated power system.
26. Carrier current as a mechanism for communication, control, metering and protection of high-voltage lines.
27. Distributed frequency and tie-line control to make possible parallel operation of complex networks of modern system and regional high-voltage grids, and the control of tie-line power flows.

Of necessity some of these choices are personal and, therefore, somewhat arbitrary. Yet, I believe, they well represent the history of how the electric power industry became today one of the most dynamic industries in the country, perhaps the most dynamic.

The power industry has had a remarkable growth in the past 80 years. Looking ahead, there are a good many reasons for being optimistic that this record of growth and technological achievement will be continued. The world of the future, even more than the world of the past, is going to be one in which energy is going to play an indispensable role and electric energy promises to more than hold its own.

The growth that has taken place over the past 80 years has been influenced by the research, development and inventive skill of thousands of people, some of whom were without any doubt entitled to be ranked among the great geniuses the world has produced. If this record is to be maintained, it is necessary to try to visualize the opportunities for future growth, project attainable goals, and then project a program of research and development indispensable to the attainment or the implementation of projected goals.

The desire to determine the future is surely a human enough objective. The future is something that most people want to look to and try to pierce. We all would like to know what will happen tomorrow and the next year and even beyond. In business trying to look ahead and pierce the fog of the future is a fundamental element for successful long-term operation. It is often given some very high-sounding names: advance planning, business forecasting, operations research, and many others. It is not a new idea. In electric power it has an established history that is perhaps older than in any other industry.

And yet, when the matter is examined closely there are bound to arise doubts. For when we attempt to look ahead more than a few months, or at most a very few years, past trends become much less valid guides to the future. But if we are skillful enough, we can invent the future. That is, following the example of Edison, we can conceive, and thus invent, a set of goals, and then visualize and implement the steps necessary for their achievement. What I am saying is that we can create the future, but we cannot predict it.

In the National Power Survey, which was issued less than 6 months ago after 3 years of a great deal of intensive effort by several hundred people under the aegis of the Federal Power Commission, a projection of growth of electric energy in the country was made on a fairly firm basis for the year 1970, and on a more generalized basis for the year 1980. This is because it was recognized that in looking ahead so far it becomes very difficult to project with any kind of precision. Thus all that can be done when making even a 15-year projection is to show some broad outlines.

Yet, even though it may appear paradoxical, as a result of my work in energy and electric energy, including atomic energy, these past 45 years, and more specifically as a result of my work in connection with the National Power Survey, I have become convinced we need to look beyond 1980 and indeed we need to look to the year 2000.

I have picked 2000, which is some years ahead, not because it is a nice round date, but because the investment decisions we now must make and the plant and equipment that we need to design and install should have an economic life of about that span, and because, if there are problems to be solved, they need to be recognized early enough to permit sufficient time for their resolution; we need time to make and develop the implementing inventions. We need to look that far ahead because, even if we allow for a slowing down in the rate of growth, the orders of magnitude with which we are going to be confronted now are going to be so large that the very character of the problems themselves change in their nature and become more numerous and complex as well as more exciting. Therefore, today I would like to present for your consideration, and as a challenge to your imaginations, an invention of the electric utility industry for the year 2000.

It is common to talk about meeting the load requirements. There is nothing wrong with that expression "meeting the load" when referring to the load that will come on later in the morning or in the evening, or next week's load—perhaps even the load that will come in the next year or two. This is because in essence most of the fundamentals determining these events have already taken place. But beyond that the most important elements that determine loads are not those that happen but those that we project—that we invent—in the broad sense of the term "invention". You have a control over such loads: you invent them and make them come into being, and then you can make plans for the best manner of meeting them.

If this kind of thinking is adopted, and then sequentially is followed with plans—technologic, economic and commercial—this new load will come into being as a result of planned effort and will be met in accordance with predetermined design. What can be done technologically is perhaps the most important single element, but not the only element, in determining what can be done to achieve growth. Thus out of the close ties between technology and invention and between technology and expansion in use, there exists a perfectly logical basis for the claim that the future can be invented.

I would like to do that for the American power industry for the year 2000. To start with, there are the following three basic elements of our invention for the year 2000. Total electric generation for that year is projected at 6000 billion kWh, peak demand 1000 million kW, and total revenues of $58.8 billion per year. These are exciting and challenging figures when they are related to the current magnitudes. They represent 6.6 times as much generation, 6.2 times the peak demand, and 4⅓ times the total revenue for the year 1963.

This relationship between growth in generation and growth in revenues is very important because of the conviction that unless the dynamism of reduced rates is maintained it may not be possible to achieve the generation projected. The figures appear imposing, as indeed they are. But notice that this projected rate of growth for the next 35 years is less than the more than sevenfold increase we experienced in the previous 25 years. Surely they should prove no more beyond reach than our 1963 figures proved to be from the perspective of 25 years ago. Nevertheless, the magnitudes are so large it is well to examine their implication and the kind of challenge they present if we are to bring such an invention to a successful fruition.

Just what kind of challenge does this invention imply? It will certainly require a series of what I call implementing inventions. With total generation of 6000 billion kWh, the industry will have to build facilities involving a total investment of about $420 billion. While this will represent a significant growth in facilities, it is less than the growth in generation. Thus, and not accidentally, this implies a more efficient use of capital.

The 6 trillion kWh to be generated in the year 2000 can be broken into two major components—the conventional thermal and hydro, and nuclear. The hydro will become relatively negligible in the future because whatever hydro is developed will be merely a relatively small extension of what is already installed. Conventional thermal generation will continue to grow, but at a much slower rate than at present as nuclear technology continues its progress. Thus thermal and hydro combined will in the interval between 1963 and 2000 rise somewhat over threefold, but nuclear energy will increase a thousandfold.

Thermal efficiency will also rise and British thermal units per kilowatt-hour will decline by almost 20% so that the total fuel equivalent will increase by only something more than fivefold despite an almost sevenfold increase in total generation.

These relationships in the implementing inventions encompass within themselves some staggering challenges. They postulate a 35% reduction in the unit cost of energy generated and sold in the next 35 years. This will have to be achieved at the same time that the complexities in operation to be anticipated increase as a consequence of growth in population and in the economy, together with the greater concern that people will have for the amenities, the intrusion of utility facilities on the environment and about greatly improved reliability of service.

Thus, inescapably, these achievements will demand more efficient design, construction and operation. This in turn will require a continuing program of research and the development of numerous subsidiary inventions. A great deal of ingenuity, inventiveness and determination will be needed to make good the basic invention—the system of 6 trillion kWh projected for the year 2000.

Some of these inventions which I started to list without regard to number, and which ended up at nine, are the following:

1. It will be necessary to reduce costs to make possible the sale of electric energy at very close to an average of 1 cent per kilowatt-hour. This will be necessary to continue to benefit from the fundamental feedback relationship with regard to lower costs, lower rates, and expanded use which has provided the solid foundation for the electric utility industry growth until now.
2. It will be necessary to locate and acquire about 300 or so new plant sites, each capable of being developed to a capacity of between 2.5 and 3 million kW. These are in addition to the sites that already exist or are in process of being developed.
3. It will be necessary to develop a thermal cycle in coal capable of producing electric energy at an efficiency of 50%, or about 6800 B.t.u./kWh.
4. Plant designs must be developed both in coal and nuclear energy capable of producing a kilowatt-hour at the bus bars on the basis of 7000 hours' use for a total cost of no more than 3.5 mills and, possibly, as low as 3.25 mills/kWh. This would represent no small achievement. The type of nuclear plant represented by the now well-publicized Oyster Creek Station simply will not be good enough for the kind of future being visualized for the industry.
5. The technology of a.c. transmission at 700–765 kV will have to be developed completely, and perhaps extended for service applications at 1,000,000–1,100,000 V.
6. It will also be necessary to develop d.c. transmission

to the fullest extent possible for effective use, either in lieu of extensive EHV alternating current or as a supplement thereto. It is too soon to tell in which direction its true development opportunities may lie.

7. An important challenge to be met is the further development of an a.c. circuit breaker for high-voltage systems capable of clearing a fault in a maximum time of 1 cycle on a 60-cycle system and to extend this development to a relay system capable of sensing and signalling the actuation of a circuit breaker in a maximum time of $\frac{1}{2}$ cycle. And with these, improvements in concomitant switching concepts and designs will be required. Such systems of relaying and switching will also have to be extended for application to the lower voltages.

8. The application of electric energy in the home will have to be expanded. This will require the continuation and intensification of efforts in the development and the promotion of electric heating. But even this will not be sufficient to achieve the kind of total load that is visualized for the year 2000.

To achieve this goal, it will be necessary to supplement the electric heating load with an additional major electric energy-consuming device, and the most likely prospect as a major electric energy consumer is the electric automobile.

9. A dry steam condenser capable of acting as a heat sink for the large power plants that will be built, in order to make them independent of even the relatively small supplies of water that water cooling towers call for, will have to be developed. The idea is already well along, but we have a long task ahead of us to develop it. The development of this idea will mean that we will be able to build a power plant wherever we have the combination of load center and fuel supply, and availability of significant supplies of water will play no part in it.

None of these will be easy, but they are not impossible achievements. To provide a more solid basis for my judgment I am going to analyze this entire problem of implementing inventions in greater detail and make them the subject of my next lecture, The Areas of Research and the Specific Problems to be Solved. I hope out of that discussion to be able to give you a better understanding of the nature of the problems and why tackling them can be an exciting affair, and one that can lead to the implementation of this great invention—a power industry with a system input of 6000 billion kWh in the year 2000 operating as a successful business enterprise in which there will have been invested some $400 billion of capital and which will furnish 40% of the total energy requirements of the United States at that time in the most flexible, most convenient and useful form—electric energy.

II. The Areas of Research and the Specific Problems to Be Solved

THE first lecture traced the dramatic and exciting history of growth of the electric power industry and the important contribution of a series of great technological developments to that growth. Against that background, a goal of growth for the industry, an invention of its future, was projected to the end of this century. Some of the implementing inventions required to make effective the primary invention—to make it a reality—were discussed and a list of supporting inventions that would be needed for that purpose was outlined.

This lecture will examine in greater detail the problems demanding research in the main areas of planning, design, and construction of the physical facilities, in successfully and economically operating the systems and in developing the much-expanded markets for electric energy constituting the basic building blocks of this invention structure.

The problems with which an effective research program will have to cope can be divided into the following five areas:

1. Utilization in all its branches, covering the full spectrum of electric energy use whether involving energy use from the tiniest fractional watt lamp to the largest motor or furnace, running into several hundred thousand kilowatts.

2. Generation, including fuels, as well as the technology of conversion.
3. Transmission in all its branches, including transmission at voltages not heretofore even explored.
4. Distribution, again in all its phases, including higher voltages, techniques for developing economical underground distribution including new materials and new methods of insulation.
5. System problems, including new methods of system analysis, the social amenities, the problem of manpower and the problem of the status of power and energy as a social–economic operation in our society.

UTILIZATION

The growth projected for the next three and a half decades presents the staggering prospect of duplicating 6.5 times over what has been created by the electric utility industry in the previous eight decades of its history.

But this growth is not guaranteed. It is an invention that needs to be made good.

Much of the past growth in electric energy use came about as a result of the replacement of other energy sources. In the case of lighting, electric energy replaced kerosene and gas. In some cases such as radio and television, electric energy provided a service for which no other form of energy was suitable. Also please recall that in the last lecture it was pointed out that no new major electric appliance has been introduced since 1940.

It must be clear, therefore, that if the growth projected for the year 2000 is to be achieved, as far as domestic use is concerned, research needs to be undertaken to develop new applications for electric energy both as a substitute for other forms of energy and for new uses which would otherwise go entirely unsatisfied in the home. One of the major functions in which the substitution of electric energy for other fuels can provide a very significant growth impetus is space heating. But here much work remains to be done to develop the basic principles of heating for comfort and health with various forms of heat and to develop more efficient and more reliable equipment, and even entirely new techniques such as heat storage.

To achieve the level of total electric generation projected for the year 2000 it will be necessary to supplement electric space heating with an additional area of electrification and for this purpose it was suggested that the most logical area is the automobile.

But the electric automobile that needs to be developed cannot be approached, as it was a few years ago, on the basis of taking any old automobile and putting a group of lead cell batteries into it. This means that a much-improved storage battery will have to be developed—one much superior in every way to the lead cell—for use in a new car that would be designed around this battery together with a new electric motor and a new system of controls. This car would receive its energy from an outlet in the home or from a series of electric service stations.

One of the immediately obvious areas requiring strong research and development effort is utilization voltage. It has been obvious for a long time, and European experience has fully confirmed it, that as use per customer grows service can be provided at lower cost if the utilization voltage can be increased. For this to be achieved, considerable research in manufacturing control and safety devices is required to make the higher voltages acceptable and completely practical. A major effort by the electric power industry to break away from the present conventional, altogether too low, utilization voltages in the United States is warranted by the large stake the industry, that is both manufacturers and the utilities—but even more importantly the people of the United States, the users of their combined product—have in their successful development.

This need to develop new uses of electric energy exists not only in the area of residential use, but the opportunities may be even greater on the farm, in commerce and in industry.

The increase in productivity, both of land and labor, on the American farm has elicited the admiration of the world. But it is important to remember that the growth in agricultural production and productivity to meet the problem the world as a whole is facing of providing enough food for the rapidly expanding population is nowhere near the end. Electric energy, while it now has been made available to virtually every farm in the United States for many years, has played a relatively insignificant role in the rising productivity of the American farm. The great increase in production and productivity has come about mainly as a result of the application of the internal-combustion and diesel engines, together with much greater use of chemical fertilizers and pesticides.

Considering all the avenues that have been barely opened but never fully explored for bringing electric energy into the farm production process, it would appear that major opportunities remain for thoroughly researching the potentialities of electric energy use in a wide range of farm operations. In dairying, to take one area, the possibilities need to be explored for utilizing electric energy in the form of ultraviolet radiation and to operate pumps and compressors, to provide green forage for milk cows in winter, and as substitute for human effort in growing and processing hay and ensilage. The opportunities in the diverse requirements for environmental control, in soil heating and treatment, in mechanizing dairying to a much greater extent than has been done thus far in production of animal feed, etc., are too full of potential to be left in their present partially developed state.

In the case of commerce the rapid expansion in the employment of more highly skilled white-collar workers and complex electric equipment has brought about problems of environmental control for the efficient functioning of both machinery and people that have barely been explored. This is true also in areas of merchandising where the elements of maintenance of merchandise quality, whether food or highly specialized and expensive women's clothes and their display, warrant much greater study in the interests both of conservation and improving the economy of distribution. The need to explore further new techniques for environmental control in establishments that serve the public is too obvious to require elaboration.

In the public domain it would appear that the new social needs that are developing as a result of increasing population and growing urbanization, such as mass transportation, traffic control, sewage treatment, water supply and purification, atmospheric control and purification, and the like, all offer challenging opportunities for opening up new areas of service for electric energy.

Government agencies—local, state and federal—are important consumers of electric energy to provide numerous community and social needs. In those areas appropriate arrangements need to be worked out to permit a co-operative research effort among utilities, manufacturers and government to find new and better ways to satisfy old needs and to anticipate and meet new needs.

Perhaps the greatest opportunity for research to expand electric use lies in the industrial field. In the past most applications of electric energy outside the home, especially in manufacturing, have been developed by the industrial consumer. It is no longer possible, however, for the electric industry to rely on this random procedure to provide an adequate basis for growth. The utility industry itself must exert its efforts to develop new ways of substituting electric energy in industrial processes now using other fuels or to develop new electrical processes and applications. What is needed here is a new approach—perhaps an industry-by-industry approach—in which every process is researched from an energy standpoint to determine how the process can be properly lighted; how air for the process itself, or for the humans who participate in it, can be supplied so as to optimize the operation; how any function involving cutting, welding, heating, forging, cooling, drying, transporting and many other related basic functions can be carried out more effectively by introducing electric energy.

There is adequate experience to warrant the judgment that, even in the most modern plants being projected today, research of this kind can reveal numerous opportunities for electric energy applications that would result in major increases in the total amount of electric energy use and substantial benefits to the production process.

But here, again, both the electrical manufacturers and the utilities must share responsibility. The utilities, because of their close contact with their customers, are in a particularly good position to analyze and understand customer needs and requirements. The electrical manufacturers, because of their experience in highly technical production processes, are especially well equipped to help develop the equipment to meet those needs electrically.

There is a special reason why research in electric utilization is particularly important from the standpoint of the national interest. Since energy and particularly electric energy will continue to play an increasingly larger role in the future growth of our society, it is important that it be available to the fullest extent that our society can effectively employ it in the process of building its future. Elsewhere*

*Philip Sporn, *Energy: Its Production, Conversion and Use in the Service of Man,* Pergamon Press, 1963.

I have shown that by the year 2000 nuclear energy will represent the largest single primary energy source for electric generation, over 53%, of the country's use of 6000 × 10^9 kWh. But in terms of the total energy used by the country, nuclear energy will constitute 21%. Yet since nuclear energy is not envisioned as being capable by then of assuming any share of the total energy supply except through the process of conversion to electric energy, it is obvious that for nuclear energy to be able to contribute an increasing share of the nation's energy requirements it is imperative to stimulate and press vigorously the further electrification of our energy utilization devices.

GENERATION

Fuels : Fossil Fuels

If adequate research and development are carried out and the major increases in load visualized are achieved, and if in fact electric energy by the year 2000 will account for 40% of total energy use, this would mean total fuel consumption by the electric industry equivalent to 1600 million tons of bituminous coal, of which coal itself is likely to account for 600 million tons, even under the most optimistic assumptions regarding the speed of nuclear power development.

This opens a very wide range of questions and problems. It raises the question of the degree of confidence with which we can look forward to the availability of these quantities of coal at anywhere near current price levels. There is little doubt that petroleum and natural gas will not be available in adequate quantities to meet the needs for electric generation of the magnitude that coal and nuclear power are expected to supply. If this is so, then it becomes increasingly important to concentrate research efforts to make possible the more extensive utilization of coal and the development of nuclear power.

The availability of coal as an economical fuel surely cannot be left entirely as a problem of the coal industry. This problem has two parts—the cost at the mine and the cost of delivery. While the coal industry has made notable strides in the development of improved mining technology that have more than doubled productivity per man-day in the last decade, much remains to be done. Still more remains to be done in the exploration and geological evaluation of our coal resources. In the case of coal delivery, while a great deal has been accomplished in the last two years to reduce the cost of rail transportation and coal pipeline research is continuing, a larger task remains if the electric industry is to have available, at the lowest cost, transportation by rail, river, truck, pipeline, conveyor or any other efficient low-cost transportation system.

But the continued availability of coal at low cost is not the only area in which we have inadequate information about coal. The truth of the matter is that even though coal has served as the very nucleus of the industrial revolution which marked the beginning of the modern industrial world, and although coal in this country was the principal energy source that brought us first to a position of might and high affluence among the world's family of nations, coal remains a fuel we know almost nothing about chemically. We are particularly ignorant about its many impurities, not only the common forms like sulphur and iron, but such elements as sodium, potassium and chlorine, their various compounds, and their interactions with metals when the latter are exposed to these elements at very high temperatures. This was not too important at one time when boilers of 10,000 kW and 20,000 kW rating were common. But with the coming of 500 and 600 MWe chemical reactors, which is what boilers are, these problems assume totally different proportions. And these problems will be even greater as these sizes grow to 750 and 1000 MWe and beyond.

Fuels : Nuclear Fuels

As for nuclear power, it is obvious that much work remains to be done if nuclear power is to contribute significantly to the supply of electric energy without incurring substantial increases in cost over current fossil fuel cost levels in all but limited parts of the United States. While the highly creditable developments in the boiling water and pressurized water reactor concepts have brought about the threshold competitiveness that appears to be in the neighborhood of 27 cents ± 2 cents per million B.t.u., few, if any, operating reactors, or reactors under construction or proposed, actually reach that point of competitiveness without subsidization by the federal government in one or more of the following phases of reactor economics:

Ownership of fuel by AEC,
Buy-back of unused fuel by AEC,
Credit for plutonium.

Thus there is need for sponsoring the development of advanced reactor systems. The need for this work has been recognized to some extent by the growing emphasis being given to breeder reactor development. But even here the major effort is being directed toward those technologies, for example liquid metal cooling, that have been the focus of attention for some time, and insufficient effort is being made to explore new possibilities. The existence of subsidies for the several types of thermal reactors has until recently acted as a disincentive toward moving ahead in this area.

Should nuclear fuel, as my most optimistic projection of the rate of nuclear development indicates, supply the equivalent of 855 million tons of coal or a little over one-half the total electric energy generated in the year 2000, it will make an important contribution toward satisfying the energy needs of the United States. But if this development is not to be accompanied by increases in cost, and nuclear fuel is to play an important role as a competitive incentive to avoid increases in fossil fuel costs, research to reduce the cost of the nuclear fuel cycle without subsidy must continue to be explored.

Energy Conversion

Increased generating unit and plant size present formidable problems.

One hears a great deal at the present time about 1000 MW units and it has been suggested that we may be coming into an era when individual plants will have a rating of as much as 5000 MW of capacity. Granting the technical and economic validity of the concept of greater and greater unit and plant sizes, there still remains the question of appropriate size limits for both individual units and plants. At $100 per kilowatt, the 1000 MW unit will represent an investment of $100 million and the 5000 MW plant $500 million. This exceeds by far any other kind of industrial complex heretofore assembled in the United States except perhaps the large-scale gaseous diffusion plants for uranium enrichment. Even some of our greatest civil engineering structures run to less than $100 million; the Mackinac Bridge, for example, represents a total cost of only $80 million.

But it now appears almost certain that economics and the absence of a very large number of good power plant sites are likely, in time, to compel consideration of much larger units and plant sizes. Do we know how best to build a 1000 or 1200 MW turbo-alternator? Can we build such turbines on a single shaft? What about alternator sizes and existing limitations due to rotor cooling and current ideas on excitation?

And what about the boiler, which is in fact a thermal–chemical reactor? Do we have even the bare data on heat transfer when handling the fantastically large masses of high-temperature gasses sweeping across corresponding large masses of steel surface?

In such plants, projecting size to levels in many cases double what had been proven previously for a relatively small thermal gain, outage or failure will impose increasingly severe financial penalties as a result of the size jump. This inevitably leads to the conclusion that such developments will have to be made in the context of new standards of reliability if they are to become economically feasible or dependable. Certainly this will involve new research efforts into the whole question of reliability, the causes of unreliability and how reliability and availability can be designed into equipment. This in itself might well be a substantive technology which needs badly to be developed to give us a complete understanding of the causes or nature of outage and unreliability and methods for materially minimizing them.

We hear a great deal these days about conventional steam technology having reached a plateau in conversion efficiency. I cannot accept this assertion. There is an imperative need to improve the efficiency of conversion both from the standpoint of achieving further economies and also from the point of view of conservation of our energy resources, and I for one cannot believe that a new generation of technologists cannot improve upon what has been accomplished by their predecessors. With an annual generation of 6 trillion kWh projected for the end of this century, a reduction of even as little as 100 B.t.u./kWh would mean an annual saving of 24 million tons of coal equivalent in the demands made upon our fuel resources. One thousand British thermal units would increase this saving to 240 million tons of coal equivalent per year. Truly, we cannot view the prospects of such significant savings in our fuel resources without being excited by the challenge it presents.

Unfortunately, up to date the excitement, if actually generated, has not spread and travelled very far. One would expect something vastly different in response from a whole group of interests supposedly responsive to national need and national interest in improving the technology of energy conversion and in conserving finite national energy resources. Surely with what is at stake—a possible saving of 300–350 million tons of bituminous coal equivalent per year by the year 2000—there would be the expectation that all of at least the following agencies—the Bureau of Mines, National Research Council, National Coal Association, the leading boiler manufacturers, the leading turbine manufacturers, Edison Electric Institute—would be crowding on each other's heels in their eagerness to get on with the business of finding answers to the many difficult problems that stand in the way of our moving on to a new plateau in energy conversion.

Sad to relate, that is not what is going on: far from alacrity, we have a dismaying apathy and, except for one small group of utilities co-operating with one of the smaller, research-oriented manufacturers, all the rest are waiting—waiting, in the words of one manufacturer, for the right time.

But efforts to achieve further improvements in conversion efficiency, and to improve the feasibility of larger unit sizes through increases in steam temperatures and pressures, are confronted by the obstacles of inadequacy of materials. Presently available materials are either excessively costly or else cannot meet the operating performance requirements at temperatures and pressures above present maximum levels. Deficiencies in materials also represent a major obstacle to successful development of new departures in generation such as magnetohydrodynamics (MHD) and superpositions of coal-fired gas turbines on a standard steam cycle which also offer promise of improvements in both capital and operating costs. Indeed materials represent a major area for research that pervades the entire spectrum of advanced practice in electric energy conversion from merely higher steam temperatures in coal-fired boilers to nuclear power generation in advanced breeder reactor concepts.

All this has as its objective efficiency and cost reduction to make possible the attainment of the 3.25–3.5 mills/kWh at the generator buses I postulated in my first lecture. Three and a half mills per kilowatt-hour would represent a 0.66 mill reduction per kilowatt-hour, compared with the best that 1964 fossil fuel technology could do with 20 cents per million B.t.u. fuel.* At 3.25 mills, this differential becomes 0.93 mill/kWh. The importance of these cost reductions cannot be overemphasized as dynamic inputs so necessary to maintain growth.

TRANSMISSION

The need for higher transmission voltages where economic generation may be remote from load centers is generally recognized. However, wide geographic distribution of fossil fuel resources and the introduction of nuclear power are likely to make EHV development for simple point-to-point transmission relatively rare. The 345 kV transmission level, now the highest in existence in the United States, but about to be topped by 500 kV, was first introduced into the already well interconnected, densely populated and highly industrialized portion of the United States. The need for EHV in this area was to transmit larger blocks of capacity efficiently, reliably and at lower costs for relatively short distances and to provide increased interchange capability among systems commensurate with generating unit and plant size. Another factor also in this densely settled region was recognition of the need to reduce the number of parallel transmission circuits because of growing congestion and difficulty in the acquisition of rights-of-way.

*The Joint Committee on Atomic Energy, *Nuclear Power Economics—Analysis and Comments*—1964, U.S. Government Printing Office, 1964.

This development of EHV is now in a most dynamic phase: 500 kV transmission is already under construction, again in a densely populated, highly industrialized and relatively short transmission distance area. It is likely that before much more time elapses it will be found desirable in some areas of the country to undertake construction of transmission facilities at the 700–765 kV level, and by the end of the century 1000 kV is a reasonable expectation. But here again the major need will be to develop the ability to move larger quantities of power without commensurate increases in the number of transmission circuits through heavily populated areas. But if this is to be accomplished, there are many technological unknowns that will have to be explored and problems resolved if these higher voltages are to be introduced with maximum efficiency and reliability.

Research on the 700–765 kV transmission level is already under way in the United States, but while still higher voltage transmission is not imminent and pressing for a crash program, it is nevertheless not too soon to begin to consider research into problems of 1000–1100 kV. One of the major difficulties of moving into this higher voltage is the lack of an acceptable system of insulation. It now appears that this voltage level, if the present technology and practice which have served the industry excellently for close to 60 years were extrapolated, would require a string of about ninety insulators. This would be wholly impractical and uneconomical. A major research effort, calling for perhaps a totally new approach to the problem of insulating high-voltage bare conductors, will be necessary if this problem is to be solved.

But even at present voltage levels, numerous difficult problems remain to be solved. While a great deal of work has been done to better understand the phenomenon of galloping conductors and to find a method of eliminating this phenomenon, and there is some indication that we may be well along toward improved understanding and the development of techniques for controlling galloping conductors, an economic method for doing so remains to be demonstrated. Again, while a great deal of knowledge of the effect of lightning on transmission lines has been accumulated, much more remains to be done. Similarly, much more work continues to be required on such problems as relaying and ultrarapid reclosing, sleet protection, communications and control at the higher voltages.

For some time it has been evident that the technology of d.c. high-voltage transmission has been moving along toward fuller development. Although the amount of power and energy transmitted by d.c. means is to date negligibly small, yet definite areas of potential application are indicated. To mention the principal areas: long submarine cable sections or crossings, point-to-point transmission and delivery of large blocks of power over long distances, possible extensive large-capacity underground entrances into, or exits from, heavily settled communities. Except for the first, none of these applications has been made or submitted to the test of experience. The most important application of EHV transmission—the development of extensive grids or networks and complex intersystem and interregional interconnections, raise many technical questions of performance for direct current, some of which are aggravated by the lack of availability of needed devices—a d.c. high-voltage circuit breaker, to mention one.

Thus while the technology of d.c. transmission needs to be developed, its particular mission is still uncertain—whether in lieu of higher EHV alternating current or as a supplement thereto.

DISTRIBUTION

Distribution today represents the largest single area of investment on a utility system. Although the technological changes that have taken place in generation and transmission have in many cases been unique and exciting, the changes that have taken place in distribution have been nowhere near as dramatic, although perhaps in total economic importance they have been equally as great. Yet, looking toward the future, it is to distribution, and particularly to distribution cost reductions, that we must look for solidly establishing the basis for electric energy as the universal or single energy source and as a basis for further reduction in costs to open up completely such areas as home heating and eventually road transportation.

Here it is obvious that a vast field for research lies open for imaginative and skillful cultivation. New conductors, new methods of insulation, new methods of support, including the possibility of completely moving underground, and new methods of switching and protection of the reliability of supply to all loads, are all open to research, development and exploitation as part of a program to reduce costs and improve reliability.

If, as is almost certain, the greater load densities and the greater development of the energy market for electric energy are in great measure dependent on the ability to sustain the dynamic element of lower costs while improving service, it is clear that the problems of electric distribution present an almost unlimited area for research and development.

SYSTEM RESEARCH AND THE AMENITIES

System Research

The six-and-a-half-fold growth in electric power generation over the next three and a half decades will require, indeed will make mandatory, more than a simple six-and-a-half-fold duplication of existing facilities. Apart from the magnitude of the load, limitations on plant sites and rights-of-way, the need to exploit fully the benefits of further integration and co-ordination of power system development will make necessary the exploitation of larger units, larger plants, much higher voltages for energy transportation, higher voltages for distribution and utilization, newer methods and materials for energy distribution, and much greater attention to the amenities.

To begin with, there is need for research in the development of analytical tools and methods to make possible, indeed to assure, optimum overall design of power systems. This includes not only aids to make possible the analysis of equipment performance before and after placing equipment into service, but also system analysis. The increasing size and complexity of power systems in the future, together with the always limited availability of high-quality power system engineers, make it essential that those responsible for system planning, design and operation be armed with the most modern and powerful tools and techniques of analysis. This includes methods of analysis as well as computing devices.

An electric power system is uniquely different in many respects from any other industrial operation, but particularly in the relationship of instantaneous response-linkage between conversion (production) and delivery (utilization). In no other industry is there the universally accepted commitment that exists on a power system to continuously and instantaneously produce, transmit and deliver to the utilization device the product to meet the consumer's demand in accordance with his varying needs, desires and even whims. Thus in no other industry in this country is the over-all "system engineering approach" more logical, but also more imperative, than in the electric power industry. The need for research in this area is fully as great as in the area of equipment, and success in this area will be vital if the challenges of the future are to be met.

The Social Amenities

Pervading all the problems discussed heretofore is a new class of problems that can be seen emerging in what the British have been referring to as the amenities. With growing population and the extension and growth of present communities and the development of new communities, there is likely to develop a growing concern with the effect on air, land and water, and the aesthetic appearance of power plants, transmission lines and distribution lines. This will be given further strong impetus by the changing economic and social patterns of our society. As people have more leisure time and higher levels of income, they will concern themselves more with aesthetic and artistic considerations.

The amenities are likely eventually to have their maximum influence in generation. Obviously, there will be increasing concern about the appearance of power plants and their surroundings. There is already apparent a growing concern about the air and stream pollution effects of generating plants, which is more likely to become intensified rather than alleviated over the next four decades, despite the fact that electric power generating plants may be one of the least important sources of pollution. It is well known that the major source of air pollution in most urban areas is the automobile. Yet it is also a fact that the utility industry now consumes annually well over 200 million tons of coal. By the year 2000, even assuming the most optimistic rate of development of nuclear power, annual coal consumption by the utility industry is likely to reach 600 million tons. This almost threefold increase will bring the question of air pollution increasingly to the fore.

To a considerable extent this problem of air pollution has been overcome at the present time by the combination of efficient precipitation and rising stack heights. But this, too, may have its limits. In some places Federal Aeronautics Administration regulations are already increasing the difficulty of increasing stack heights as a solution. Research to find new ways of removing pollutants from the fuel prior to burning could contribute significantly toward alleviating this problem and could even result in the development of a new source of marketable minerals—sulphur, for example.

And the effect of the rejected heat on stream temperatures in the conventional steam cycle is also likely to become at least a bothersome problem. We are already beginning to see some indication of that in the press reports regarding the opposition to the location of a steam power plant on the St. Croix River in Minnesota on the ground that the plant would result in thermal pollution of the river. A glimmer of hope is the dry air-cooled condenser, but here again a great deal of research is required if this is to become an economic solution.

Higher voltage transmission will help to reduce the number of rights-of-way and transmission lines through highly populated areas, but in many areas not now affected it may become necessary to place transmission underground, and much remains to be done to make possible efficient underground cable transmission at extra-high voltages. This could bring d.c. cables sharply into the picture. But whether EHV, a.c. or d.c., if imposition upon the landscape is to be held to the minimum, it will be necessary to explore and develop new mechanisms and techniques for co-ordinating the transmission requirements of contiguous but separate corporate groups to the highest conceivable degree to assure maximum utilization of every mile of right-of-way. Only then can the utilities face a population, sensitive to the infringement of overhead transmission lines on the landscape and jealous of its proprietary rights, with a request to be permitted to take private property and dedicate it to public service.

It is becoming quite clear that we shall have to develop a series of completely integrated designs of the elements of a power system consisting of fossil fuel or nuclear power plants, transmission lines, substations, subtransmission and distribution lines so designed and built that they are in pragmatic harmony with the landscape; with the forest, fields and valleys; with the farms, homes, and commercial and other institutional structures on the landscape. It will be necessary for parts of the power system to go underground, but a way must be found to apply this selectively and ingeniously so as to avoid any great sacrifice of economics which would jeopardize growth and development. This surely opens up a virgin area for research.

It is becoming equally clear that we shall also have to develop the science and art of so operating our system, including power plants, substations and electric lines of various sorts, that there is a pragmatic ecological harmony between what our system produces and the living environment —vegetable, animal and human—in the vast areas which are traversed by electric power system facilities. This means that such matters as emission of carbon dioxide, sulphur dioxide, particulate matter like ashes or cinders, nuclear radiation, or discharges like ozone which produce chemical reactions—all of these will have to be brought under control. If these problems do not become supercritical by the year 2000, when the United States is likely to have a population close to 300 million people, then these problems are bound to become more critical with each succeeding decade beyond that.

And these problems, too, open up new research areas.

Problem of Manpower

It is no secret that the industry has had for some time a difficult problem in obtaining sufficient manpower of quality adequate for and responsive to the challenges that will be presented by the enormous increase in size and complexity of the future. Over the last decade or two the electric utility industry has had difficulty in capturing the imagination of adequate numbers of highly capable graduates, not only of our engineering schools, but of our law and business schools also. The schools themselves have failed to comprehend fully the challenges and opportunities that await their graduates upon entering the electric power industry. A well-diversified program of research can help to recapture for the industry in many areas the magnetic attraction that will induce the very ablest of the new engineering, business and law school graduates to seek employment in the industry in sufficient numbers to make possible the successful achievement of the great rewarding goals that lie ahead.

The Need of an Authentic Voice in the Field of Power and Energy

Research in power would serve still another function, important to the industry, but much more important to the national interest. It would help bring the industry to a position where it would be able to make a significant contribution toward the solution of national problems affecting the nation's welfare, defense and safety. All too often today, when a national problem such as defense arises, involving difficult questions in power and energy which are of direct interest and concern to the electric power industry, and in which the industry has a high degree of expert knowledge, the government agencies will seek advice on, and solutions to, such problems outside the power industry, and from those who may have little or no comprehension of electric power systems, their design and operation. And even where eventually utility people are brought into the deliberations on such problems, they are not brought in as primary partners, so to speak, and the industry itself, either individually or over-all, does not have a full opportunity to serve and so receives very little credit for its contributions.

A continuing research program of significant magnitude by the electric power industry would help to gain and establish for the industry proper recognition of its capabilities. It would thus provide the country with an authentic voice in the field of electric power and energy and a well-established locus to which those requiring solutions to difficult power problems associated with national needs and responsibilities could, and would, turn for help.

The problems confronting the electric utility industry, if it is to achieve the future I have described, are diverse and difficult. They call for a bold, vigorous and imaginative program of research and development. There is no question of the need for, and benefits from, such a program. However, the question remains, how can such a program be stimulated, decided upon and organized for implementation? In my next and final lecture I shall deal with this question.

III. A Rational Program for the Organization of Research in the American Power Industry

In the two previous lectures I discussed at length one of the principal, if not *the* principal, reasons for research—its indispensability as an element in inventing the future. In addition I described in some detail a number of specific problem areas requiring research if the invention of the electric power industry in the United States for the year 2000 that I projected is to be successfully implemented. I hope that I have been able to impress upon you the vast scope of the research that must be carried out in electric power if the great potential that I believe lies ahead for the industry is to come into being. In this third and final lecture I would like to lay before you and discuss what I believe is a rational program for the organization of research in the American power industry.

This is not the first time that programs of one kind or another have been proposed to meet the power industry's research needs. However, I believe it is the first time that research in electric power has been projected on a series of plans which makes possible examination and focusing in forward-looking depth and breadth of scope on the industry's research needs in every quarter.

Some years ago, I recall the chief executive of the Edison Electric Institute, the principal trade organization of the investor-owned portion of the electric utility industry, in testifying on research in electric power before a congressional body, categorically declaring that the power industry carried out no research, and that this job was being done for it by the electrical equipment manufacturers. And a few years later, in a private conversation, the head of one of our two largest electrical manufacturers made an earnest plea for maintaining what he believed to be the *status quo* in research under which the manufacturers would continue to do all the electric power industry's research. I believe he was somewhat shocked when I told him he was very badly mistaken in thinking that all the industry's research was being, or could be, performed by the manufacturers. Indeed, I pointed out that it was very apparent that such an arrangement could not suffice for the future, and that the electric utilities would have to greatly expand their research activities.

Less than 2 years ago, the chairman of the Federal Power Commission, Mr. Joseph S. Swidler, speaking at the annual convention of EEI in Denver, Colorado, urged the bringing together of a group of

> knowledgeable people representing the private, public and cooperative sectors of the industry, the manufacturers and the research community, to consider how the industry could best serve its own interests and the interests of the nation by stimulating more intensive research effort in areas where such research effort was likely to be rewarding.

Later that year, the chairman met with a representative group of electric power industry executives to discuss the implementation of his Denver proposal. This led to the establishment of a group that came to be known as the *Ad Hoc* Committee on Research and Development in the Electric Power Industry. This committee, which only recently completed its work, consisted of representatives from the investor-owned and government-owned sectors of the electric utility industry, three representatives from the electrical equipment manufacturers, and two representatives, one each, from two of our great institutes of technology.

For almost 2 years I participated as a member of this group in an industry-wide dialogue on, and study of, research, the articulation of a basis for research, and the formulation of an organizational set-up to promote research in electric power on a national scale. However, after having finally reached the delivery stage of the idea that had been in active gestation for almost 2 years, and after examining the fruit of that delivery, I have reluctantly come to the conclusion that in a country as large and diverse as the United States, with its wide variations in regional characteristics—a country where the power industry has had the courage and imagination to project an industry as vast as that projected in the first of these lectures—the whole concept of centralized research is a mistake. More specifically, my conclusions are as follows: (a) the setting up of a joint electric power research and development council to screen, guide and direct research activities for the electric power industry of the United States is an even greater, and potentially tragic, mistake, and (b) the whole idea of one grand centralized headquarters for research would prove to be as ineffectual in its results as the fundamental ideas are faulty in concept.

There are many basic weaknesses in the concept of centralized research for the American power industry. The more general of these are obvious, but some are specific and stem largely from the nature of the industry.

One of the most prominent general objections is that centralized research and centralized selection and control of research projects are basically self-defeating. Such an organizational set-up would, by its inherent nature, strengthen the forces opposed to the desired end-result or research, which is the production of meaningful change. Moreover, even centralization of the selection process alone would have the effect of greatly diminishing the degree to which diversified judgment would otherwise function in the selection of research projects.

A typical example of meaningful research that might well have been ignored by a national, centralized body is the current effort in magnetohydrodynamics (MHD). Whereas several very prominent United States electrical manufacturers and most electric utilities did not, in 1958, believe that the development of this advanced concept for generation of electric energy merited support, a small group of utilities headed by American Electric Power and Avco Corporation undertook a joint research project which, in addition to producing exciting technical results, has succeeded (a) in spurring support by EEI of some MHD work, and (b) in arousing world-wide military and civilian MHD research by the early 1960s. Today, in addition to the Avco–utility-group program in the United States, there are extensive MHD research programs under way in Europe and Asia, including the USSR. However, had the decision of a nationally centralized research body cast the stigma of refusal of support of MHD in 1958, it is doubtful that much work would be under way today.

If we start with the assumption that during the sixfold growth of the power industry which I have projected for the balance of the century many changes will have to be invented, then it is important that we have a clear understanding of why and how change comes about in the first place.

The type of change that results in improvement can be attributed to a number of strong motivating factors, all of which focus on the production of change, and the strongest of which is dissatisfaction with the *status quo*.*

*In this discussion of the inherent flaw in the concept of centralized research, I have benefited from the thinking of Dr. Lloyd P. Smith, a colleague on the Advisory Council of the Cornell College of Engineering. His views are covered particularly well in his address, The Management Problems of a Changing Technological Environment, given at the national convention of the American Psychological Association in Los Angeles on 7 September, 1964.

This sense of dissatisfaction has to be strongly developed as an emotional as well as an intellectual discontent. There are many other stimuli, but the other two principal motivating factors are:

1. The desire to make better use of material and human resources.
2. Recognition of the certainty of the coming competitive obsolescence of established products or established methods.

With each and all of these, it is necessary that there exist:

(a) A talent to create.
(b) A desire to excel.
(c) A fundamental understanding of the technical–economic nature of the industry for which the improvement is sought.*
(d) A fairly strong rate of acceleration in the development of technology in the particular area or field.

Confidence in one's creative talent backed by a desire to excel, fundamental understanding of the industry for which one is inventing, and an accelerating area of technology, provide the ability to create change and to improve the *status quo*. It is necessary to recognize, however, that the number of individuals in any group so motivated is a small minority.

On the other hand, the forces resisting change are pal-

*Here one cannot help but recall the earliest days of atomic power development during which scientists, educators, politicians and journalists, most of whom were lacking a basic knowledge or understanding of the commercial generation, transmission and distribution of electric power, were making very rosy claims for an imminent revolution in electric energy costs as a result of nuclear fission. Today, after 20 years of painstaking carving efforts—evolutionary, not revolutionary—we are out of the woods and well on the road to economic atomic power.

pable and they are normal, the norm being a penchant for the *status quo*. This has two components: (a) an almost universal handicap of heavy mental inertia (the predilection to keep on repeating what has been done before), and (b) a fear of embarking on a course that could lead to failure, with consequent loss of face or even loss of economic status.

Inasmuch as engineering research has as its objective the invention of meaningful change, centralized research is fundamentally self-defeating because it will increase the influence of that preponderant majority which is normally opposed to change. Therefore, one can draw the conclusion, confirmed by a long record of experience, that the more centralized the research operation the less likely it is to produce fundamental change. When this central organization becomes the sole national research agency, the problem of producing change faces the obstacle of so many negative influences that the very idea of change is predestined to early suffocation.

In their growth and development many innovating technical, and technical–economic, ideas have failed for years to be given proper recognition by the larger organizations and by the vast majorities, and only the insistent drive of the smaller, sometimes very small, companies and a few farsighted individuals has helped to bring about the change.

Let me give you some illustrations from the development of some of the great principles of modern power systems which had a rough time gaining acceptance and which almost certainly would have been totally rejected by a centralized or national research council.

1. The grounded versus the isolated high-voltage systems: after the establishment of high voltage, a great debate raged for many years over the relative effectiveness and desirability of a basic or ground point on a high-voltage system, i.e. the problem of whether to operate such a system on

the basis of an isolated or a grounded neutral. By the time I began to take an interest in power, toward the end of the second decade of this century, the matter was still hotly debated. I recall one meeting of AIEE at which the brilliant and famed C. P. Steinmetz arose to categorically declare that this lengthy debate had fortunately come to an end because it was then (this was in 1919) quite evident that the difficult question had been resolved in favor of the isolated delta system. In both respects Dr. Steinmetz could not have been more wrong. The problem had not been settled and it definitely had not been settled in favor of the delta system.

In the subsequent decade I personally participated in the grounding of *scores* of 22, 34.5, 66 and 88 kV systems, all of which, having been built on the isolated delta principle, were operating with far too many interruptions and too many failures of equipment. In every case subsequent grounding produced an enormous improvement in their performance. But it took many years for the largest of engineering organizations, which Steinmetz represented, to support this principle.

2. Another item also relates to grounding of transmission systems: here again, as systems developed over the world, the fear of grounding led to the adoption of all kinds of semi-grounded systems either through resistance or through compensating inductance coils. One of these methods of grounding, bearing the name of a famous German electrician, utilized a coil known as the Peterson coil. This concept gained a great foothold, particularly on the continent of Europe, where solid grounding was relatively unknown even by the end of the third decade of this century. Again the majority opinion was completely wrong, and eventually all those power systems not only yielded to the categorical imperative of solid grounding, but also accepted this as the basis for improved operation.

3. A third example is the improvement in the speed of

circuit breakers and its effect on the performance of transmission systems. This, too, was a much-debated subject, and the idea that speed was a sort of academic luxury, rather than a progress-related necessity, gained solid footing in the industry. This idea was so well accepted that in the late 1930s the Switching and Switchgear Committee of AEIC wrote a report and unanimously asserted its conviction that nothing faster than 8 cycles was needed in the way of the opening of a circuit on a 60-cycle system. Some dozen or more outstanding engineering representatives of the power industry signed this report and presented it at an annual meeting of the Association. I dissented from this view and gave the reasons for my strong conviction that these conclusions were completely invalid. Consequently, these views of the committee—a national committee, in effect—were rejected on the AEP System and by one perceptive manufacturer. Thus it was possible to encourage effectively the development of faster and faster breakers, to the point where on this system 2-cycle breakers at higher voltages are now standard, and the search for a still faster breaker is now going on.

All the advantages of speed of breaker opening, including preclusion of long-duration heavy overcurrents with their consequent destruction of lines and equipment, avoidance of loss of synchronous load, the consequent feasibility of rapid and ultrarapid reclosure, were completely overlooked by a select technical group representing an entire industry. The need for greater speed in both opening and reclosing a circuit has since been recognized by the industry, although there is still a tendency to lag in the effort to push beyond current standards.

4. Many other equally striking illustrations can be cited. For example, the principle of reheat, first successfully utilized by the British in the very early twenties, was developed in this country as early as 1923. Yet, for a period of almost a quarter of a century, the vast majority of the power system

engineers in the country insisted that the economics of reheat were so fragile that no justification for it existed. The manufacturers of turbine, boiler, and heat exchanger equipment were no help; they gave their customers what they wanted. They *knew* what was wanted—and it was not reheat. It was not until the end of World War II, a quarter of a century after it was first developed, and thereafter installed in plant after plant of a very small, almost negligible, number of companies, that the industry and all the manufacturers supplying the industry newly discovered reheat, adopted the idea, and urged its commercial exploitation.

5. The same experience can be cited in detail in regard to the development of larger-sized units operating at higher temperatures and higher pressures as one of the most important routes to improving the thermal efficiency of energy conversion simultaneously with improving its overall economics. The latest chapter of this story involves supercritical pressures and double reheat. It was only as a result of the persistence of a very small minority that supercritical pressure has now been accepted as an industry standard. And it was an equally small minority that led the manufacturers to re-examine their studies and conclusions on variation of costs with unit size and recognize that substantially lower costs were possible with increasing size.

6. In utilization a similar sad but instructive story can be told about the heat pump and its contribution to opening up the market for electric heat. The heat pump, a technically beautiful device aimed at providing year-round human comfort through climate control, has had to wait an unbelievable period of more than 30 years before our utilities took enough interest in it and manufacturers really dug in and developed, at least for domestic use, a machine that could perform well and with high reliability—a machine that would be a credit to them as engineering manufacturers and to the industry which sponsored it as a means of providing

a unique level of year-round human comfort, not to mention its potential as the "open sesame" to new markets. For many years a large section of both the manufacturing and the utility industry continued in the belief that the heat pump was a sort of glorified perpetual motion scheme and, since they could not possibly have been so ignorant of thermodynamics as to really believe that, one can only ascribe it to the mental inertia I discussed earlier.

We therefore come to the inescapable conclusion that leaving the welfare of a great industry to some kind of consortium or grand committee, organized on whatever basis one may choose, simply cannot provide the mechanism for sensing areas of research, reaching decisions regarding the need for researching in those areas, and carrying out measures for implementing research programs. The United States is too vast, too diversified in its economy and too regionalized to make fruitful a single center for research or to make of such a center anything but a device for discouraging progress.

In generation research, where the availability of local fuels, that is, fuels endemic to a given region, is bound to play a significant part; in transmission, where local geography and topography are bound to play critical roles in design, construction and operation; and in distribution, with local topographical, meteorological and sociological considerations playing a significant role both in the basic designs adopted and in the materials selected and in their performance under local weather conditions and quirks; in all of these, regional thinking is necessary. In marketing, the basic economic development and major sources of income have important regional characteristics. Climate has an important marketing influence and it is regionally variable. Desert coolers? Why not? But in Arizona, not in New Hampshire or Maine. Defrosting problems on heat pumps? Very important in Vermont and Massachusetts, but not in southern California or Florida.

Even in considering manpower, the kind of industry predominant in the region and the prevailing educational facilities will have a great deal to do with the skills and characteristics of the people that a power system can find in its direct and indirect operations.

In all the above areas, while certain basic industry phenomena and thinking are common denominators, the most fruitful research and development will be that which is adaptive to the local scene and the local conditions.

The clinching argument for regionalization of research is that it provides an opportunity for diversity of thought and greater exercise of company individuality and responsibility in the conduct and control of research. As I pointed out earlier, the record of the past is not an encouraging indication of the universal acceptance of the need for research. A good many people have for years held the attitude that pioneering was for those who did not have any good sense, and that the really solid citizens, the smart people, let others pioneer while they themselves trailed behind 5 or 10 years and picked up an already developed, tested and proven technology.

I believe that development and acceptance of the regional research idea will discourage the "let George do it" type of thinking. People who have known each other as corporate neighbors and regional cohabitants have participated and will continue the relatively recently developed trend of participating and co-operating in many regional activities. They will, I am sure, continue to find it quite natural to bring themselves together to meet a research need, with everyone —or substantially everyone—willing to participate and lend support to a regional rather than a nationally centralized effort. People with common operational, regulatory and economic problems can, in my judgment, mount a great effort in productive research for the future—an effort that I believe is an indispensable element for the vigorous and sustained growth and development of the industry.

Although I am thoroughly convinced of the soundness of the concept of regional research for the United States electric power industry, I recognize that in certain infrequent situations rigid adherence to the idea of regionalization of research may represent in itself an intolerable inflexibility of thought. Urban power systems may on occasion have some unique common problems that transcend strictly regional considerations, as might systems serving basically rural areas. Occasionally, very large or very small power systems will encounter some unique needs for which company size is a more readily identifiable common denominator than is the general service region or area. And so, with an understanding of its limitations as well as its usefulness, the concept of a relatively small *ad hoc* grouping of companies from within the electric power industry to fulfill a need for specific research should be considered as a valuable occasional adjunct to regionalization.

While I have been critical of many aspects of research as it has been carried out in the past by both the utility and the manufacturing segments of the electric power industry, I cannot find much fault with the great record established by the industry in the field of nuclear energy. And it is especially interesting to note that this record has been built largely on the regional and *ad hoc* concepts of organizing electric power research. Moreover, these approaches were adopted only after the industry, in a meeting of its principal executives, had considered seriously, and rejected, a plea for complete centralization of the industry's nuclear research effort along one line of reactor development and in support of one reactor concept. The basis for this rejection was the conviction that making the industry's nuclear future dependent on this one, narrow centralized effort represented too great a risk. It was not until that point of view was almost completely accepted that the regional idea began to take root and grow. With the aid of a few outstanding *ad hoc* ventures, the regional concept has provided the organizational basis for a great performance by the industry in the difficult area of nuclear research, where the forces of the power industry, the manufacturers and the government all came together in a highly effective, mutually complementary role. With the exception of the fact that by and large the universities and technical centers of education in power were unimaginatively left out of most of the development activities in commercial nuclear energy, this activity has been so striking an example of the type of progress that can be achieved by regionally oriented groupings that a further discussion of just what took place may be of value.

In any discussion of the development of nuclear energy the Dresden and Yankee nuclear power projects deserve prime attention for their very significant milestone contributions. Dresden, the first privately financed nuclear electric generation station, was made possible not by a centralized research agency, but by an *ad hoc* group comprising seven investor-owned utilities and a leading architect-engineering and construction organization. This group, formally known as the Nuclear Power Group Inc., underwrote and participated in a $15 million research and development program that led one of its members to construct the 180 MWe* boiling water reactor plant at Dresden, Illinois. The Dresden project not only demonstrated to the nation that the electric power industry was prepared to take a major hand in the development of nuclear energy, but it also clearly established the value of the small *ad hoc* group dedicated to electric power research.

Approximately contemporaneously with the Dresden project, another, but very much larger, *ad hoc* group of forty

*Now 200 MWe (net).

companies, including utilities and manufacturers, known as the Atomic Power Development Associates Inc., was engaged in the design and construction of the Enrico Fermi sodium-cooled fast reactor plant near Detroit. Although the attempt to make a very great extrapolation of almost nonexistent sodium breeder technology has plagued the Fermi project with a diverse number of technical and regulatory problems, the size of the sponsoring partnership itself created problems. Thus the chairman of the board of one of the larger sponsoring companies of the Fermi R and D work told me that the multitudinous sponsorship made it impossible for him to follow just what was happening, let alone exert any beneficial influence. I would venture a guess that the fifty-three-member group called the High Temperature Reactor Development Associates, which has contributed almost 40% of the cost of the nearly completed 40 MWe Peach Bottom gas-cooled reactor plant, has also been hindered by its unwieldy size. Both APDA and HTRDA are big enough to encounter some of the inherent flaws of centralization rather than to reap undilutedly the benefits of limited *ad hoc* groups.

Although the contributions to nuclear energy of *ad hoc* power industry research groups have been impressive, they are no more so than the progress effected through the efforts of many of the thirteen regional research groups, each of which is dedicated to researching those ideas which promise specific advantages for its region. In New England, where the delivered cost of fossil fuels is relatively high because of transportation, the Yankee Atomic Electric Company, comprising eleven neighboring investor-owned utilities, built the 150 MWe* pressurized water reactor driven Yankee Atomic Power Station which ranks with Dresden as a milestone in the development of nuclear energy.

*Now 175 MWe (net).

Thus the regional groups and some individual utilities, in those areas where relatively high delivered fossil fuel costs indicated the most attractive early market for nuclear energy, were constructing or considering construction of nuclear plants. At the same time there were other regional groups which, by virtue of a much more favorable delivered fossil fuel cost situation, were looking at more advanced reactor concepts. These concepts were far less developed than boiling or pressurized water systems, but had intrinsic promise for the kind of significant improvement in final energy cost needed to be competitive in areas of relatively low fossil fuel costs. Among the groups in this category are:

1. The East Central Nuclear Group, which comprises fourteen investor-owned electric utilities serving the coal-rich Ohio Valley and contiguous areas, has devoted seven years and almost $5 million to researching (a) alone, (b) with the government, and (c) jointly with a reactor manufacturer, a total of five advanced reactor concepts, any of which, if successfully developed, might have led to nuclear energy costs that could be attractive almost anywhere in the United States. Achievement of the ultimate goals of ECNG has not been possible as yet, not only because of the level of the competing fossil fuel cost, but also because rapid progress in conventional technology has continued to present a moving target that seems always to keep its distance beyond the pursuing atom. Among the most significant of ECNG contributions are a better understanding of the technical–economic limits of heavy-water reactors, a timely 1962 appraisal of the likely economic effects of then-pending legislation to permit private rather than mandatory government ownership of nuclear fuel, and the preliminary evaluation of the feasibility of employing supercritical steam as a breeder reactor coolant.

2. The seven-member Empire State Atomic Develop-

ment Associates Inc. (ESADA), which has spent $15 million on nuclear energy development projects, current among which are efforts on nuclear superheat reactors, high-temperature gas-cooled reactors, and research support for the first privately owned reprocessing plant for nuclear fuel.

3. The four-member Carolinas–Virginia Nuclear Power Associates Inc., which built a $34 million, 17 MWe pressurized heavy-water reactor plant.

4. The ten-member (North) Central Utilities Atomic Power Associates, which provided $4 million R and D support to the 40 MWe Pathfinder superheat reactor.

5. The fifteen-member Southwest Atomic Energy Associates, who are providing $6 million R and D support for the SEFOR fast sodium breeder experimental reactor.

6. Other groups, representing several other regions.

The diversity and success of the effort in nuclear research, carried out largely at the regional level, dramatically affirms the wisdom of the industry's rejection of centralized effort. It should serve as a valuable lesson for the future.

The three groups with a big stake in research in power are the utilities, including both the investor-owned and the government-owned segments, the manufacturers and the engineering schools. A fourth group with an interest, particularly in the underlying areas of basic science research, and in some technological areas in the early stages of a new technology, is the federal government. But except for nuclear power, the federal government's interest in electric power technology has heretofore been minimal.

For many years the utilities did not provide sufficiently vigorous leadership, and the manufacturers did what they thought was needed. If this arrangement served reasonably well for a long time, it has been evident for some time that it is totally inadequate for the years ahead.

The universities had maintained ties with electric power for many years mainly through faculty contacts with the larger electrical manufacturing organizations. But about 20 years ago the universities embarked on what I believe has been the unfortunate trend of staffing their engineering faculties with scientifically trained, rather than engineering-oriented, people. As a consequence, for the most part today all too many engineering school faculties are staffed by people trained almost wholly in the sciences and having little or no understanding of engineering and engineers and of the need and opportunities for young engineers in the heavy-engineering industries, particularly in electric power. This state of affairs has proven unsatisfactory, both from the standpoint of the engineering schools and their graduates, and from the standpoint of meeting the needs of our society. There are many exciting areas in power technology that remain almost completely unexplored or inadequately explored, and this condition exists in the face of the fact that electric power continues to become an increasingly important element in our society with each passing year. These three vitally concerned groups—the electric utilities themselves, the electric manufacturers and our schools of engineering—simply cannot permit the continuance of this condition if they are to meet their responsibilities to our society in the succeeding decades.

Let us examine the reasons why research is so important to each of these three groups.

To start with the utilities: accepting the postulate that research is indispensable in order to clear the way for the sixfold growth we have discussed, it is obvious that the utilities, unless they lose all sense of responsibility to themselves, to their investors and indeed to the country in which they represent the largest capital-intensive industry, simply cannot sit by idly leaving the job to others. They cannot allow some other group, which does not share all or most of the utilities' interest, needs or responsibilities, or does not assume a substantial portion of the financial burden, to determine what research is most urgently required and most indispensable to the long-range welfare of the utilities. Research not only affects the utilities' ability to do their job efficiently and effectively, but it is an important element in their ability to maintain the confidence of their customers, the people living and working in their service areas, the regulatory bodies at state and national levels, their representatives in Congress and the state legislatures, their investors and the confidence of the people of the United States as a whole. If an excellent record of invention, improvement and discontent with the *status quo* cannot be established and maintained, it is unlikely that any future generation will give the utility industry that vote of confidence which represents the most solid type of foundation for industrial health and growth.

As for the manufacturers: research must be a way of life for them. It is the only way they develop the confidence indispensable to bring out new products and improve existing products or services, confidence in doing a better job of applying new principles, new materials or in developing new processes in which more efficient manufacturing performance is attained and costs and prices per kilowatt and per kilowatt-hour are reduced. As a result of research the manufacturer finds himself with a more solid foundation for his operations, including an improved competitive position with better and more consistent profits, a better image in his communities—local, state and national—and better financial performance for the owners of his business. The manufacturers must believe in this and act accordingly as a matter of principle. If they do not, barring some complete miscarriage of the economic regulatory process which might reward inactivity and standpatism, the manufacturer who has not been carrying on research is simply doomed to failure.

But with the electric industry's future so bright, with the horizons so unlimited, no manufacturer already having people of quality can afford to limit his future horizons—to persist in maintaining things as they are. He needs to plan a continuing program of research to achieve developments and improvements that will simply pale into insignificance his previous technological performance.

This is so obviously sound a policy that it is difficult to understand the skeptical questioning of its validity for the future. Some manufacturers, however, have now taken the position that, because of the decline in electrical equipment prices in response to competitive market conditions, the future of research in their operations has been severely jeopardized. Higher prices are necessary, they contend, to compensate the manufacturer for his research expenditures, if research is to be continued.

This view has completely misconstrued the function of research and its relationship to the manufacturer's market position. Research is undertaken as a means of strengthening the manufacturer's market position, and to raise profitability over what it otherwise would be. Lack of research, or inadequate research, poses the danger of loss of vitality, market standing and, ultimately, loss of earning power. It is recognition of this vital role of research that should lead the electrical equipment manufacturers to embrace research as an integral part of their way of life that can be ignored only at their very great peril.

And the engineering schools, which have for so long been beguiled by the excitement of electronics, space developments, integrated circuitry, solid state physics and the like, simply have to find their bearings and recognize that, as exciting and important as these new developments are, the fundamentals of energy and the mastery of new forms of energy, and of new ideas and concepts in energy conversion, transmission and distribution, are too important to our society, current and future, not to be given adequate representation in the composition of faculty, curricula and campus-based research programs. Further, all these developments are so fabulously exciting, it is inconceivable that any modern school of engineering can be considered to be truly modern and doing its job unless it finds a way of solidly training people who can contribute to progress in all these areas without which the world of the future can hardly be visualized.

Thus the conclusions of our engineering schools that there is nothing new in energy or power—conclusions which caused them to stop bringing to their ranks engineering people who would be attracted by the challenge and excitement of new ideas and concepts in energy, energy conversion and energy utilization, will be reversed. We then shall be able to alter the cycle by getting engineers of quality into teaching positions where they can kindle the fires of interest among talented students. Only in this way can the field of power avoid losing the contributions that many great young minds might make to it. And we shall also be able to alter the unfortunate conditions under which many of these great young minds were not afforded the opportunity to find their creative careers in the field of power and energy.

These considerations, it seems to me, lead directly to the conclusion that the subject of research in power is so important to these three vital segments of our society that it cannot be put into the hands of any one group. Rather, all these groups must play their roles in it and in many ramified and interwoven relationships.

There are actually at least seven different kinds of cooperative arrangements in every region that in the long run can and must be developed in order to do a proper job in research in electric power. These are:

1. Joint work by one utility or a small group of utilities and the utility industry as a whole. By this I mean that the research would be carried out, sparked and directed in every

way by one utility or a small group, but that financial support for the projects would be contributed by the entire utility industry.

2. A research program between a utility or a small group of utilities and a manufacturer, or less preferably even two manufacturers, in which both the manufacturer and the utility would share the direction and cost of the research.

3. An arrangement between a utility or a small group of utilities and a governmental agency such as the Atomic Energy Commission, the Department of the Interior, the Office of Saline Water, etc. In this case I would hope that in general the utility would provide direction for the research with the approval of the governmental agency, and with both sharing the costs.

4. An arrangement between a manufacturer or a small group of manufacturers and the government or governmental agencies, such as AEC, Bureau of Mines, Office of Saline Water, etc. Here again I would hope research could be carried out under arrangements similar to those I described in paragraph 3 with respect to joint utility–government research programs.

There are three more areas, but these involve the universities and engineering colleges:

5. An arrangement between a utility or a small group of utilities and a college or a group of colleges in which the utility would provide the general direction and financing of the research to be carried out by the college.

6. An arrangement between a manufacturer or a small group of manufacturers and one or more colleges similar to that between a utility and a college.

7. An arrangement between the government or a governmental agency and a college or colleges. Here again the college would actually carry out the research under the general guidance and financing by the governmental agency.

Each of the first four of these has had a number of exemplifications in the past, but has never, to my knowledge, been clearly recognized as representing a single band in a wide spectrum of potentially fruitful arrangements. There have been a number of very successful co-operative agreements for research between utilities and a manufacturer or manufacturers and there have been quite a few examples, particularly in the field of atomic power, of co-operative research arrangements between utilities and government. Of course, there also have been many cases of research operations involving the manufacturers and the government.

In the case of the utilities the number of operations involving a utility or a small group of utilities and a college or colleges has been rather small. Nevertheless, there have been some outstanding examples. Here again the problem is not whether it is possible to carry out such a program, but rather the problem involves the question of organizing on a solid continuous basis so that every year there would be either a new area of research suitable for their undertaking, or continuing work on existing projects. In other words, work should be committed to them well in advance, so that there would be a continuous flow of research funds and support.

The development of a challenging program of research in electric power will require dynamic and imaginative leadership of the electric power industry. It will also require courageous and understanding financial leadership and support.

On the manufacturers' side it is difficult to imagine any real need for concern. The background for research in electric power is well established. I hope and want to believe that the manufacturers will find their way back to the road of solid progress by way of research.

As for the utility industry: at the present time it has annual revenues of almost $12 billion. If it were to undertake the financing of research programs to the extent of

½% of its revenues, and if 75% of the industry participated on such a comprehensive basis in one form or another, there would currently be available support for a program running close to $50 million per year. But as I indicated in my first lecture, by the year 2000 revenues will have grown to almost $60 billion, or enough to support a research program involving annual expenditures of $225 million. This would indeed represent an exciting research program.

I am confident that if the industry does not permit itself to be placed in the strait-jacket of centralized control and direction of its research it will be able, working together with its manufacturing and academic allies, to rise to the research challenges that lie ahead to achieve the great future being visualized—being invented for it.