Managing Electrotechnology Innovation in the USA

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FOREWORD

In 1982, the International Institute for Applied Systems Analysis initiated an Innovation Management Task that brought together many leading managers from the electrotechnology industry as well as researchers and policy makers. This endeavor resulted in several meetings with the active participation and support of representatives from industry from both East and West. The first of these meetings, of which Electrosila was one of the supporting organizations, took place in Leningrad in May 1982. This meeting also identified the focus of those future activities that were esteemed to be of predominant importance for managers in the electrotechnology industry. These included the strategic development of a company, and the human and organizational factors in managing innovation.

In his paper, Professor Thomas H. Lee presents an overview of innovation management in the United States electrotechnology industry from an historical perspective. He touches on all three factors that were recommended at the Leningrad meeting and describes them from the point of view of his many years of first-hand experience and direct involvement. Further, he describes the role of the user in as much as it significantly effects the technical development of the industry.

The paper describes in clear, concise scientific terms the interaction of new technologies and the economy of industrial performance as well as national policy and its impact on the overall development.

This paper will be of interest not only to policy researchers, but also to managers from industry and decision makers in government. It is also a welcome sign to all former participants in the innovation management meetings that IIASA strongly supports this activity.

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I. INTRODUCTION

The electric power industry in the USA is slightly more than 100 years old. The first power station, Pearl Street in New York City, was built by Thomas Edison and began operation in 1882. Since then, the generating capacity in the USA has grown to over 600,000 megawatts, linked by transmission networks that spread over the continental part of the nation. For many years, the US electric power industry was one of the world leaders in developing large and efficient power plants, reliable transmission systems, and sophisticated power system operations. In this brief paper, we do not attempt to review all the innovations and how they were managed; but rather we highlight some of the important lessons learned by us in our active involvement in the management of innovation for the electric power industry in the USA. We also try to compare the lessons we learned with some recent research on the process of innovation.

In the USA, the management of innovation (the translation of ideas unto useful products or processes) in the electrical industry can be characterized by three different regimes. In an historical sense, these regimes overlap. The first regime is the traditional development of new products and processes by the vendors of electrical equipment in response to market forces. This regime was predominant from the beginnings of electric power until about 1970 and continues today, but at a reduced level.

The second regime was that of federal support for the development of technologies of value to the electrical industry, although federal objectives were not necessarily in support of that industry. This regime began with the advent of World War II and the development of two technologies - nuclear power and radar - to assist the war effort. After World War II, federal support continued, particularly for the development of nuclear power. In addition, other electric generation technologies began to receive federal support. In the 1950s, the government supported the development of gas turbines for aircraft, which led to the introduction in 1961 of gas turbine electric generation plants. In the 1960s, it also supported the development of fuel cells and photovoltaics for the space program, and, from the early 1970s, it provided support for other technologies - solar, thermal, wind, geothermal, electrical systems, batteries, coal gasification and liquefaction, fluidized-bed combustion, and conservation.

The third regime is that of direct support by the utilities for R&D. Historically, individual electric utilities had supported R&D by the manufacturers by guaranteeing to purchase the products of successful R&D programs. In 1965, the utilities began a modest voluntary collective effort to support specific projects under the Electric Research Council (ERC). This support was greatly broadened in 1972 with the creation of the Electric Power Research Institute (EPRI). This regime continues today as a significant part of the R&D process of electric power generation and utilization.

The support of R&D by the vendors, the government, and the utilities was greatly influenced by changes in the social and economic environment which occurred in the 1970s. The cost of electric power, which had been declining since the turn of the century, began to rise (Figure 1); and state public utility commissions began to scrutinize utility finances more carefully. New regulatory agencies were established - the Environmental Protection Agency (EPA) in 1970 and the Nuclear Regulatory Commission (NRC) in 1974. Congress passed the National Environmental Policy Act (NEPA) in late 1969, which required Environmental Impact Statements (EIS) for all federally-licensed projects. Procedures were established for review and approval of projects, which allowed consumer and special-interest groups to participate in the proceedings. As is described later, these, and many other changes, resulted in shifts in the emphasis of R&D planning and in the climate for innovation.

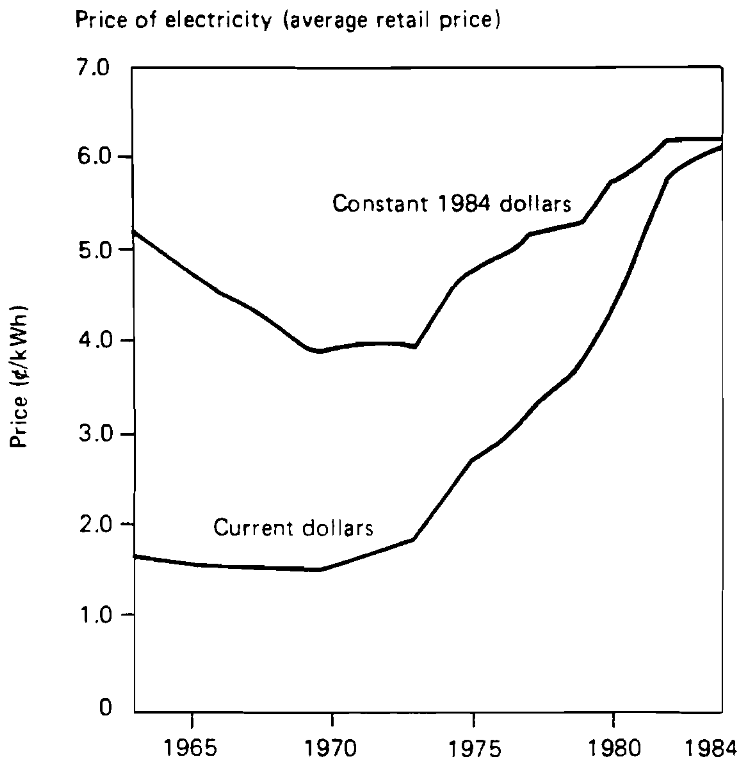


Figure 1 (Source: Electricity Outlook: Foundation for EPRI R&D Planning, Report 4391SR, Electric Power Research Institute, Palo Alto, CA)

II. CHARACTERISTICS OF THE INDUSTRY

To understand the innovative process in the US power industry, we must begin with an examination of the historical development of the industry - the social, economic, and political environment within which the industry operates.

The electric power industry was created by Thomas Edison, who also owned manufacturing operations. There was also an early intimate relationship between the utilities and manufacturing companies, who owned significant fractions of the equities of the former. The motivation for the manufacturers to innovate was thus very strong. Although legal considerations finally led to the break-up of this initial relationship, and eventually to a much larger user (utility) sector, it was responsible for the heavy dependence of the users on the manufacturers to do the R&D necessary for most of the 100-year history of the industry.

The electric power business is different from many other businesses in the USA. While it operates in a market economy, like other businesses, it also faces a unique regulatory environment. In the market economy, electric power must compete against other energy sources; for example, against natural gas and oil for space and water heating, cooking, and transportation. The electric utilities must compete against generation facilities owned by industrial enterprises. At the same time, the utilities must satisfy the regulatory agencies, whose interests focus mainly on the protection of the consumers, instead of the stockholders who own the utility companies. This latter force has two important effects: first, it forces the utility companies to provide reliable power supplies and, second, it forces the utility to keep the price of electricity down. The combination of market forces and regulatory pressure had a profound influence on the "users´ needs" that drive the innovative process. Emphasis on economy of scale, energy conversion efficiency, and higher transmission voltages are all consequences of this combination.

The regulatory environment also had a great deal of influence on the attitudes of electric power companies toward R&D. If R&D expenses are borne directly by the utilities, they are a part of the utilities´ operating expenses and are thus reflected in the rates charged for electricity. Such R&D expenses are, of course, scrutinized by the state regulators. If the manufacturers pay R&D expenses and recover them in the price of the equipment, there is less need for the utilities to defend them to the regulators. To provide the manufacturers with incentive for advanced product development, the leading utilities, such as American Electric Power, would guarantee the purchase of a number of units once the new product has been tested to the satisfaction of the user. The user, in addition, would also offer its system for testing.

So, the dependence on manufacturers for R&D continued until the late 1960s, when significant social changes began to appear. Within the industry, the enforcement of the anti-trust law against price fixing brought more competitive pressure on the manufacturers (even though there were doubts as to whether the price-fixing conspiracy really worked). At the same time, foreign competition intensified. Suppliers in foreign countries sometimes enjoyed government subsidies for the development of state-of-the-art products and were able to offer prices to US utilities lower than those offered by US manufacturers. Complaints and antidumping suits did not produce any favorable results. This further weakened the tight link between manufacturers and utility companies. Manufacturers became more conscious of the cost-benefit relationship in R&D expenditures. Utilities became less willing to offer purchasing commitments to stimulate R&D in US manufacturing firms.

In analyzing cost-benefit relationships of R&D projects more critically, manufacturers discovered that certain projects were of interest principally to utility companies. For example, the knowledge required for the physical construction of high voltage transmission lines was important to the utilities, but was of little use to the manufacturers of high voltage equipment. In addition, the relative merits of high voltage a.c. transmission versus high voltage d.c. transmission were important to the utilities, but were not critical to the manufacturers, particularly because the results of this type of research, when carried out by the utilities, were made public and were available to all competing manufacturers. As a result, a number of R&D needs evolved that required the utilities themselves to undertake some R&D.

Other issues, not related to electrical equipment R&D, but important to the public interest, also appeared at about the same time. These were the environmental and public health and safety aspects of electric power production and transmission. Support for R&D on this issues became the responsibilities of either the utilities or federal government. Therefore, in an evolutionary way, the electric utilities undertook a collective R&D program, first through the Edison Electric Institute (an industry association for private utility companies), then through the ERC (a cooperative effort between private and public utility companies), and, finally, through an industry-wide research institute - EPRI, which was organized in 1973. After that, innovation management in the US electric power industry underwent a significant change. In this paper, we try to cover the lessons both before the formation of EPRI and the years hence. It, therefore, is useful to keep in mind the very important changes in the circumstances under which innovations were introduced.

III. THE USERS´ ROLE

A number of researchers on technology innovation have pointed out the importance of users in the process. Von Hippel [1] stated:

- Approximately three out of four commercially successful industrial good innovation projects are initiated in response to a perception of user need.

- o Accurate understanding of user need is the factor which discriminates most strongly between commercially successful industrial good innovation projects and those which fail [2].

He further suggested [3] that lead users are an important source of novel product concepts and that appropriatability of innovation benefit can be a predictor of the source of innovation. It is of interest to examine experiences in the utility industry (which did not do R&D on its own for many years) in light of these conclusions.

We illustrate the importance of understanding users´ needs with three examples.

Example 1 - Steam Turbine Generators

The utilities´ need to reduce the cost of electricity was the driving force to improve conversion efficiency (Figure 2), and to rely on economy of scale (Figure 3) afforded by building larger plants.

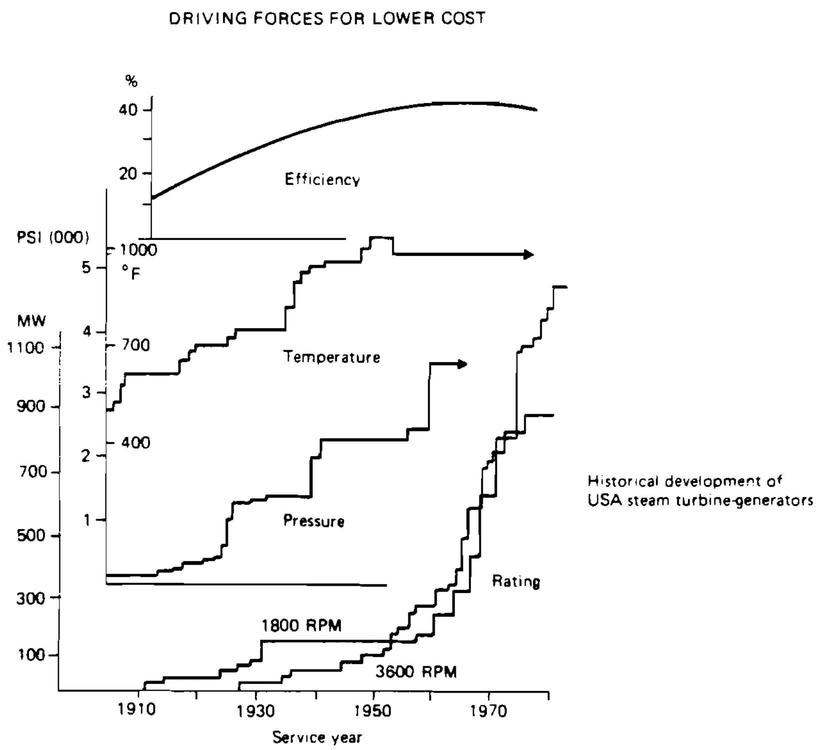


Figure 2: Historical Background of USA Steam Turbine Generators

LARGEST US TURBINE/GENERATOR ORDERED

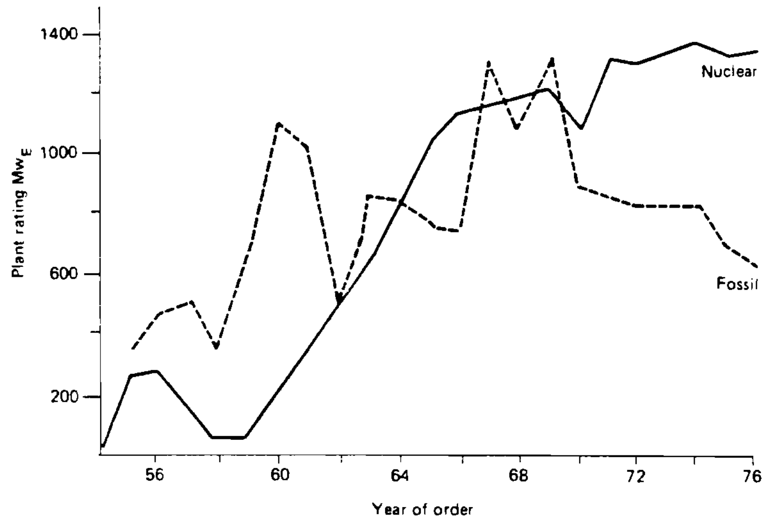


Figure 3

There were two dominant suppliers of turbine generators in the USA: General Electric (GE) and Westinghouse. These major competitors marched neck-and-neck in the race for higher efficiency and larger size. In the process, they followed two different strategies. GE put more emphasis on reliability leadership, while Westinghouse on cost leadership. In adopting the reliability leadership strategy, a number of programs were put in place by GE, such as:

- An internal policy not to increase size by more than 20% over the largest unit.
- A field program to document the performance, failure rates, and failure effects in the customer´s plants.
- Reliability engineers assigned to the field.
- Heavy investment in materials R&D.
- Analysis and promotion of the economic value of reliability.

One sales brochure pointed out that "if the availability of a competitor´s turbine is lower by a few percent, the customer cannot afford to have that turbine for free".

The other competitor, Westinghouse, invested in new and cost-reduced designs; and was, in general, more aggressive in larger size units and claimed leadership in efficiency.

One interesting feature in the turbine generator market was that the utilities did evaluate reliability and efficiency in the decision-making process; but they would not actually pay for the claimed leadership, since both properties are difficult to measure and are not guaranteed by the manufacturers. But in the long run, the outcome was clear. The competitor with the reliability strategy won, as reflected by the two-thirds market share it enjoyed over an extended period of time.

The point is that reliability is more important to the user than initial cost, because the price of the turbine generator is only about 10% of the total cost of the plant. A forced outage is a costly nuisance. Even though the users would not pay a significant premium, they rewarded the reliability supplier in market share.

Example 2 - Circuit Breakers for 500 kV Systems

For transmission systems at voltages of 345 kV and below, lightning was always the most difficult duty for insulation design, i.e., if insulation systems can handle lightning strokes, they can handle satisfactorily other types of surges in the system. For 500 kV systems it was found that this criterion does not hold. Power surges, caused when circuit breakers are closed onto a line with trapped charges, represent a more difficult duty than lightning. It was also found that the magnitude of these switching surges is a statistical phenomenon, influenced by a number of factors, such as the point in the voltage wave at which the breakers close and the difference in timing between the closing of the three phases in a three-phase breaker. Thus, statistical criteria are needed for the design of the mechanical operators of the breaker. Two slightly different criteria were chosen by the competitors. One chose a very low probability (less than 1%) of having a surge voltage more than twice the normal, while the other chose a surge voltage 10-15% higher for the same probability. The consequences of the different criteria were that the more stringent criterion was more costly, but the probability of line flashovers on closing was much lower. The manufacturer using this criterion was not able to obtain, however, either a premium price or a higher market share and, eventually, it went out of the business.

Why? Reliability in this case was not as important. If a line flashes over on breaker closing, the breaker will open and, after a given elapsed time (less than a second), it will attempt to close again. Since switching surge is a statistical phenomenon, it is very likely that the second attempt would be successful. Therefore, damage due to the flashover is rather insignificant and the user is not prepared to pay for the added reliability.

Example 3 - Speed of Circuit Breakers

The development of high-speed circuit breakers is a good example of innovation by a lead user. Philip Sporn [4], one of the outstanding leaders in the American utility industry, in commenting on the need for improvement in the speed of circuit breakers and its effect on the performance of transmission systems, noted:

> 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 (Association of Edison Illuminating

Companies) 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 (American Electric Power) 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 over-currents 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.

These examples clearly show that the conclusion drawn by von Hippel for instruments are also applicable to the electric power industry.

IV. HUMAN RESOURCE MANAGEMENT

To improve the coupling between manufacturers and users, many human resource management programs have been developed. We briefly review a few of them here to indicate the importance of this activity. All the examples here were the programs of GE.

For many years, GE offered a power system engineering program to engineers in utility companies. The candidates came to Schenectady, NY, for one year, during which they were taught power systems courses comparable to a master's program, and had many opportunities to interact with GE personnel and visit GE plants and laboratories. At the end, in addition to gaining a good graduate education, the candidates developed personal acquaintances which became the foundation for future interaction.

For a few years, the management in GE's transmission division in Philadelphia and the Bonneville Power Administration, a government-owned utility company, had an exchange program. Each would send one engineer every year to the other organization to work for a week. Although this program did not last very long because of management changes, feedback today indicates that it usefully increased technical dialogue.

Perhaps the most interesting program was the old, now non-existent, test program in GE. In the 1940s and 1950s, GE hired about 600 graduates from engineering schools. They were all assigned to a test program for about a year, during which they were given four 3-month assignments to test the equipment produced in the factory. On completion, they were interviewed for permanent jobs in the company. On average, there were only 300 openings, so half of the 600 usually left the company, but they had become quite familiar with some of the GE products. A significant fraction joined utility companies. Again, that one year laid a good foundation for future interaction.

V. SYSTEMS ANALYSIS AND CONTINGENCY PLANNING

There are times when a technology is developed or applied commercially, but not because of user needs or technology push. There are other factors to be considered, such as the application of systems analysis and contingency planning. Gas turbine technology is such an example. In light of the importance of this technology in the electric power industry, we review here the historical events.

The initial development of gas turbines was started by technology push. With the development of jet engines, there came the possibility of developing an energy conversion system which was efficient, lower in cost, and flexible in its use of different kinds of fuels. But the initial development was rather tough going. After many difficult years of R&D activities, commercial gas turbines finally became available. But the conservative attitude of the utility industry made it difficult to promote the idea that for peak loads, gas turbines were a very attractive choice. The person in charge of the gas turbine business in the leading manufacturing firm had to adopt a strategy to offer the machine from the shelf. If a utility company discovered that it forecasted its peak load lower than actual, in less than two weeks it could obtain a gas turbine generator to fill the gap. In other words, many of the initial installations were made to take care of mistakes in forecasting. On a much larger scale, the surge in gas turbine orders after the 1965 northeast blackout occurred for the same reason.

In the late 1960s, GE felt that there was a need to better plan generation additions. An effort was launched to develop a computer program to optimize the total cost for utility companies over an extended period of time, e.g., 20 years. This was the first of this kind, though subsequently several new programs were introduced to improve GE's Optimized Generation Planning (OGP) program. It was a major undertaking. The program had a data base of all major generating facilities in the USA and their operating characteristics. It logged weather data and load profiles in different regions. The output of this program invariably indicated that wider acceptance of gas turbines for peak loads would offer significant savings to the utility companies. Prior to that, it was inconceivable for large utilities, such as the Tennessee Valley Authority, to consider "small" gas turbines for large systems. The systems analysis did reverse that position and firmly established gas turbines as a technology for peaking duty.

After 1973, the growth of electricity demand in the USA declined. Because of advanced ordering, the entire utility industry faced serious overcapacity, so the domestic gas turbine market disappeared for all practical purposes. And in 1978, the US Government passed the Fuel Use Act, prohibiting the use of natural gas for electricity generation after 1990. The country was running out of gas!

This was a severe blow to the future of gas turbine technology. In fact, Westinghouse did close its plant in Round Rock, but GE´s gas turbine business was saved by a very aggressive and clever international strategy: the formation of a network of manufacturing associates (MAs). Under the arrangement, GE offered technical information to MAs so that they could build the stationary part of the gas turbine while GE built the rotating part. GE guaranteed the performance to the MAs. Although in the international marketplace, GE and MAs were competitors; because of differences in marketing strength, financing capability and historical national relationships, this arrangement permitted the "GE design" to enjoy a very significant market share. By doing the advanced R&D needed, GE was able to keep the MA network in operation (in 1983, the People´s Republic of China signed up as an MA), and to keep the gas turbine technology moving ahead.

A key to the success of this strategy was advanced R&D. Figure 4 shows the progress, both technical and economical, for one of the machines, Figure 5 shows the increasing importance of MAs, and Figure 6 shows the importance of MAs in different geographical locations.

In 1986, 13 years after the energy crisis, the situation is very different. There is now a broader acceptance of the possibility that natural gas may still be a very important source of energy for the foreseeable future. Combined cycles utilizing natural gas offer much lower capital cost and higher efficiency. A new generation of gas turbines, significantly different from jet engines, is now under development. Conversion efficiencies of 55% appear to be technically and economically feasible. The future of gas turbine technology now looks very bright.

Had GE failed to put in place the innovative international strategy, the USA may not be able to enjoy its leadership in combined cycle technology today.

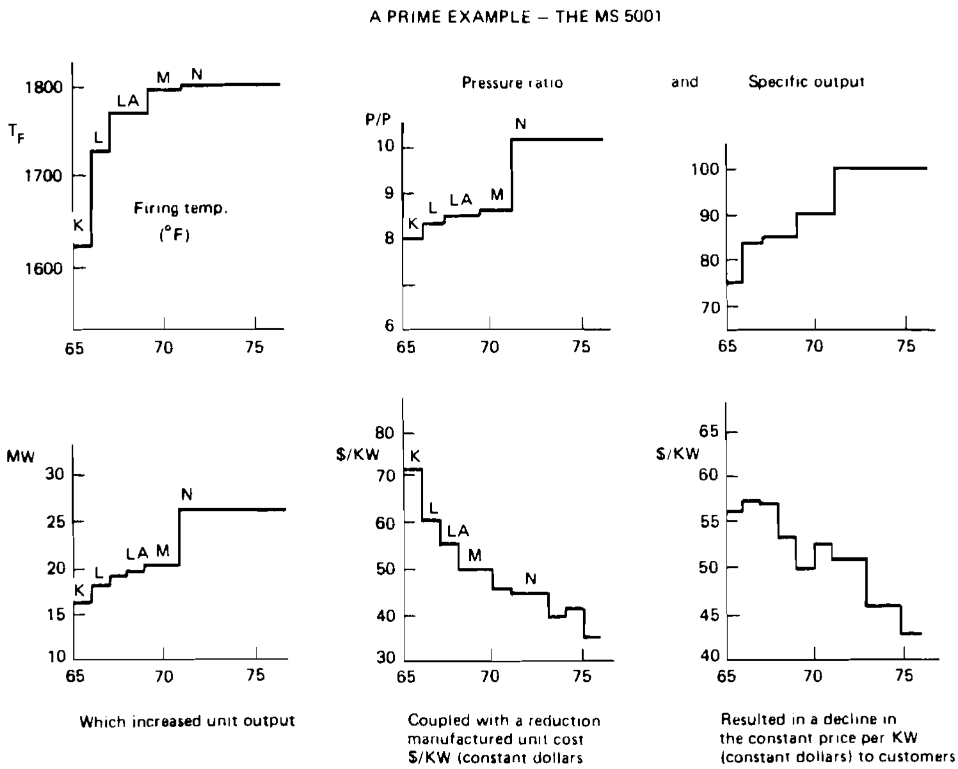


Figure 4

Technology advancement is critically important to the marketability of the MA product (as it is to GE), as evidenced by how quickly they pick up the new technology and how it has affected their business growth.

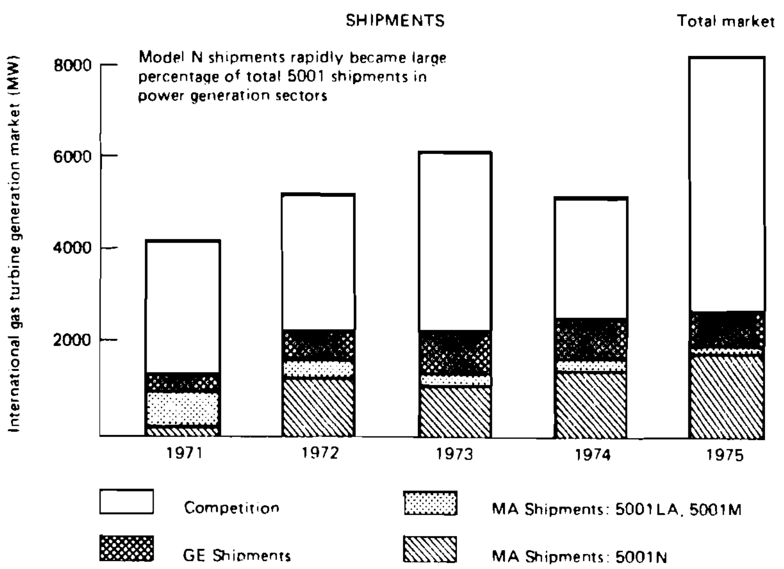


Figure 5

And in areas otherwise difficult for GE to penetrate.

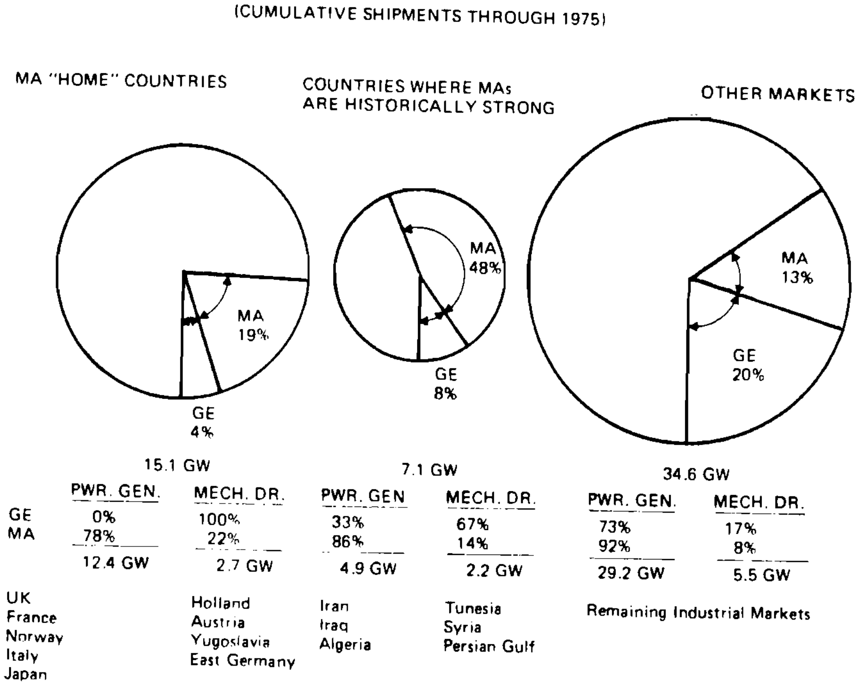


Figure 6

But, in addition to the creative international strategy, another consideration was important in the innovative process, i.e., the question of contingency planning. In 1975, Marchetti [5] (Figure 7) suggested that after oil, natural gas would be the dominant energy supply for several decades.

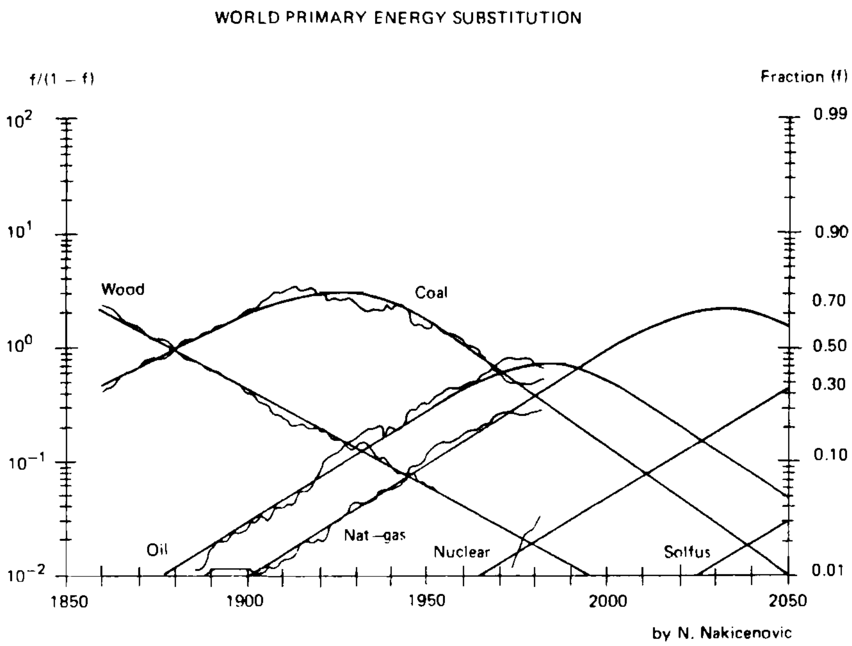


Figure 7

That forecast was very difficult for Americans to accept. In 1978, President Carter introduced the previously mentioned Fuel Use Act, and GE spent billions of dollars to acquire Utah International, a major coal company. The country's national policy was to depend on coal and nuclear energy, so Marchetti's forecast was highly controversial. During one debate on this, the point was made that planners should not find themselves debating which forecast is correct, a hopeless endeavor. The questions that should be asked were: "What does it mean if Marchetti's forecast turned out to be correct?" and "Should the company protect itself against such a contingency?"

The answer to the first question was obvious: the large steam turbine business would lose its importance in power generation and the gas turbine business would become more important. The answer to the second question was a business decision. If the decision was to protect against such a contingency, then the R&D effort on gas turbine technology should continue. In GE's case, both the international strategy and the need for contingency planning led to the same conclusion. The decisions were, therefore, straightforward. In other situations, contingency planning should be seriously considered as a very important factor in innovation management.

Finally, we should mention the importance of market forces on innovation. In commenting on an expected load growth of only 2 to 2.5% per year in 1985, Craig Tedmon of the GE R&D Center stated:

> That kind of load growth decreases the incentive for utilities to be venturesome in adding technically innovative new capacity. It increases the incentive for utilities to upgrade existing capacity.
>
> The extent to which utilities upgrade, rebuild, and otherwise stretch out the life of their existing equipment adds further uncertainty about future markets. And the greater the uncertainty, the harder the electrical manufacturing industry finds it to justify and support the rapid and costly development of radically new technology.
>
> Technology opportunities do exist today, and in many cases they are very significant.
>
> So it's not a question of technology opportunities not existing. It's a question of the market driving forces not being in place.
>
> I want to make a very important distinction here between market driving forces and economic driving forces. You can make a very nice economic argument in favor of each of the technologies I've mentioned.
>
> But economic feasibility isn't market feasibility.

> The economically feasible things will happen only if the market forces are right. And market forces are influenced by barriers. Right now those barriers are high - barriers of slow load growth, high costs, uncertain financial health, uncertainties about fuel cost and availability, environmental issues, reliability questions, and the regulatory environment. From the point of view of the manufacturers, the barriers are excess manufacturing capacity that keeps profit margins low, and strong foreign competition, aided by a strong dollar and foreign government protectionist trade policies and subsidies. All of these do not invalidate the long-run economic arguments favorable to new technology. But they do put high barriers in the way of the development of markets for those technologies. [6]

VI. FEDERAL GOVERNMENT'S ROLE IN INNOVATION

Two technologies supported by the government during and after World War II are of particular significance to the electric power industry: nuclear reactors and jet engines.

The development of nuclear power in the USA represents a unique involvement of federal government in a massive and directed support of the process of innovation - from the collection of necessary scientific data to the construction of demonstration nuclear power plants.

In no period in history there has been, as a result of a combination of circumstances, a more rapid innovation, that is, a translation of theoretical ideas into widely used technology. These circumstances included not only the intellectual challenge of investigating a new realm of science and technology, but also the ability, under the exigencies of war, to engage prominent scientists and engineers in an enterprise of high priority. The management of this innovative process during World War II has been described by Smyth [7] and Seaborg [8].

Development of nuclear power did not begin, however, immediately after World War II. On January 14, 1946, Bernard Baruch presented a US proposal to the United Nations Atomic Energy Commission to establish an international agency with exclusive authority to own all nuclear materials and to conduct all dangerous nuclear operations (i.e., operations of military significance) [9]. This proposal was not accepted and the US government decided that the science and technology developed in the Manhattan Project would remain secret (with the exception of the information provided in the Smyth report [7]). Congress passed the Atomic Energy Act of 1946, which prohibited any peaceful nuclear cooperation until Congress was satisfied that international safeguards were in place. This policy of secrecy and denial not only inhibited commercial development of nuclear power in the USA, but also it was ineffective in preventing other countries from developing nuclear explosives. The Soviet Union conducted tests of a nuclear fission device in 1949 and a thermonuclear device in 1953. The British conducted a test of a nuclear explosive in 1952.

The failure of this policy of secrecy to prevent proliferation then led the USA to adopt a dramatically different approach. In a speech to the United Nations on December 8, 1953, President Eisenhower outlined an "Atoms for Peace" program under which the USA would declassify the information necessary for development of the peaceful uses of atomic energy - including the information needed for nuclear power plants. He suggested also that the international community move toward agreements that would assure the availability of the information to all countries and that would also address the proliferation question. As a result, the International Atomic Energy Agency was established in 1957. Nations of Latin America agreed to create a nuclear weapons free zone in their countries under the 1967 Treaty of Tlatalolcol, and 130 nations have subscribed to the Non-Proliferation Treaty of 1970 under which they agree to forgo the development of nuclear explosives in return for access to peaceful nuclear technology.

This new policy of the USA provided the basis for an accelerated development of nuclear power beginning in 1954, not only in the USA, but also in other countries. There had been some development of nuclear power reactors in the USA during the 1946-1954 period at two of the national laboratories - the Argonne National Laboratory first operated the Experimental Breeder Reactor-1 in 1961, and the Boiling Reactor Experiment (BORAX-1) in 1963. The Oak Ridge National Laboratory completed the Homogenous Reactor Experiment (HRE-1) in 1952. During this period, industrial firms had also been involved in studies and development programs under contract to the Atomic Energy Commission (AEC), but widespread industrial interest in the development of commercial nuclear power began with the "Atoms for Peace" initiative.

The period from 1954 to 1965 was marked by the development of many different nuclear power systems - some by industry and some by government. The circumstances were conducive to innovation. There was generous government support for R&D; there was public enthusiasm for nuclear power; the demand for electricity was increasing by 7% per year; and the low fuel costs for nuclear power plants held the hope that they would provide lower cost power than other alternatives. To further encourage the development of nuclear power, in 1957 Congress passed the Price-Anderson Act, which provided a limit on the liability of electric utilities in the case of an accident in a nuclear power plant.

Not all the nuclear reactor concepts developed during this period survived after 1965, when AEC support for reactor development was redirected almost entirely to the breeder reactor concept. Among the casualties were water-moderated homogenous reactors, molten-salt reactors, organic-cooled and moderated reactors, sodium-cooled and graphite-moderated reactors, CO_2-cooled and graphite-moderated reactors, and boiling-superheat reactors. These casualties were due to a number of factors. Some reactor concepts - homogeneous, molten-salt, and CO_2-graphite reactors - had been developed by national laboratories and had no industrial sponsor to continue their development. Others - the organic-cooled and the sodium-graphite reactors - encountered technical difficulties. The successful reactor developments were those that involved the most conventional technologies; that is, those that used water as the reactor coolant. The adoption of pressurized water reactors by Admiral Rickover had a tremendous influence on the sponsorship of boiling-water and pressurized-water reactors by major industrial firms who were regular suppliers of power plant equipment to the electric utilities. These firms were not only able and willing to take financial risks, but also had the confident of the utilities in terms of supply and service.

The first commercial order in the USA was in 1963 for the Oyster Creek plant. Orders for nuclear plants continued at an accelerated pace until about 1975, at which time the social and regulatory circumstances had changed to the extent that utilities no longer felt they could afford the financial risks involved in the construction of nuclear power plants.

VII. THE CHANGING ENVIRONMENT & THE FORMATION OF EPRI

Since about 1970, the innovative process with regard to the supply of electricity has been subject to a variety of social pressures, which have profoundly changed the direction of innovation. These pressures shifted emphasis toward environmental assessment and control, nuclear safety, alternative systems for power generation, conservation and end-use technologies, demand management, and the extension of the life of existing power plants.

The social issues that influenced the development of electric power from 1970 to 1986 included a rising concern about environmental protection, an augmented concern about personal health and safety, a growing consumer movement, dramatic changes in the economy, shifts in the federal management structure, and a growing public distrust of big government and big industry.

Environmental Issues

Protection of the environment in the USA began in the late nineteenth century with legislation to create national parks and forests. The key legislation affecting the electric utilities was, as noted previously, the passage of NEPA in 1969, which required EISs to be prepared for any project that needed federal government approval. At the same time, a new regulatory agency was established, the EPA, and a new agency in the Presidential Executive Office, the Council on Environmental Quality. The importance of NEPA was that any group of citizens, regardless of how small that group might be, could question the validity of the EIS made by the proposer of a new power station.

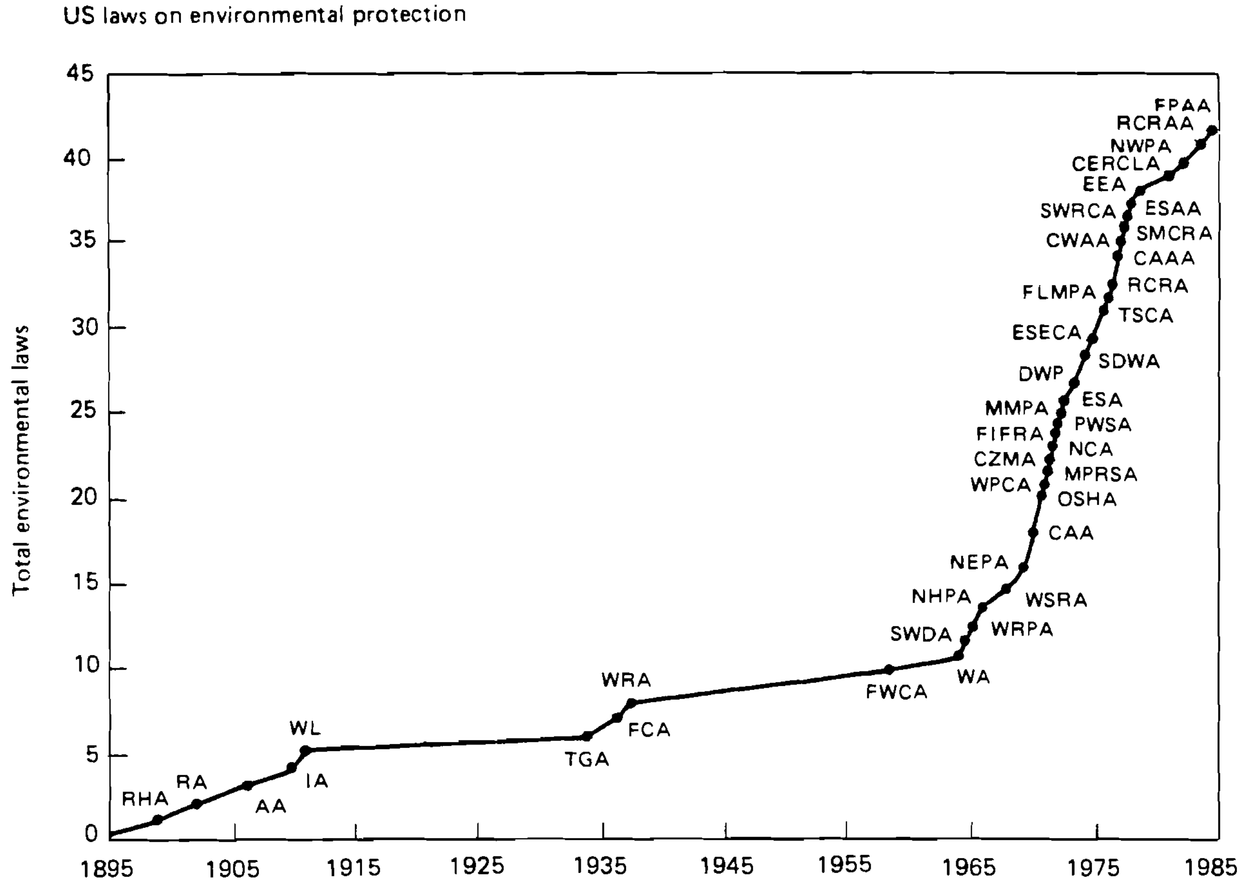
This opportunity for intervention by special-interest groups in the construction was to prove a dominant factor in proposals to construct not only nuclear power plants, but also fossil-fuel power plants and hydropower plants. The importance of NEPA is that the final judgment on environmental protection was often shifted from federal agencies to the federal courts.

In addition to NEPA, Congress also passed a large number of bills to regulate specific aspects of the environment - clean air, clean water, toxic materials, endangered species - to name a few (see Figure 8). In some cases, Congress also mandated deadlines by which EPA was to emplace control regulations. This environmental legislation created a great deal of uncertainty for the electric utilities, not only as to what the final regulations would be, but also as to the delays in construction schedules which might be occasioned by suits brought in the courts.

Public Health and Safety Issues

A dominant theme in US society since 1970 has been a public desire to do all possible to reduce their personal risks. A concept arose that federal government should grant licenses for only those products or operations that presented "zero risk". In particular, public concern about the relationship between radioactivity and cancer has been an important element in public opposition to nuclear power plants. Opponents to nuclear power have not only been very talented in raising public concern about radioactivity, but have also been very effective in using this issue in delaying tactics against the construction of nuclear power plants, the transport of radioactive material, and the construction of sites for the disposal of radioactive materials. As of early 1986, these three issues had not been finally settled in terms of public acceptance. The recent accident in Chernobyl certainly will intensify and prolong the debate. The level of release of radioactive materials from a nuclear power plant accident has been an issue of particular importance. Based on the data obtained from the accident in Three Mile Island, it has been shown that the releases of radioactivity were 10 to 100 times lower than the resolutions assumed by the NRC. The NRC has not yet, however, changed its regulations. This issue of release of radioactivity during a nuclear accident is of direct interest to the electric utilities, since it is an important factor in the size of the evacuation zone required around a nuclear plant. Because of this unresolved issue, there has been a major emphasis on research both by the government and the private sector to determine the exact level of release of radioactivity from nuclear power plant accidents.

In addition to radioactivity from nuclear operations, there are other issues of public health concern. One of these is concern about the possible carcinogenic effect of a component of the oils used in transformers, the polychlorinated biphenyls. The public has also been concerned about the possible biological effects of electromagnetic fields under transmission lines. These issues have stimulated research to assess the significance of such phenomena, as well as technologies that could reduce public exposure.



Legend:

RHA	– Rivers and Harbors Act (1899)
RA	– Reclamation Act (1902)
AA	– Antiquities Act (1906)
IA	– Insecticide Act (1910)
WL	– Weeks Law (1911)
TGA	– Taylor Grazing Act (1934)
FCA	– Flood Control Act (1937)
WRA	– Wildlife Restoration Act (1937)
FWCA	– Fish and Wildlife Coordination Act (1958)
WA	– Wilderness Act (1964)
SWDA	– Solid Waste Disposal Act (1965)
WRPA	– Water Resources Planning Act (1965)
NHPA	– National Historic Preservation Act (1966)
WSRA	– Wild and Scenic Rivers Act (1968)
NEPA	– National Environmental Policy Act (1969)
CAA	– Clean Air Act (1970)
OSHA	– Occupational Safety and Health Act (1970)
WPCA	– Water Pollution Control Act (1972)
MPRSA	– Marine Protection, Research and Sanctuaries Act (1972)
CZMA	– Coastal Zone Management Act (1972)
NCA	– Noise Control Act (1972)
FIFRA	– Federal Insecticide, Fungicide, and Rodenticide Act (1972)
PWSA	– Ports and Waterways Safety Act (1972)
MMPA	– Marine Mammal Protection Act (1972)
ESA	– Endangered Species Act (1973)
DWP	– Deepwater Port Act (1974)
SDWA	– Safe Drinking Water Act (1974)
ESECA	– Energy Supply and Environmental Coordination Act (1974)
TSCA	– Toxic Substances Control Act (1976)
FLPMA	– Federal Land Policy and Management Act (1976)
RCRA	– Resource Conservation and Recovery Act (1976)
CAAA	– Clean Air Act Amendments (1977)
CWAA	– Clean Water ACt (1977)
SMCRA	– Surface Mining Control and Reclamation Act (1977)
SWRCA	– Soil and Water Resources Conservation Act (1977)
ESAA	– Endangered Species Act Amendments (1978)
EEA	– Environmental Education Act (1978)
CERCLA	– Comprehensive Environmental Response, Compensation, and Liability Act (1980)
NWPA	– Nuclear Waste Policy Act (1982)
RCRAA	– Resource Conservation and Recovery Act Amendments (1984)
EPAA	– Environmental Programs Assistance Act (1984)

Figure 8 (Source: Electricity Outlook: Foundation for EPRI R&D Planning, Report 4391SR, Electric Power Research Institute, Palo Alto, CA)

Consumer Issues

The consumer movement in the USA has several origins. The publication of Ralph Nader's book [10] "Unsafe at Any Speed" on the automobile, the Corvair, and the subsequent action by General Motors to discredit Mr. Nader, gave great impetus to the movement. This distrust of US industry was augmented by a growing public opposition to the war in Vietnam. Finally, the resignation by President Nixon over the cover-up of the break-in at Watergate convinced the public that neither big industry nor big government were to be trusted. As a result, law firms devoted to public-interest causes were created. Congress passed a law requiring government agencies to make records available to the public under the Freedom of Information Act. In addition, Congress passed the so-called Sunshine Act, which requires all government commissions to provide access for the public to most of their meetings. At the state level, offices for public defenders were created and, in a few states, Citizens Utility Boards were established. There were also requirements that government agencies hold public hearings on proposed new programs. These actions to protect the interests of the consumer also provided great uncertainty in the process of licensing and construction of power plants and, as a consequence, uncertainty as well in the planning of R&D programs.

Economic Issues

The steady 7% annual increase in the demand for electric power during the 1950s and 1960s had led most utilities to undertake aggressive programs for the construction of new generating plants. In the late 1960s and early 1970s many of the new plant orders were for nuclear power plants. This rate of increase in demand, however, was to begin to change downward after 1970 (see Figure 9). As a result, many utilities found that the plants they were building were no longer necessary on the time schedule they had expected. For example, of the 139 nuclear power plants ordered after 1971, all but 33 have been cancelled.

In addition, utilities that decided to continue with the construction of nuclear plants were faced with a number of unexpected factors. The construction time, which was about six years for plants completed before 1975, became 10-13 years due to new regulatory requirements and interventions in the licensing process by special-interest groups. In the late 1970s both interest rates and inflation were well above 10%, adding significantly to the financing costs of plant construction. These circumstances also applied, of course, to the fossil-fuel power plants constructed during the same period. Consequently, these nuclear and fossil-fuel power plants were much more expensive than originally expected. According to US practice, the capital cost of new power plants is included in the investment base for determining the rates for electric power only upon completion of the plants. Thus, the high cost of the latest plants results in a substantial increase in the rates charged for electricity.

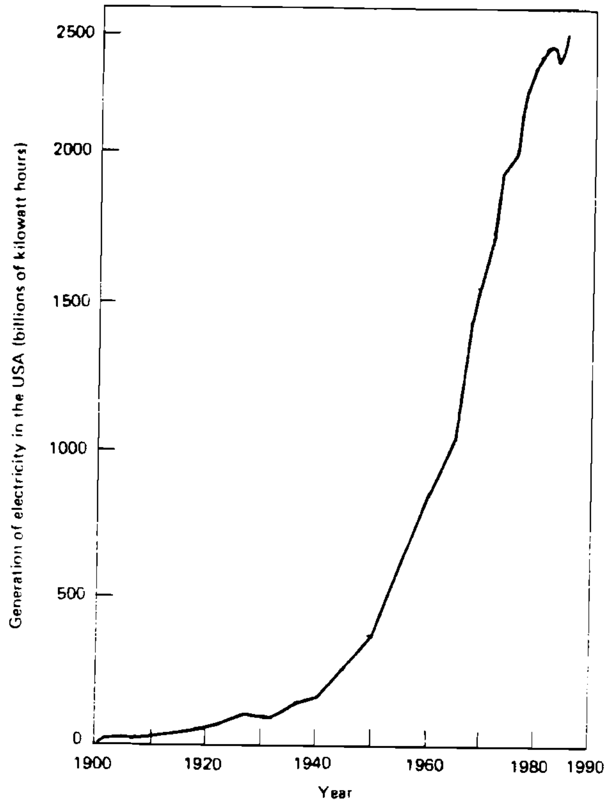


Figure 9: Historical Generation of Electricity in the USA

In contrast to the historical downward trend in the cost of electricity, this new phenomenon of upward "rate shock" led many State utility commissions to question the prudence of the original investment, and to deny upward rate adjustments to cover the investments in these plants. Such decisions had, of course, a negative impact on the revenues of the utilities and on their ability to attract investment capital or to issue bonds for the construction of new plants. Utilities have, therefore, adopted a capital preservation posture under which they have decided not to build new large power plants, but rather to explore other less capital-intensive approaches - life-extension of old plants, load-management, conservation, and the purchase of power from non-utility companies, as well as from Canada and Mexico.

The uncertainty in the demand for electric power, as well as the new economic realities, shifted utility interest toward smaller power plants, for which the construction schedules might be predictably short and the capital costs of manageable size.

National Security Issues

The oil embargo by the Organization of Petroleum Exporting Countries in October 1973, and the Indian detonation of a nuclear explosive in May 1974, raised new issues related to energy policy and to nuclear nonproliferation.

Prior to 1973, energy questions had been the responsibility of the AEC (nuclear power and nonproliferation) and the Department of the Interior (DOI; fossil fuels and the federal power marketing agencies). In Congress, nuclear issues were covered by a powerful Joint Committee on Atomic Energy (JCAE), and the issues of the DOI by single committees in the Senate and House. The oil embargo and the Indian nuclear test made energy policy and proliferation questions matters of high national importance. In the Administration, a Federal Energy Office was quickly established in the White House, to be followed by the establishment in 1974 of a Federal Energy Administration which was, in 1978, to be absorbed into a new Department of Energy (DOE). In Congress, the JCAE was abolished in 1974 with the responsibility for energy policy being distributed among many committees in both the Senate and House. In 1974, the AEC was also abolished with the creation of a new NRC and an Energy Research and Development Administration (ERDA; the fossil fuel R&D activities and the Power Marketing Agencies of the DOI were incorporated into the DOE along with the ERDA in 1978).

All of these administrative reorganizations, undertaken to provide for national economic independence from oil imports, had, of course, an influence on the direction and management of R&D. Also, in 1978 Congress passed the Power Plant and Industrial Fuel Use Act, which prohibited the use of oil and natural gas in fuels for power plants after 1990. In 1980, under the Energy Security Act, a Synthetic Fuels Corporation (SFC) was created to fund the development of the production of synthetic fuels from coal and oil shale. (The SFC was abolished in 1985.)

Under the aegis of the AEC and the "Atoms for Peace" programs, US vendors had, until 1974, positive support in the development and sale of nuclear power plants, both domestically and abroad. After 1974, however, circumstances changed. Concern about additional proliferation of nuclear weapons capability after the Indian test device in 1974 occasioned a reappraisal of the US position. In 1977 the Carter Administration decided to defer the construction of the Clinch River Breeder Reactor (CRBR) and the reprocessing of nuclear fuel because of concern about the potential weapons application of the plutonium produced in these operations. In 1978 Congress passed the Nuclear Nonproliferation Act (NNPA), which restricted the exports of nuclear hardware. While Congress kept the CRBR active until 1982, the net effect of the NNPA was to make foreign nations reluctant to rely upon the US as a supplier of nuclear equipment and fuels. The competitive position of US vendors was, therefore, eroded and made them less able, or willing, to support R&D on domestic nuclear projects.

Alternative Energy Sources

During this period of uncertainty, the public was also entranced by a philosophy that bigness, whether in public bureaucracies or in private corporations, results in impassivity, insensitivity, and a lust for power. This attitude was eloquently described by E.F. Schumacher in his book, "Small is Beautiful", published in 1973. The introduction to this book describes this as a part of the anarchist faith that "small is free, efficient, creative, enjoyable, and enduring".

In the 1970s, there was a general acceptance of this philosophy that one should advocate smaller technologies. As a result, the program for development of energy technologies took a new course. Federal budgets for alternative energy resource development increased, tax credits were provided for these technologies, and legislation was passed to further encourage the adoption of "small" technologies. In 1978, Congress passed the Public Utilities Regulatory Policy Act (PURPA), which mandated that electric utilities buy electricity generated from these alternative electric energy sources at "avoided costs"; that is, at the rate of highest cost generation otherwise available on the utility system.

In response to public enthusiasm for this decentralization philosophy, the government undertook a massive program to support alternative energy sources, which affected the R&D programs of the vendors and the electric utilities. R&D support for various energy technologies, including alternative technologies, is shown in Table 1. This figure demonstrates the dramatic increase and subsequent decline in DOE support for energy technologies. This rise and fall in federal support for energy R&D has been, of course, a destabilizing factor in the interest of vendors to invest their own R&D funds in these technologies.

In a recent report [11], the Office of Technology Assessment of Congress discussed the prospects for a number of these developing technologies - wind, solar thermal, photovoltaics, geothermal, fluidized bed coal combustion, integrated coal gasification, combined gas-steam cycle plants, and battery and compressed air storage systems. While the OTA report notes that several of these technologies may be significant contributors to electric power generation in the future, immediate generation needs would have to be met by established technologies.

As of early 1986, however, some of the circumstances related to renewable energy resources had changed. While the "avoided cost" purchase of power under PURPA continued, the renewable energy tax credits had been discontinued (but may possibly be reinstated) and federal R&D support had also been greatly reduced. Further investor interest was in doubt.

This period of uncertainty is not yet over. The Administration of President Reagan has stipulated that the government should support only long-range, high-risk R&D. The Administration has also recently advocated a philosophy of transferring, to the extent possible, all federal electric utility operations to the private sector. While these policy initiatives by the Administration may not be accepted by Congress, they do contribute to the sense of uncertainty felt by electric utilities and to the difficulty in formulating programs for R&D.

Table 1. Federal support for energy R&D programs: fiscal years 1971–83 (dollars in millions).

	Actual											Estimates	
Agency and program	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
Total	$556	$574	$630	$759	$1,363	$1,649	$2,562	$3,134	$3,461	$3,603	$3,501	$2,889	$2,034
Energy Research and Technology Administration (Commerce)[1]	534	548	596	699	1,205	1,470	2,335	2,867	3,192	3,309	3,170	2,613	1,779
Solar[2]	–	–	–	4	40	94	256	332	463	409	442	248	73
Geothermal	–	–	–	6	25	31	51	105	132	123	131	44	10
Hydropower	–	–	–	–	–	–	2	NA	5	15	7	3	–
Nuclear fission[3]	271	276	295	316	460	520	801	880	875	872	886	927	717
Magnetic fusion	28	31	37	53	98	130	195	207	211	235	259	293	359
Electric energy and energy storage systems	–	–	–	–	–	–	–	88	95	101	85	57	–
Biological and environmental research	65	68	77	87	119	135	163	185	195	215	148	151	121
Supporting research	93	89	89	89	109	113	129	160	192	218	235	244	273
Fossil energy[4]	36	38	49	88	312	369	557	687	668	727	650	407	104
Energy conversion	–	–	–	9	34	66	167	165	226	264	197	84	19
Uranium enrichment[5]	26	31	35	45	2	4	7	44	131	129	131	156	104
Other[6]	16	16	14	2	7	10	6	17	–	–	–	–	–
Nuclear Regulatory Commission[7]	22	26	34	42	64	88	112	137	157	191	227	223	220
Environmental Protection Agency	–	–	–	18	95	90	114	130	113	103	104	52	35

[1] For fiscal years 1971–73 data for the Atomic Energy Commission (AEC) were used; for the period 1974–76 data for the Energy Research and Development Administration (ERDA); for 1977–80 data for the Department of Energy (DOE); and for 1981–83 data reflect the proposed Energy Research and Technology Administration (ERTA) programs.
[2] Includes biomass energy technology programs.
[3] Includes fuel cycle R&D, space and terrestrial applications; and nuclear research and applications programs.
[4] Includes funds for the Department of the Interior programs, 1971–76, transferred to DOE in 1977.
[5] Includes some uranium enrichment programs that are included under nuclear fission in 1978–79.
[6] Includes applied energy technology, 1971–83; advanced technological and assessment projects, 1977; and policy analysis and studies, 1978. Programs in this category were redistributed among various other energy programs with the establishment of ERDA in 1974; includes funds for the Bonneville Power Administration, 1971–76, transferred to DOE from the Department of the Interior in 1977.
[7] In 1974 the safety aspects of AEC were placed under the Nuclear Regulatory Commission (NRC), a new agency.

NOTE: Data for 1971–77 are shown in obligations; data for 1978–83 are shown in budget authority. Detail may not add to totals because of rounding.

Table 1 (Source: 1985, New Electric Power Technologies: Problems and Prospects for the 1990s, Office of Technology Assessment, US Congress, Washington, DC)

The Electric Power Research Institute

Collective support for R&D by the electric utilities began in 1965 with the creation of an organization, the ERC, under which utilities participated voluntarily in R&D projects of particular interest to them. These projects were contracted to industrial organizations and managed by committees of utility engineers. By 1970, it became apparent not only that part-time management by committees was not ideal, but also that many apparent R&D requirements were not being undertaken by either the vendors or the government. The ERC, therefore, undertook a study of the R&D needs of the industry [12], which was published in June 1971, and recommended a program of R&D costing about $30 billion to the year 2000, and also recommended the creation of EPRI to manage it.

The creation of EPRI was greatly accelerated by the introduction of a bill [13] in Congress by Senator Warren Magnuson to create a Federal Research and Development Board to be funded by a 0.15 mill/kwh tax in electric power generation (about 1% of revenues in 1971), and to be managed by a government organization.

The leaders of the electric utilities concluded they would much prefer an R&D activity under their management and asked Senator Magnuson to defer consideration of his bill while the utilities attempted to establish their own R&D program as recommended in the ERC report. In the fall of 1971, agreement was reached among the utilities that they would sponsor EPRI, which would be funded by its utility members. EPRI was incorporated in the District of Columbia in March 1972. The Magnuson bill was tabled.

In terms of innovation management, there are several factors of importance in the procedures established for the operation of EPRI. The Institute was to be a planning and management organization with the R&D projects to be carried out, as much as possible, by vendors who would later be suppliers of hardware. To the maximum extent possible, electric utilities were to be involved in the testing and demonstration of new technologies. The R&D program would be planned by task forces and committees comprised of engineers drawn from the utility members of EPRI. These procedures did not guarantee that all ideas would be translated into useful hardware and software; but by involving both vendors and utilities, they did provide an approach that would attempt to meet the needs of the utilities and also encourage vendors to produce the products desired. The completion of the innovation process, that is, the transfer from the R&D stage to utility use has been, however, a continuing problem. EPRI has taken, therefore, several additional technology transfer initiatives.

Utilities have been asked to appoint technical information coordinators whose responsibility is to channel EPRI technical reports to the appropriate individuals within their utility. Utility engineers have been asked to complete profile forms indicating their areas of technical interest. In their proposals to EPRI for support for hardware and software development, contractors are asked to indicate how they would bring the product into commercial use if the R&D is successful.

During 1985, a survey was made of some two dozen member utilities to ascertain whether they were using the products of EPRI research and whether they were receiving a return on their R&D investment at EPRI. The survey indicated a cumulative return on the R&D investment of between two-to-one and three-to-one. In order to encourage the participation of utility management in EPRI affairs, a decision was made in December 1985 to increase the size of the Board of Directors from 15 to 24 members. These initiatives reflect the necessity not only for the successful development of products from research, but also the equally important necessity to pursue actively the transfer of such technologies to prospective users.

As noted previously, EPRI was established during a period of significant changes in the social and economic environment. An EPRI report of December 1985 [14] notes: "As a consequence, the planning of R&D programs by EPRI has been greatly influenced by regulatory requirements for environmental protection and public health and safety, and by the changing economic situation. The EPRI R&D programs have, therefore, shifted over the years from a long-range emphasis on the development of new technologies to a short-range resolution of immediate problems posed by regulatory requirements or economics."

In the 1985 EPRI Annual Report, the current situation was described as follows:

> Today, much of the political and economic turmoil that marked the 1970s has abated; change and uncertainty have become permanent elements in this industry's business environment. While the industry struggles to gain control of costs that have clearly increased in all dimensions, competitive pressures have greatly intensified as a result of a complex set of factors, including a persistently high real cost of capital, competition between electricity and other forms of energy (in part because of recently softening oil and gas prices), a firmly entrenched national environmental protection ethic, and the rapid growth of federal and state regulations.
>
> With competition emerging as a new and powerful driving force in the industry, utility priorities have once again shifted. The most important concerns today (in order of importance) are reducing and controlling the costs of electricity to consumers, maintaining and enhancing markets for electricity, minimizing environmental and financial risks, and continuing to build a technological base for the future.

The strategy that stems from this situation includes R&D emphasis on: extension of the plant life of existing coal-fired and nuclear plants; the development of smaller, modular power plants, which can be quickly constructed to meet demand growth - such as fuel cells, fluidized-bed coal combustion; coal gasification combined cycle plants; reduction of operation and maintenance costs; management of fuel costs; management of daily consumer demand to reduce need for new generating capacity; maintenance and enhancement of residential, commercial, and industrial markets for electricity; and minimization of risks associated with environmental and safety regulation. The emphasis on technologies for the future includes the development of hydrothermal geothermal power plants, photovoltaics, storage batteries, compressed-air storage, standardized nuclear power plants, and the use of computers in utility operations. This strategy for the EPRI program is, of course, a direct response to political and economic circumstances, as well as to technical opportunity. These same circumstances will have had equal impact on the R&D programs of vendors and government. All of the participants in the electric power R&D enterprise have had difficulty in responding to the uncertainties in the economic and political situation since 1970. The only certainty is that these uncertainties will continue.

VIII. CONCLUSIONS

Management of technological innovation in the electric power industry in the USA has undergone significant changes, due to the combined effect of market forces, political considerations, and social concerns.

Today, manufacturers have very little incentive to consume their own resources because the market is depressed and government's policy no longer emphasizes the need to support the electric power industry. Thus, the burden of R&D lies principally with the utility industry. This shift has made the problem of technology transfer and commercialization a serious issue. Manufacturers might be quite anxious to accept EPRI funding for R&D, but when it comes to investing their own resources to produce the products generated by R&D, the attitude may be quite different. Here, the market consideration becomes a dominant factor. This issue must be addressed by EPRI and the utility companies in order to turn inventions into innovation.

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