Chapter 9

The Commercial Transition for Developing Electric Technologies

CONTENTS

List of Tables

List of Figures

Chapter 9

The Commercial Transition for Developing Electric Technologies

INTRODUCTION

This chapter discusses past development of the electric generating and storage tech nologies examined in this assessment, and discusses their commercial outlooks. Factors which constitute serious impediments to widespread commercial deployment in the *1990s–assuming a demand for additional generating or storage capacity'* – are identified. Deployment levels will depend on a combination of changes in cost, performance, uncertainty, and other changes i n the com mercial environment within which the technologies are developing.

'This assumption is an important one, as a general lack of demand for additional generating capacity could itself constitute the major impediment to the deployment of the technologies in the 1990s.

STATUS AND OUTLOOK FOR THE DEVELOPING TECHNOLOGIES

Solar Photovoltaics

History and Description of the Industry

Photovoltaic cells (PVs) first were developed in the 19th century. In the 1950s and 1960s, a combination of technical breakthroughs and the need to power spacecraft stimulated substantial cost reductions, performance improvements and wider applications. During this period, Federal support, channeled primarily through the space program, was the dominant stimulus to the technology's progress.

In the 1970s PVs entered larger terrestrial markets, the most important of which was power generation in remote locations. A notable trend during the 1970s was the growing support for PVs by large petroleum-based companies and the Federal Government. In 1978, Federal support was solidified by the passage of several key laws which provide for a program of research, development, and demonstration and for direct Government purchase of large numbers of solar cells.[2]

From 1980 to 1985, about 30 laboratories across the country were conducting PV research.[3] By 1985, the price of PV modules decreased 80 percent (in constant dollars) from $35,400/kWe in 1976 to $7,000/kWe in 1984; performance also improved markedly. The volume of sales increased rapidly as world PV shipments increased over a hundredfold from 240 kWe in 1976 to 25,000 kWe in 1984. Total revenues increased twenty-fold, from $6.8 million to $174 million during the same period. Q

In the 1980s the PV industry changed considerably. By 1985, the industry consisted mainly of companies which were affiliated with large mu 1-tinational petroleum-based corporations. By the early 1980s, many companies sought to concentrate their operations towards the raw material

'The most important laws were: 1) the Federal Photovoltaic Utilization Act of 1978 (Public Law 95-619, Part 4); 2) the Solar Photovoltaic Energy Research, Development, and Demonstration Act of 1978 (Public Law 95-590); and 3) the Department of Energy Act of 1978 (Public Law 95-238, Section 208).

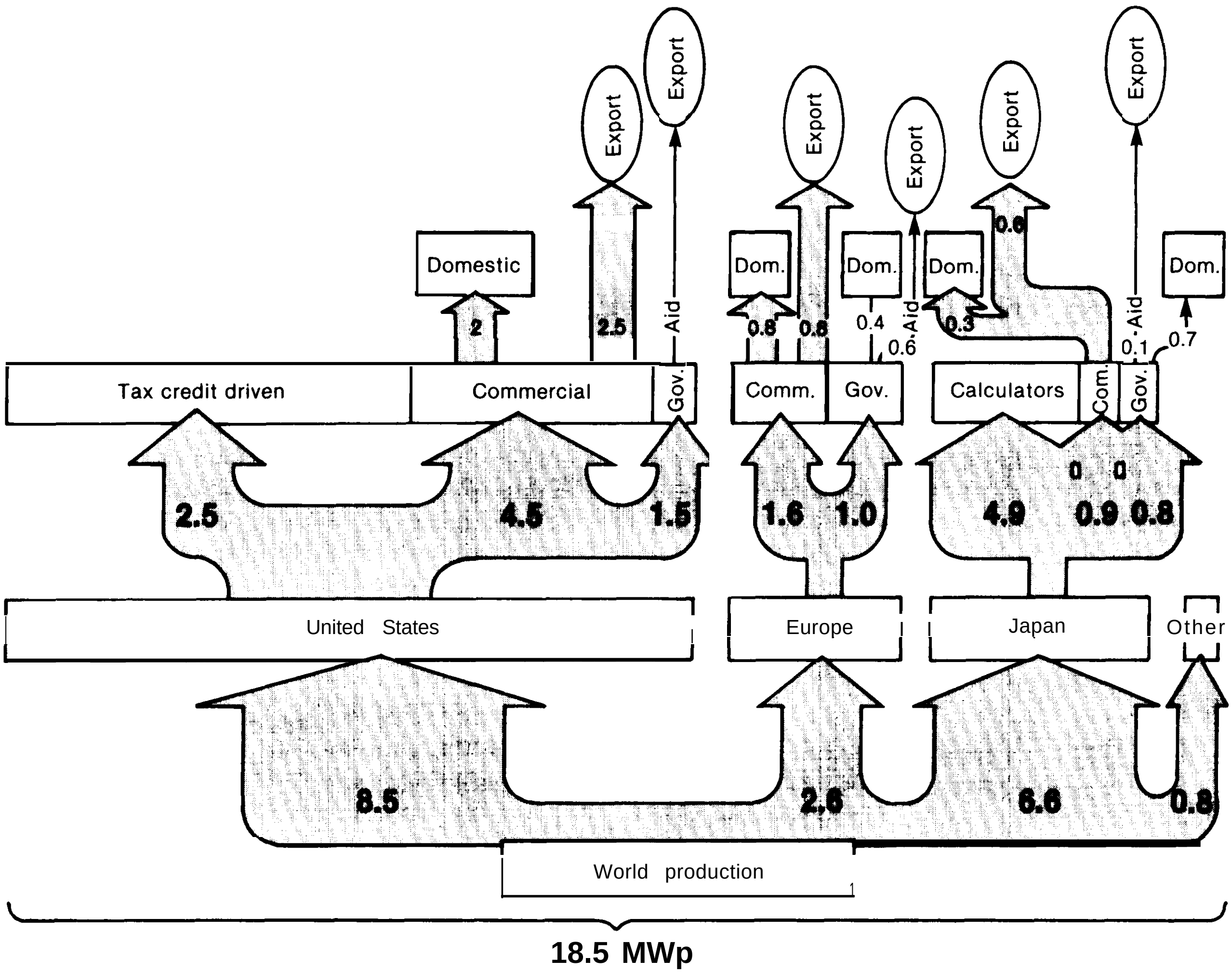
[3]Larry N. Stoiaken, "A New Generation of Photovoltaics. Commercialization Efforts Gain Momentum, ' *Alternative Sources of* Energy, vol. 67, May/June 1984, pp. 6-15.

[4]See: 1) Strategies U n l i m ited, *Analysis of Equipment Manufacturers and Vendors in the Electric Power Industry for the 1990s. Wind Turbines, Solar Thermal Electric, Photovoltaics* (Mountain View, CA: Strategies Unlimited, December 1984), OTA contractor report. 2) Pau l D. Maycock and Vic S. Sherlekar, *Photovoltaic Technology, Performance, Cost and Market Forecast to 1995. A Strategic Technology & Market Analysis* (Alexandria, VA: Photovoltaic Energy Systems, Inc., 1984).

end of the production process, emphasizing cell or module production. At the other end of the production chain, however, decentralization occurred, i.e., companies sold off or closed down operations involving other system components than the PV arrays themselves. As the technologies developed and market prospects changed, businesses also shifted emphasis among the different PV systems.

The market during the first half of the 1980s is depicted schematically in figure 9-1. During this period the United States dominated world production, with Japan ranking a distant second. The end-use markets for 1984 are broken down in table 9-1. The table highlights the importance of the U.S. central station market both as a fraction of the U.S. market and of the world market. The application of the Public Utility Regulatory Pol-

Figure 9.1 .–1984 World Photovoltaics Supply



SOURCE: Strategies Unlimited, "Analysis of Equipment Manufacturers and Vendors in the Electric Power Industry for the 1990s, " contractor repotl prepared for the Office of Technology Assessment, U.S. Congress (Mountain View, CA: Strategies Unlimited, Dec. 7, 1984).

Table 9.1 .—Estimated Magnitude of End"Use Markets for Photovoltaics, 1984

Market sector	MWe(p) shipped worldwide
World consumer products.	5
U.S. off-the-grid residential	2
World off-the-grid rural.	0.2
Worldwide communications	5
Worldwide PV/diesel	2
U.S. grid-connected residential	0.1
U.S. central station and third-party financed projects	10
Total MW	24.3
Japanese grid-connected.	—
Total MW	25
Price ($/Wp)	
Revenues ($ M)	$175

SOURCE Paul D Maycock and Vic S. Sherlekar, *Photovo/faic Technology, Performance Cost and* Market *forecast to 1995 A Strategic Technology and Market Analysis* (Alexandria, VA Photovoltaic Energy Systems, Inc , 1984)

icies Act of 1978 (PURPA) and favorable Federal and State (especially California) tax policies was very important in encouraging the deployment of photovoltaics in these facilities.

Federal support for photovoltaics during the first half of the 1980s shifted considerably in emphasis. Direct expenditures in support of photovoltaics declined in importance after peaking in 1980-81, but they continued to have a substantial effect on the development oft he technology (see table 9-2). While the Federal Government has concentrated on high risk research and development (R&D) with potentially high payoffs, some direct support was provided elsewhere. Export promotion was recognized as an important element in any program to encourage photovoltaics and assumed a more prominent position among Federal efforts in the 1980s. The Federal Government also continued to support a major demonstration project in California. As direct Federal support declined, indirect support for photovoltaics through tax incentives increased during this period and strongly influenced the rate of progress in the industry.

Industry Outlook and Major Impediments

The 1990s likely will witness rapid growth in the application of hybrid photovoltaics/diesel power systems in remote areas, primarily overseas. Indeed, this market could dominate world PV deployment during the period. Also very important will be grid-connected PV plants in the United States and in Japan. At the same time, the worldwide communications and consumer-products markets will continue to be of major significance to the industry. The magnitude and relative importance of different market segments, and the character of the industry itself, will depend heavily on whether or not the Federal Renewable Energy Tax Credit (RTC) is extended beyond 1985. The exact effect of either action, however, is difficult to accurately predict.

Table 9-2.—Federal Program Funds in Support of Developing Technologies (millions of dollars)

	Year											
Technology	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986 (requested)
Wind	7.9	14.4	27.6	35.5	59,6	63.4	54.6	34.4	31.4	26.5	29.1	20.8
Photovoltaics	5.2	21.6	59.7	76.2	104.0	150.0	152.0	74.0	58.0	50.4	57.0	44.8
Solar thermal	13.2	20.6	79.1	114.7	109.3	135.0	120.0	56.0	50.0	43.9	35.5	28.4
Geothermal.	28.0	78.3	76.7	132.9	188.4	171.0	156.3	86.6	73.6	30.5	32.1	12.0
AFBC	2.0[a]	7.0	21.2	24.5	23.6	25.9	11.4	0.3	4.9	1.4	18.7	17.3
Surface coal gasification (includes IGCC)	116.3	117.7	143.2	208.2	122.4	123.3	70.0	54.2	39.0	36.5	32.0	15.0
Fuel cells[c].	n/a	3.0	17.8	33.0	41.0	26.0	32.0	34.5	29.9	42.3	40.8	9.3
Batteries[d].	2.9	6.8	9.7	11.2	15.3	20.3	13.9	12.9	12.8	12.8	8.4	6.3
CAES	0.0	0.6	1.2	4.5	4.5	3.2	2.1	2.0	0.0	0.0	0.0	0.0
Total	175.5	270.0	436.2	640.7	668.1	718.1	612.3	354.9	299.6	244.3	253.6	153.9

[a]OTA estimate.
[b]Does not include support from the Synthetic Fuels Corp.
[c]Includes funding for all fuel cells R&D and is not restricted to phosphoric acid fuel cells
[d]The funding levels listed are the estimated levels of support for all stationary batteries, including but not restricted to lead-acid batteries and zinc-chloride batteries. The estimates assume that roughly 50 percent of the funding for DOE's Electrochemical Program is applicable to stationary batteries

SOURCE: U S Department of Energy, *Congressional/ Budget Request" FY 7986* (Washington, DC: U S. Government Printing Office, 1985) and the corresponding documents for preveious years if the RTC is not extended in any form, the overall level of deployment is likely to be greatly diminished and it is likely that the largest markets would be the worldwide PV diesel markets and grid-connected applications in Japan. important, but considerably smaller markets would be world consumer products, remote communications systems, and, finally, grid-connected power systems in the United States.

Termination of the tax credits would have especially severe effects on grid-connected central station applications involving third-party ownership. According to one analysis, this sector by the end of 1986 would shrink by 35 to 85 percent of what it would be with a continuation of the tax credit; by 1990, it would be 5 to 10 times smaller (see table 9-3).[5]

The character of the industry might change as well, with the larger companies in the business withdrawing or greatly reducing their involvement. As a result of depressed oil prices, the oil companies are already cutting back their involvement outside of the petroleum industry.[6] Less favorable tax treatment of PV investments could cause these firms to scrutinize their commitment to photovoltaics even more closely.

Smaller firms, particularly those heavily devoted to the central station market, may be hit hardest. Of special importance is the small segment of the industry dedicated to the concentrator technologies. Several of these companies are quite small. Expiration of the RTCs is likely to severely affect these businesses, greatly limiting the deployment of this promising PV option in the 1990s.[7] Industry dominance could then pass swiftly to the Japanese and the Europeans, whose aggressive and effective PV programs could enable them to dominate overseas markets, and, perhaps, even to capture a large portion of U.S. central station markets by the end of the century.

If, however, the tax credits are extended in some form, the results could be quite different. First, and most directly, for a given photovoltaic system, the level of demand in the United States could be higher than it otherwise would be. Second, the actual cost and performance of PV systems would improve, as the higher demand stimulated innovation and high volume production. This in turn could encourage growth in demand both in the United States and overseas. Finally, larger deployments in the near term would in many other ways accelerate subsequent deployment of photovoltaics. The infrastructure necessary to produce, deploy, and operate PV systems would develop more rapidly, overall experience with the technology would be greater, and institutions—e.g., utilities, public utility commissions, local permitting authorities, and others–could adapt sooner to the technology.

[5] Jet Propulsion Laboratory, *Effects of Expiration of the Federal Energy Tax Credit on the National Photovoltaics Program* (Pasadena, CA: Jet Propulsion Laboratory, 1984), DOE/ET-20356-l 5.

[6] Winston Williams, "Big Oil Starts Thinking Smaller, " *New York Times,* Mar. 17, 1985, sec. 3 (Business), pp. 1ff.

[7] Jet Propulsion Laboratory, *Effects of Expiration of the Federal Energy Tax Credit on the National Photovoltaics Program,* op. cit., 1984.

Table 9-3.—Projected 1986 Photovoltaic Shipments by Domestic Manufacturers

	With tax credit expiration		With extended tax credits	
Market sector	Shipments (MW)	Share of market (percent)	Shipments (MW)	Share of market (percent)
Residential, non-grid-connected	5	12.5-7.7	8-10	10.0-8.3
Residential, grid-connected	1	2.5-1.5	2-5	2.5-4.2
Electric utility (third party)	10-25	25.0-38.5	40-60	50.0
Water pumping	2-3	5.0-4.6	3-7	3.8-5.8
Communications	7-9	17.5 -13.8	9-11	11.2-9.2
Other industrial (includes government experiments)	5-7	12.5-10.8	8-12	10.0
International	10-15	25.0-23.1	10-15	12.5
Totals	40-65	100.0-100.0	80-120	100.0-100.0

SOURCE" Jet Propulsion Laboratory *Effects of Expiration of the Federal Energy Tax Credit on the National Photovoltaics Program* (Pasadena, CA: Jet Propulsion Laboratory, 1984), DOE/ET-20356-15.

The cumulative .effect of extension of the RTC on market size and distribution could be considerable. Virtually all market segments would be larger, some considerably more important than they otherwise might be. Dramatic growth could occur in the volume of sales of photovoltaics for use in PV/diesel hybrid systems in remote overseas applications. This market qlJickly could come to dominate the international PV market, The U.S. central station market would also be much larger.

Extension of the RTCs also will affect the relative importance of different PV designs. Rapid growth in the deployment of concentrate systems could be stimulated, along with other systems that are favored in central station applications.

Continuation of Federal tax support also could strengthen the position of U.S. manufacturers over foreign competitors—both here and overseas. Overseas competitors, especially the Japanese, are moving rapidly ahead in PV—often with the support of their governments. Tax credit support could serve to slow the erosion of the U.S. position in the industry and perhaps even reverse the trend.

While the issue of the RTC dominates current discussion of the outlook for the photovoltaics industry, a broad range of other factors will affect the prospects for photovoltaics during the 1990s. These are discussed below.

Equipment Cost and Performance. -If PV systems in the 1990s were identical to those available today, they probably could not compete extensively and successfully with the alternatives in U.S. grid-connected applications. Current levels of cost and performance are too high. Investments in both R&D and in industrial capacity to mass produce the technology will be required. The present status of the technology and the changes necessary for extensive commercial application in the 1990s are discusred in chapter **4.**

The Risk of Obsolescence.–The technologies of photovoltaics are evolving rapidly. This rapid rate of change may discourage would-be investors from investing in production lines out of fear that their investments could quickly become outdated in the event of technological breakthroughs, Some industry observers think that this is the reason the U.S. industry has been reluctant to invest in the facilities necessary to mass produce crystalline silicon modules. Instead, it largely has opted for the longer term payoff which might be obtained from the less mature amorphous silicon technology. Should progress in the amorphous technology prove slower than expected, the relative lack of emphasis in the U.S. industry on commercial production of crystalline silicon may delay commercial deployment of photovokaics, and foreign competitors, most likely the Japanese, may seize the opportunity to increase their market share by selling crystalline silicon modules in the United States and abroad.[8]

Solar Resource Assessment.—The current knowledge of the solar resource in the United States is insufficient for the optimum design and siting of PV plants. The best available information is the SOLMET data, based on several years of readings at 26 sites.[9] The SOLMET data gives monthly averages of solar insolation for each hour at typical geographic locations.

While such figures are useful for calculating generic capacity factors and peak system outputs for a particular region, the characteristics of a particular site may be significantly different than the average. Before utilities can integrate photovoltaics into their operations, they must have a detailed understanding of PV operating dynamics, based on a minute-by-minute understanding of the insolation patterns at a site.[10]

Also, to optimize the design of PV modules, it will be necessary to understand much more about the detailed spectral and directional distributions of light energy as a function of time-of-day and day-of-the-year. Such information not only influences the decision of whether or not tracking systems are cost effective, but it also affects the detailed design of the cells, since the

[8]Roger G. Little, President, Spire Corp., testimony presented in hearings held by the Subcommittee on Energy Development and Applications, House Committee on Science and Technology, U.S. Congress, *The Status of Synthetic Fuels and Cost-Shared Energy R&D Facilities* (Washington, DC: U.S. Government Printing Office, 1984), No. 106, June 6, 7, and 13, 1984, pp. 386-389.

[9]Roger Taylor, *Photovoltaic Systems Assessment: An Integrated Perspective* (Palo Alto, CA: Electric Power Research Institute, September 1983), EPRI AP-3176-SR.

[10]Ibid.

light absorption and current carrying capacity of these cells must be carefully matched to the solar spectrum.[11]

Cost and Performance Data.–A serious obstacle to timely deployment of photovoltaics in any application is the lack of accurate and useful information about the technology and its economics. What are the specific capital costs of a specific PV system? How will it perform at a specific locality? What kinds of operating and maintenance expenses might be incurred? This problem already has been an obstacle in overseas applications where investors often do not know enough about PV cost and performance or lack the analytical means to adequately compare photovoltaics to conventional alternatives .[12]

Standards.–The lack of standard definitions, testing methods, and other criteria relating both to PV modules and balance of system equipment reportedly has hindered development and deployment. it is thought by some that the application of standards ultimately will expedite the commercial application of the technology. Several groups are working on such standards, though who should set and enforce them is a matter of considerable controversy within the industry.

Warranties.–The extent to which warranties are available, and the nature of such warranties, will strongly affect the commercial success of PV systems in the 1990s. It was not until late 1984 that anyone in the industry offered even a limited warranty and an Underwriters Laboratories listing for a PV module. [13] Vendors will be reluctant to provide strong extended warranties until the technology has been adequately proven in real conditions. This requirement likely will put relative newcomers such as amorphous-silicon modules at a disadvantage until sufficient experience is built up.[14] The ability to provide extended warranties will be influenced greatly by the amount of capital available to the industry, which in turn will depend on market size and profit margins.

Utility Energy and Capacity Credits, and Interconnection Requirements.—Grid-connected PV plants can be owned by utilities or by others. As discussed earlier with wind systems, low energy credits, low capacity payments, and stringent interconnection requirements discourage deployment by nonutilities. Even where the possibility exists that credits could drop during the lifetime of a project, investment is discouraged. Also, any difficulties (such as delays) encountered in seeking to obtain favorable credits or interconnection requirements discourages nonutility deployment.

Overseas Markets.–Overseas markets will serve to encourage mass production of PV systems and hence lower costs. The larger market also will serve to indirectly stimulate technical development which could lead to further reduced costs or improved performance. As a result of such improvements the exploitation of overseas markets could help ensure that U.S.-made systems remain competitive in the domestic market.

Current evidence suggests that the U.S. photovoltaics industry is not as successful as it could be in overseas markets; as mentioned earlier, the situation will be exacerbated with the scheduled termination of the renewable energy tax credits. Meanwhile, competitors–especially the Europeans and the Japanese–are more actively and successfully developing these markets, often supported by favorable government programs. Failure to fully exploit export markets could slow the development of U.S. photovoltaics, extend the period required before extensive grid-connected applications will occur, and increase the likelihood that large segments of the U.S. market will eventually be served by foreign vendors.

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[11] OTA staff interview with Charles Gay, Vice President, Research and Development, ARCO Solar, Inc., Aug. 10, 1984.

12 For example, see Clyde Ragsdale, manager of Marketing for Solavolt International, testimony presented to the Subcommittee on Energy Development and Applications, House Committee on Science and Technology, U.S. Congress, Hearing on the Current State and Future Prospects of the U.S. Photovoltaics Industry, Sept. 19, 1984,

[13] " Slants and Trends, " *Solar Energy Intelligence Report*, vol. 10, No. *43, Oct. 29, 1984, p. 339.*

[14] "Intense Competition Among Five Silicon Technologies Seen for PV: Maycock, " *Solar Energy Intelligence Report*, Apr. 2, 1984, p. 110.

Solar Thermal Electric Plants

History and Description of the Industry

By 1879, the French had converted solar radiation into thermal energy and produced small quantities of electric power. Though this work led to the operation of several demonstration units, the devices proved to be prohibitively expensive to build and operate, and the idea of producing electric power from solar thermal energy was largely abandoned. Not until nearly 100 years later was heat derived from the Sun widely considered as a means of producing electric power.

A variety of solar thermal electric technologies are now being developed. But as discussed in chapter 4, their current status and prospects differ substantially. The solar pond technology faces many limitations that make widespread commercial application within this century unlikely. The prospects for three other technologies–central receivers, parabolic troughs, and parabolic dishes —are brighter. The histories of these technologies in the United States have been shaped by the Federal role in their development. Their prospects in the 1990s likewise probably will also depend heavily on Federal activity between now and the end of the century.

Direct Federal sponsorship of the technologies rose rapidly in the 1970s, spurred by the desire to develop technologies which were less vulnerable to fuel disruptions and price increases, and which had less severe environmental impacts than many conventional technologies. But direct Federal support has declined from $135 million in 1980 to less than $36 million in 1985 (see table 9-2). The impact of the decline was offset in part by an increase in indirect support in the form of tax incentives during the first half of the 1980s. The effects of conservation, which moderated conventional fuel prices, also dampened the prospects for near term-commercial success.

During the latter half of the 1970s and the early 1980s, the central receiver technology progressed rapidly, culminating in 1982 with the operation of a 10 MWe pilot plant, the Solar One pilot facility. Eighty percent of that project's costs were paid by the Department of Energy (DOE). The plant, while not of commercial scale, has operated quite successfully.

Private sector involvement in the central receiver technology has primarily involved electric utilities as well as equipment developers and vendors. These and other private investors, however, have been unwilling to invest in a commercial plant without Government subsidy, until they had evidence of a successfully operating close-to-commercial unit. Yet neither the private nor public sector participants, alone or in cooperation with each other, have been willing to finance a commercial demonstration unit. Various parties have sought ways around this impasse; others have disbanded and moved away from the technology, assuming that the combined effects of Federal spending cutbacks, the impending expiration of the renewable energy tax credits, and other factors preclude extensive commercial deployment in the near term.[16] By mid-l 985, work on the central receiver technology was confined primarily to federally supported research and development at DOE's Central Receiver Test Facility and on federally funded efforts at the Solar Energy Research Institute to develop low cost and durable heliostats.

The parabolic troughs, meanwhile, progressed much further into the market place. By the early 1980s, the Federal Government had funded nearly a dozen experiments and demonstrations. The technology had reached the point where it was nearly ready for commercial applications.

The relatively short lead-time of the technology allowed the Luz Engineering Corp. to initiate two projects which could be completed soon enough to exploit the Federal renewable energy tax credits even if they expired as planned at the end of 1985. Because the projects were in Cali-

[15]Ken Butti and John Perlin, *A Go/den Thread (New* York: van Nostrand Reinhold Co., 1980).

[16]The central receiver teams at Martin Marietta, Boeing, Rockwell, and to a large extent McDonnell Douglas are being disbanded. In addition, the government and utility support teams at Sandia Livermore, Sandia Albuquerque, Jet Propulsion Laboratory and Electric Power Research Institute also are being disbanded and the personnel being transferred to other positions. See Strategies Unlimited, *Analysis of Equipment Manufacturers and Vendors in the Electric Power Industry for the 1990s. Wind Turbines, Solar Thermal Electric, Photovoltaics,* op. cit., 1984).

fornia, they could also enjoy State tax incentives, favorable solar insolation levels, and high utility avoided cost energy payments. I n December 1984, the first of the two plants, known as Solar Electric Generating System-1 (SEGS-1) and capable of producing 13.8 MWe, had begun operating. By February 1985 construction of a second 33 MWe plant (SEGS-11) was initiated and was expected to begin operating by late 1985 or early 1986. Luz designed these systems, coordinated the projects and was an investment partner in them. The remainder of the investment was provided mostly by large institutional investors through a limited partnership. The system's performance was guaranteed for 20 years by Luz industries (Israel) Ltd., the parent firm, which also provided an insurance policy for the project. Southern California Edison agreed to purchase the power for 30 years. C)ther than the Luz projects, private sector involvement in the trough technology is limited.

Federal support for parabolic dishes developed somewhat later than for the central receiver and troughs. As a result, their development has lagged behind that of the other solar thermal electric technologies. However, the efforts of over half a dozen firms, coupled with direct Federal support and other favorable conditions (including Federal and State tax incentives and the provisions of PURPA) fostered rapid development of the technology, especially during the first half of the 1980s. Notable was the fact that among the firms whose support of parabolic dishes increased during the period were several who previously concentrated on either the central receiver or parabolic troughs.17

By mid-l985, a privately financed commercial dish facility had been installed by the LaJet Energy Co. in southern California. It was financed by the parent company, La Jet, Inc.–a privately held petroleum exploration, drilling, and refining company–and through limited partnerships. Meanwhile, other commercialization efforts were proceeding, the most important of which appeared to be the joint venture of McDonnell Douglas, an aerospace corporation active in the energy field since the early 197os, and United Stirling, AB, a Swedish manufacturer of Stirling engines.

Industry Outlook and Major Impediments

As discussed in chapter 4, widespread commercial deployment of solar thermal electric technologies is unlikely unless costs are reduced, and performance improved. Moreover, investor interest is not likely to be forthcoming until performance is demonstrated.

As with photovoltaics, wind, and geothermal technologies, the Federal Government's policies strongly influence the outlook for the solar thermal electric industries. Without either an increase in direct Federal support or an extension of the renewable energy tax credits beyond 1985, none of the solar thermal technologies is likely to be used much commercially in the 1990s.[18] After 1985, the limited solar thermal electric industry which exists today is likely to shrink rapidly. The commercial activities of Luz in solar troughs and La Jet in parabolic dishes probably would be cut back substantially, as would the efforts of other smaller, entrepreneurial companies in the industry. Only the largest companies may be able to sustain the involvement required to successfully deploy the technology in the 1990s.[19]

Even with increased direct Federal support and favorable tax policies, with the necessary cost and performance improvements, and with commer-

[17] McDonnell Douglas, now a major supporter of the dish technology, previously was heavily involved with the central receiver. Acurex Solar Corp. presently is emphasizing dish technologies too, after having focused its solar thermal electric efforts on trough technology. Acurex still is working on trough technology, but it is emphasizing the use of the technology for industrial process heat or cogeneration.

[18] This was reflected in the testimony of Frank F. Duquette before the U.S. Congress on Mar. 1, 1984. He stated that:

> The nearer term technology, at this stage of development, still requires Federal **support to reduce technical risk and validate commercial or near commercial applications, Private industry is unable to assume the entire burden of completing the R&D tasks remaining for this current generation of technologies.**

(Frank F. Duquette, Chairman, Solar Thermal Division, Solar Energy Industries Association, testimony presented to the Subcommittee on Energy Development and Applications, Committee on Science and Technology, U.S. Congress, Mar. 1, 1984.)

[19] See: 1) Strategies Unlimited, *Analysis of Equipment Manufacturers and Vendors in the Electric Power Industry for the 1990s. Wind Turbines, Solar Thermal Electric, Photovoltaics,* op. cit., 1984; 2) Peter B. Bos and Jerome M. Weingart, *Impact of Tax Incentives on the Commercialization of Solar Thermal Electric Technologies* (Livermore, CA: Sandia National Laboratories, August 1983), SAND 83-8178.

cial demonstrations, success is still by no means guaranteed for these technologies in the 1990s. There are other potential impediments to their deployment. Among these might be problems relating to energy credits, capacity payments, and interconnection requirements. Problematic too could be the lack of widespread experience with the technology; and licensing and permitting delays (among which extensive land impacts and access to water might figure importantly).

In some cases, problems also may develop with regards to the Fuel Use Act. The leading trough technology, that employed at the SEGS-I and II plants in California, requires natural gas to supplement the solar energy in producing steam for the steam turbines. Currently, the Fuel Use Act prohibits the use of gas and oil in many new generating facilities except u rider special conditions. While exemptions to the law may be obtained, the law could delay or even prohibit construction of oil- or gas-using facilities.

The following sections discuss for each technology some of these impediments as well as problems which are crucial to the individual technologies,

Central Receivers.—For the central receiver technology, one impediment stands out among all others—the lack of a commercial-scale demonstration plant, Unless such a plant is initiated very soon and begins operating before the end of the decade, the prospects for this technology in the 1990s are very limited. Should a demonstration plant be initiated later than this, it will be extremely difficult in the time remaining to overcome the many other obstacles blocking significant contribution by this technology to power production in the 199os. In particular, the lack of a commercial demonstration project in the near future is likely to lead to the continued disbanding of organizations originally established to deploy both a demonstration plant and subsequent commercial units.

Several attempts to finance demonstration units by private sources have been initiated but have failed. Hence, it appears unlikely that such plants will be built without Government support .[20] Without timely Government action, this technology's prospects are likely to be severely limited during. the 1990s. Other major impediments which could limit deployment, even if there is prompt construction of a demonstration plant, are: 1) the high cost of heliostats, 2) technical problems with the central receiver and other components, and 3) various nontechnical problems relating to such things as licensing and permitting.

Parabolic Troughs and Dishes.–Unlike the ponds and central receivers, parabolic dishes and parabolic troughs, financed by private investors assisted by State and Federal renewable energy tax credits, already have been deployed and operated in commercial-scale units. Both for dishes and troughs, the combination of cost and performance characteristics and numerous uncertainties at present mitigate against private sector investment that is not in some manner accompanied by Government support. How these conditions will change over the next 5 to 10 years will depend on the interaction of a complex of variables. Estimates and opinions of what will happen range widely; each technology and each particular subvariety of technology has its proponents and detractors.

Generally speaking, capital costs must be reduced and performance improved if the technologies are to be deployed widely. To some extent, this can be fostered by research oriented towards incremental improvements of the commercial-scale systems now operating. Also necessary will be adequate information on the solar resources. And if the technologies are to be extensively deployed in the 199os, perhaps the most pressing

[20] The need for further government support repeated ly surfaces both in the literature and in conversations with knowledgeable individuals. See for examp'e: 1) L.K. Ives and W.W. Willcox, "Economic Requirements for Central Receiver Commercial ization, " *Proceedings of STTF (Solar Thermal Test Facility) Testing for Long Term Systems–Performance Workshop, Jan. 7-9, 1984* (Albuquerque, NM: National Technical Information Service, July 1984), PC Al 5/MF AO1, pp 61-67; 2) Edgar A. DeMeo, "Molten Salt Solar-Thermal Systems, " *EPRI Journal, vol.* 8, No. 12, December 1983, pp. 38-41; 3) McDonnell Douglas, "Response by McDonnell Douglas to General Workshop Discussion Questions, " submitted to OTA in response to written questions submitted in connection with OTA Workshop on Solar Thermal Electric Technologies, 1984; 4) Arizona Public Service Co., et al., *Solar Thermal Central Receiver Development P/an for Me/ten Salt Technology,* mimeo, prepared for U.S. Department of Energy, Jan. 31, 1984; and 5) C.J. Weinberg (Pacific Gas & Electric), letter to Howard S. Coleman (Department of Energy), dated Dec. 21, 1984.

need is to reduce uncertainty and to increase demand to the point where economies of scale can drive costs down.

The extent to which uncertainty will be reduced by the 1990s depends heavily on the amount of additional capacity installed for each of the systems during the next 5 years. Should the tax credits be extended, additional trough and dish systems probably will be installed, serving to reduce considerably the importance of uncertainty as an impediment to commercial deployment. The mounted-engine dishes in particular—where uncertainty now is especially great—could benefit from greater deployment of commercial-scale units, and improved commercial prospects might result. Under such conditions, the mounted-engine parabolic dishes could eliminate the current lead enjoyed by parabolic troughs among the solar thermal technologies. If the engines perform well, the parabolic dish technology could provide serious competition to the troughs and to other generating alternatives in the 1990s.

Without either sizable tax credits or greater direct Government support, however, fewer and perhaps no additional trough or parabolic dish units may be installed. Indeed, the private enterprises which are presently pursuing the technologies may completely cease activities in support of the technologies altogether. Our market analysis suggests that only one of the parabolic dish developers is likely to maintain a significant effort to support the technology if the renewable energy tax credits cease to be available at the end of 1985.[21]

Wind Turbines

History and Description of the Industry

Wind turbines first were used to generate electricity in Denmark nearly 100 years ago. Later, in the early 1930s through the late 1950s the technology was deployed in the United States, predominantly in rural areas. As transmission lines were extended to these areas and cheap electricity provided, the wind turbines ceased to be an attractive option. By the 1960s and early 1970s, technical progress slowed to a crawl and deployment continued at only a very low level.

Interest in wind turbines resurfaced in the 1970s when energy costs skyrocketed, fuel supplies became uncertain, and environmental concerns grew. The resurgence was strongest in the United States and in Europe, especially in Denmark. During the early 1970s, major government programs both in the United States and abroad emphasized the development of large, multi-megawatt wind turbines, though important work applicable to smaller machines also was supported. Outside of government-subsidized programs, smaller units with ratings less than 100 kWe were favored, as these offered the most immediate commercial applications.

By mid-May 1985, wind turbines–mostly small units—with a total rated capacity of over 650 MWe were installed nationwide. Most–about 550 MWe—were in California's wind-farms, which became the focus of the worldwide wind turbine industry. Several basic interrelated elements appear to have shaped development during this period.

First, developers of the large multi-megawatt wind turbines encountered serious technical difficulties. In the United States, the Federal Government cut back its direct support of wind research and development (see table 9-2). The industry, heavily dependent on Federal support, shifted away from the large machines when the Federal aid receded and concentrated on small wind turbines which afforded a more immediate commercial promise.

Second, a combination of favorable circumstances in California prompted rapid growth in the deployment of grid-connected wind turbines. Among these circumstances were the adoption of PURPA Section 210, high electric-utility avoided costs, availability of an excellent and accessible wind resource which had been carefully assessed, favorable Federal and State tax treatment; and favorable treatment by the California Energy Commission and public Utility Commission.

[21] Strategies Unlimited, *Analysis of Equipment Manufacturers and Vendors in the Electric Power Industry for the 1990s. Wind Turbines, Solar Thermal Electric, Photovoltaics,* op. cit., 1984; Peter B. Bos and Jerome M. Weingart, *Impact of Tax Incentives on the Commercialization of Solar Thermal Electric Technologies,* op. cit., August 1983.

Finally, technical development of smaller sized wind turbines proceeded very rapidly as costs declined and performance improved. The extremely favorable conditions in California encouraged the initial commercial deployment of equipment which was new and not fully proven. The processes of research, development, and commercialization came together into one step as California's wind farms became de *facto* open-air laboratories. While this greatly accelerated the development of the technology, it also led to inevitable mechanical failures and inadequacies associated with an emerging and immature technology.

In 1984, there were about 100 wind turbine manufacturers worldwide. They were mostly small, independent businesses dedicated exclusively to the wind industry, and owned and operated by risk-taking entrepreneurrs without extensive business experience, [22] Most of the companies had limited financial reserves, and depended on company growth to cover their past debts and provide working capital. Approximately 70 of the companies in 1984 provided mostly turbines of sizes less than 50 kWe. About 30 companies were active in wind farms and of these, six accounted for 95 percent of the world wind-turbine sales in 1983.23

I n other words, the world wind-turbine industry presently consists of many small firms, but it is dominated by a few manufacturers who possess an advantageous combination of adequate equipment and financial resources. However, even these six companies are relatively small. For example, Energy Sciences, Inc., the third ranking U.S. supplier in 1983, sold $17.5 million worth of wind equipment in 1983. By comparison, the smallest company on the Fortune 1000 list had sales of over $122 million in 1983.[24]

Companies based in the United States dominated the world market for wind power equipment in 1983, accounting for an estimated 72 percent of world sales. But this position is being eroded by foreign competition. By 1984, U.S. manufacturers accounted for 69 percent of world sales of approximately $405 million. The decline of the U.S. position in world markets has been paralleled by its decline in the domestic market as well. The erosion of the U.S. industry's market share is expected to continue. European vendors may achieve parity with U.S. producers in U.S. markets by the end of 1986 and surpass them by 1988. This appears possible due to a superior combination of equipment quality and cost, the latter being greatly affected by the strength of the U.S. dollar. I n addition, European vendors have been very aggressive in exploiting foreign markets.[25]

During the 1980s, the industry has been highly competitive; many companies have entered the business and many others have withdrawn. Currently, the number of firms is declining.

The great bulk of wind turbine capacity deployed in the United States is financed by investors other than the electric utilities and orchestrated by wind *farm developers.* While some developers are independent of the turbine manufacturers (the open "merchant" market), a large and growing share of the wind farms is directly affiliated with the turbine manufacturers themselves.[26] This "captive" wind farm market allows vendors to: 1) capture the developer's profits, which generally exceed their own; 2) regulate turbine demand over the span of each year so that demand is not overly concentrated at year-end; and 3) gain better control over adverse publicity relating to turbine performance.

To date, capital for wind farm investment has rarely come from public stock offerings or from venture capitalists. Most investment has been in the form of limited partnerships, either sold directly by the developer or through brokerage firms. Since 1982, major brokerage houses have been involved and their importance in the industry has increased. Some developers, however,

[22] See for example comments of Bror Hanson in *Alternative* Sources *of Energy, vol. 50,* July/August 1981, p. 5.

[23] Strategies Unlimited, *Analysis of Equipment Manufacturers and Vendors in the Electric Power Industry for the 1990s. Wind Turbines, Solar Thermal Electric, Photovoltaics,* op. cit., 1984.

[24] 1 bid.

[25] Ibid.

[26] This vertical Integration typically takes several forms: the manufacturer may itself obtain the land, utility contracts and capital required for the wind farm; or 2) it may simply acquire a developer, or form exclusive relationships with a developer or an equipment distributor.

use so-called "chattel" sales to avoid dependence on brokerage houses. Each of these financing arrangements has its advantages and problems, and affects wind turbine deployment in a different way. The manner in which financing is obtained therefore will continue to be of critical importance to the industry. (See chapter 8 for more details on financing arrangements.)

Industry Outlook and Major Impediments

As mentioned earlier, wind turbines during the first half of this decade have benefitted from favorable tax treatment; chapter 8 discusses the effects of specific Federal tax provisions on wind turbine economics and highlights their importance. Potential tax changes, therefore, are of concern to the industry. The tax change of most immediate concern is the scheduled expiration of the Federal renewable energy tax credit (RTC) at the end of 1985.

Expiration of the RTC is likely to result in a major shake-out in the U.S. wind industry. Barring unexpected increase in electric utility involvement, demand for wind turbines probably will drop sharply, and many small firms are likely to collapse. Only larger firms with sufficient capital to further develop medium-sized turbines and weather a period of intense competition and relatively low sales will survive. Though the size of the industry and the variety of firms could be greatly diminished, and though technical progress is likely to be slowed considerably, many industry observers believe that the industry could survive, and perhaps even benefit, from a termination or phase-down of the RTC.

Though the RTC has stimulated technical development and commercial deployment, which otherwise could not have occurred in the early 1980s, they also have been abused by some investors as short-term tax shelters.[27] Such abuse has prompted Federal tax fraud investigations and hurt the reputation of the industry.[28]

Alternatives to a simple extension of the current Federal credits have been suggested. One would gradually phase-out the tax credits over several years; this might help the industry complete the commercial transition from small tax-subsidized turbines to unsubsidized and economic medium-sized units. Another would establish a system of credits based on energy production rather than capital investment; [29] these are discussed in greater detail in chapter 10.

Aside from the immediate issue of the RTC, other possible circumstances could also slow the development and deployment of competitive, medium-sized turbines in the 1990s. Problems relating to the following could arise.

Equipment Quality.—Technical improvements are necessary if wind turbines are to compete without subsidy. While improvements are being made, cessation of the RTC at the end of 1985 and of the California tax credit several years later is likely to severely reduce the capital available to finance development and production of new wind turbine designs. Moreover, the likelihood of smaller markets will reduce the opportunity to actually deploy the units and thereby generate the data necessary for further improvement. The difficulty in financing the redesign and manufacture of new equipment probably will be particularly severe among the small wind turbine manufacturers.

Wind Resource Information.–Detailed wind resource information is crucial to the growth of wind-farms around the country. While current meteorological data allows identification of potential sites,[30] detailed site-specific information must still be gathered for at least 1 to 3 years to adequately assess the potential of specific sites. While site-specific information is being generated at a rapid pace, the lack of such information still could hinder deployment in the 1990s.3' The

[27] See **statement** of Bill Adams, San Gorgonio Farms, as quoted in "San Gorgonio Farms (SGF) Will Install 53 Carter Wind System Model 225's, " *Wind Industry News Digest,* vol. 4, No. 4, Feb. 15, 1984, p. 3.

[28] Largely in response to tax-shelter abuses, the American Wind Energy Association established an ethics committee to monitor the industry and discourage behavior which harms the long-term interests of the business. See: Burt Solomon,'Windmillers Clean Up Act, " *Energy Daily, vol.* 13, No. 12, Jan. 17, 1985, pp. 1 and 3.

[29] Strategies unlimited, *Analysis of Equipment Manufacturers and Vendors in the Electric Power Industry for the 1990s. Wind Turbines, Solar Thermal Electric, Photovoltaics,* op. cit., 1984.

[30] Battelle, pacific Northwest Laboratories, *Application Examples for Wind Turbine Siting Guidelines* (Palo Alto, CA: Electric Power Research Institute, March 1983), AP-2906.

[31] See: 1) JBF Scientific Corp., *Ear/y Utility Experience With Wind Power Generation: Goodnoe Hi//s Project* (Palo Alto, CA: Electric Power Research Institute, January 1984), vol. 3, EPRI AP-3233; 2) Dean W. Boyd, et al., *Commercialization Analysis of Large Wind Energy Conversion Systems* (Palo Alto, CA: Decision Focus Inc., June 1980).

need for wind assessment extends to prospective export markets as well, where data are especially inadequate.[32]

Land Access and Cost of Access.—Access to wind-swept land has in some instances been a problem.[33] Furthermore, costs of access have increased substantially. Development of the wind resource presupposes access at an acceptable cost. These potential problems may slow deployment in the next 15 years.

Cost and Performance Data.–Current cost and performance data are very important to prospective wind turbine investors as well as to utilities, public utility commissions, and the turbine manufacturers themselves. At present such data are difficult to obtain, precluding accurate prediction of wind turbine cost and performance prior to deployment. Efforts are being made in some States to increase the information available on current machines.[34] Where performance data are available, use is often limited by inconsistencies and other problems.

Standard Definitions and Performance Leveis.– The effective use of performance data often is limited by inconsistencies; standard definitions might assist investors and others in comparing wind turbines with each other as well as with competing generating technologies. The value of such standards is enhanced when they are provided by an independent and trustworthy source. Of even greater value might be the establishment of minimum standard performance levels which turbine performance must meet in order to receive certification. Many industry observers believe standards should be applied to the industry, though there is disagreement over who should impose the standards and what the standards should be.

Warranties.–Investors, in view of the past poor performance of some wind turbines, are reluctant to invest in hardware unless it is accompanied by a strong warranty. This essentially shifts part of the risk of owning and operating a wind turbine back to the vendor. Because current technology is immature, however, such warranties are in themselves risky and could lead to high costs for vendors. indeed, some manufacturers have been driven out of business because of these costs.[35] While vendors can purchase "warranty insurance, " this insurance has become progressively expensive as insurers have become more cautious with wind turbines.[36] Should the industry be short of capital during the next 15 years, the warranty issue could constitute an important impediment to industry expansion.

Government Permits and Licenses.–Wind farm promoters are expected to encounter problems as they seek approval for their projects from Federal, State, and local regulatory agencies. The most serious problems are likely to be at the local level, where wind farms have already encountered public opposition because of visual and environmental impacts.[37]

Transmission Facilities.—Without access to transmission facilities, even the most attractive site cannot be 1 inked to the grid. Major transmission facilities often require lead-times of 3 to 10 years. Clearly, if candidate wind sites do not already have easy access to transmission lines, serious delays may be encountered. Widespread wind turbine deployment in the 1990s will either be limited to areas which already have access to transmission lines, or if currently remote areas are to be developed, efforts to extend transmission

[32] S.K.Griffith, et al., *Foreign Applications and Export Potential for Wind Energy Systems* (Golden, CO: Solar Energy Research Institute, 1982), subcontractor report, SE RI/STR-21 1-1827.

[33] R.), Noun, et al., *Utility Siting of WECS: A Preliminary Legal/Regulatory Assessment* (Golden, CO: Solar Energy Research Institute, May 1981).

[34] The State of California, for example, requires that production and other data (Including cost data) be provided on a quarterly basis by all wind project operators in the State, The American Wind Energy Association is developing a voluntary national reporting program similar to California's mandatory program,

[35] For example, see: 1) "How Wind Power Cracks Up, " New *Scientist,* Apr. 12, p. 31; 2) Arthur D. Little, Inc., *Wind Turbine Performance Assessment* (Palo Alto, CA: Electric Power Research Institute, 1984), Technology Status Report No. 7, EPRI AP-3447; 3) Larry Stoiaken, "The Small Wind Energy Conversion System Market: Will 1984 Be 'The Year of the SWECS'?" *Alternative Sources of Energy,* vol. 63, September/October 1983, pp. 10-23; and 4) Strategies Unlimited, *Analysis of Equipment Manufacturers and Vendors in the Electric Power Industry for the 1990s. Wind Turbines, Solar Thermal Electric, Photovoltaics,* op. cit., 1984.

[36] Ronald L. Drew, "Wind Energy: The Present Status of Relevant Insurances, " *Alternative Sources of Energy, vol. 72,* March/April 1985, pp. 56-59.

[37] See chs. 4 and 7 for further details.

facilities to those areas must be initiated within the next decade.[38]

Utility Energy and Capacity Credits, and interconnection Requirements.– Low energy credits, low capacity payments,[39] and stringent interconnection requirements discourage deployment by nonutilities. Even where the *possibility* exists that credits could drop during the lifetime of a project, investment is discouraged. Also, any difficulties (such as delays) encountered in seeking to obtain favorable credits or interconnection requirements discourages non utility deployment.

Overseas Markets.–Over the next decade, foreign markets are likely to be important outlets for wind turbines, especially small machines for remote applications;[40] under some conditions they could be crucial to the survival of major manufacturers. Already, exports account for a sizable share of turbine sales by U.S. manufacturers, and current evidence indicates that many are actively developing overseas markets.[41] The promotion by the companies themselves and by others of overseas sales appears to constitute a major opportunity to nurture the industry and to indirectly foster further refinement of the technology. Difficulties in exploiting these markets (including problems relating to foreign competition) therefore could severely damage the industry, reducing its capacity to supply the domestic markets with turbines of acceptable quality and in the quantities demanded for the 1990s.

[38] For example, the lack of transmission capacity in California reportedly prevented development of some prime wind sites. Source: OTA staff conversation with Mike Batham, California Energy Commission, November 1984.

[39] For a discussion of capacity credits in the wind industry, see Fred Sissine, *Wind Power and Capacity Credits: Research and Implementation Issues Arising From Aggregation With Other Renewable Power Sources and Utility Demand Management Measures* (Washington, DC: Congressional Research Service, 1984).

[40] See: 1) Birger T. Madsen, "Danish Windmills: A View From the Inside," *Alternative Sources of Energy, vol. 69,* September/October 1984, pp. 24-26; 2) S.K. Griffith, et al., *Foreign Applications and Export Potential for Wind Energy Systems* (Golden, CO: Solar Energy Research Institute, 1982), subcontractor report, SERI/STR-21 1-1827; 3) Les Garden, "The Overseas Market: Does the Post-Tax-Credit Transition Start Now?" *Alternative Sources of Energy, vol. 69,* September/October 1984, pp. 28-30; 4) Larry Stoiaken, "International Marketing: U.S. Wind Firms Make Their Move," *Alternative Sources of Energy,* vol. 72, March/April 1985, pp. 21-23.

[41] See, for example: 1) "FloWind Signs 'Document of Mutual Interest' With Chinese for 40 Darrieus Turbines," *Solar Energy Intelligence Report,* Jan. 21, 1985, p. 24; 2) Larry Stoiaken, "The Small Wind Energy Conversion System Market: Will 1984 Be 'The Year of the SWECS' ?" op. cit., 1983; 3) Larry Stoiaken, "Going International," *Alternative Sources of Energy,* vol. 63, September/October 1983, pp. 24-25.

Geothermal Power

History and Description of the Industry

In 1904, Italy became the first country in the world to use geothermal energy to produce electricity. In 1923 geothermal resources were tapped in the united States to produce electric power. At that time, a small, remote 250 kWe unit began generating power for a California hotel at The Geysers. ***Over*** 35 years elapsed, however, before further capacity was installed in the United States when, in early 1960, the first grid-connected geothermal unit began to generate power at The Geysers. During the following 20 years, further development occurred and by the end of 1983, 1,300 MWe of geothermal capacity were on-line in the United States—more capacity than in any other country. Worldwide, about 3,400 MWe were operating.[42]

Most U.S. geothermal development, located at The Geysers in California, employed direct steam conversion technology. As discussed in chapter 4, however, most U.S. geothermal resources are of lower quality than those found there and cannot be exploited with the conventional technology used at The Geysers. As development activity progressed in the 1960s, the need for different technologies for lower quality resources became evident. Further geothermal development increasingly would require other equipment such as the developing technologies considered in this assessment—dual flash and binary systems.

While the need for technological progress was apparent in the 1960s, it was not until recently that these new technologies began to be deployed in the United States. Several factors, including problems regarding Federal leasing policies and technological questions, served to impede the development of the lower quality geothermal resources. Progress in these matters, along with the passage of PURPA, favorable Fed-

[42] Ronald DiPippo, "Development of Geothermal Electric Power Production Overseasr " *Energy Technology XI, Applications& Economics: Proceedings of the Eleventh Energy Technology Conference, Mar. 79-21, 1984,* Richard F. Hill (cd.) (Rockville, MD: Government Institutes, Inc., August 1984), pp. 1219-1227.

eral and State taxes, and high avoided costs, brought commitments to the technologies during the first half of the 1980s. By the end of 1985, a single 47 MWe (net) dual-flash geothermal unit will be in place. One large (45 MWe, net) binary plant will have been installed and at least 30 MWe of small binary plants will be operating. Together these will account for about 122 MWe, or about 7 percent of total U.S. installed geothermal capacity at the end of 1985 (about 1,780 MWe[43]).

Important to these technological developments has been the Federal Government's support of the industry since the mid-1970s. The first major Federal assistance came in the form of the Geothermal Loan Guarantee Program. This soon was coupled to stepped-up support for research and development (see table 9-2). From 1973 through 1983, approximately $1 billion was spent on geothermal power by the Federal Government, roughly matching industry's expenditures. Direct Federal expenditures in support of the technology, concentrated in DOE and its predecessor agencies, grew from $3.8 million to $171 million in 1980; however, as of fiscal year 1985 this had dropped to $32.1 million. The recent decline in direct Federal expenditures was partially offset by increases in indirect Federal support of the industry through various tax incentives, including the Renewable Energy Tax Credit.

Discovery of geothermal resources has long been associated with oil exploration and development in this country, When geothermal activity picked-up in the 1960s, several oil companies entered the geothermal business. Since then, the oil industry has continued to be deeply involved with geothermal development, and indeed heavily dominates the industry. At the same time, a group of smaller, independent enterprises has sought to develop geothermal power, usually by pursuing the relatively marginal resources.

Among the businesses in the geothermal industry is a core of about two dozen companies capable of sustaining the full effort required to bring geothermal projects to fruition. In addition, there are many other companies and organizations, such as electric utilities, drilling companies, architectural and engineering firms, and the Electric Power Research Institute (EPRI), which support the development and deployment of the technology.[44]

Until the late 1970s, geothermal development was carried out through cooperative ventures between field developers and electric utilities. The field developers located the resource and then worked with the electric utility and architect-engineering firms to design and construct a powerplant. The field developer then would tap the geothermal resource and deliver the hot water or steam "over the fence" to the electric utility. Since 1978, though, PURPA, favorable tax treatment, and high avoided costs have stimulated nonutility investment in power generation projects, and purely nonutility projects have become prevalent in Oregon, California, and Nevada.

Industry Outlook and Major Impediments

By the year 2000, a total U.S. geothermal capacity from 2,600 to about 6,800 MWe may be in place. A sizable portion of this could consist of the developing technologies discussed in chapter 4. Most will be located in California, Hawaii, Arizona, New Mexico, Nevada, and Utah.qs The degree to which the potential will be realized depends on a variety of circumstances.

As with the other renewable energy technologies, the status of various State and Federal tax incentives will strongly influence deployment levels. As mentioned in chapters 4 and 8, the tax incentives make geothermal investments much more attractive and have been especially important in advancing the technologies during the

[43] Vasel Roberts, "Utility Preface, " *Proceedings: Eighth Annual Geothermal Conference and Workshop,* Altas Corp. (cd.) (Palo Alto, CA: Electric Power Research Institute, 1984), EPRI AP-3686, p. v.

[44] Vane E. Suter, "Who Will Develop the Governmental Resources?" *Proceedings: Seventh Annual Geothermal Conference and Workshop,* Altas Corp. (cd.) (Palo Alto, CA: Electric Power Research Institute, 1983), EPRI AP-3271, pp. 7-10 through 7- 13; and Vasel W. Roberts, "EPRI Geothermal Power Systems Research Program, " *Proceedings: Eighth Annual Geothermal Conference and Workshop,* Altas Corp. (cd.) (Palo Alto, CA: Electric Power Research Institute, 1984), EPRI AP-3686, pp. 4-1 through 4-3.

[45] Vasel Roberts and Paul Kruger, "Utility Industry Estimates of Geothermal Energy," *Proceedings: Eighth Annual Geothermal Conference and Workshop,* Altas Corp. (cd.) (Palo Alto, CA: Electric Power Research Institute, 1984), EPRI AP-3686, p. 4-27 through 4-31.

early 1980s.[46] Elimination or reduction in the size of the tax incentives—or even the possibility of such changes—is likely to slow deployment.

Important too will be other government activities at the Federal, State, and local levels. The level of direct support for R&D will continue to be a key determinant of technical progress in the industry. Also influential will be the many forms of regulatory control government agencies exert over the activities required to deploy geothermal technologies. Because of the importance of government, and the number and diversity of relevant agencies, the degree to which their activities are coordinated will be equally important .4'

Other factors that may impede the deployment of geothermal technologies in the 1990s include:

Equipment Cost and Performance.–As discussed in chapter 4, dual-flash and binary-cycle technologies are relatively immature. Cost reductions and performance improvements in some cases may be necessary, not only with the equipment used in actually producing the electric power, but in some cases also in the technology required to deliver brine to the surface. The rate at which progress occurs depends strongly on the amount of capital devoted to R&D.

Three factors may retard R&D investment. First, the members of the geothermal industry most capable of shouldering R&D investments–those affiliated with the petroleum companies–may not invest the necessary capital,[48] partly because of the current soft petroleum market, Second, activity in the geothermal industry is affected heavily by nonutilities, whose investment levels are influenced strongly by State and Federal tax policies. possible changes in the policies, the most immediate of which is the expiration of the Federal renewable energy tax credit, will greatly diminish geothermal investment. Third, the Federal Government, which historically has been the major source of R&D funds, has sharply cut its support (see table 9-2).

Technology Demonstration.–Beyond the geothermal demonstration plants already being built or operating, very little additional capacity is planned with the developing geothermal technologies. Should few additional plants be deployed in the next 5 to 10 years, the lack of extensive commercial experience is likely to impede rapid expansion of capacity in the 1990s, since the associated risks may be perceived as too high. Difficulties in gaining access to adequate information on cost and performance could also slow timely deployment of developing geothermal technologies in the 1990s.[49]

Geothermal Exploration, Resource Identification and Assessment.–Once a geothermal resource is discovered, more precise information on the quality of the resource is needed in order to assess the economics of site development and to optimize plant design. This requires that resource qualities be measured further and the information analyzed. The lack of site measurements and adequate analytical capabilities are considered major impediments to the development of geothermal power.

Federal Leasing Requirements.–A considerable portion of the geothermal resource in the United States lies under Federal lands. The leasing of this land, administered by the Bureau of Land Management, is characterized by two requirements which may impede deployment of geothermal technologies. First, no single leaseholder may hold leases covering more than 20,480 acres in any specific State. SO This report-

[46] Subcommittee on Energy and Mineral Resources, Senate Committee on Energy and Natural Resources, U.S. Congress, *Geothermal Energy Development in Nevada's Great Basin: Hearing to Examine the Current Status and Future Needs of Nevada Geothermal Energy Industry* (Washington, DC: U.S. Government Printing Office, 1984) Sparks, Nevada, April 17, 1984, S.Hrg. 98-801,

[47] Alex Sifford, *Background Geothermal /formation for the 1985 Energy P/an* (Salem, OR: Oregon Department of Energy, February 1985), mimeo, and James Ward, "Geothermal Electricity in California, " Transitions to Alternative Energy Systems–Entrepreneurs, New Technologies, and Social Change, Thomas Baumgartner and Tom R. Burns (eds.) (Boulder, CO: Westview Press, 1984), pp. 167-186.

[48] See, for example, Chris B. Amundsen, et al., *A Summary of U.S. Department of Energy Geothermal Research and Development Program Accomplishments, Industry Response, and Projected Impact on Resource Development* (Philadelphia, PA: Tech necon Analytic Research, Inc., 1983).

[49] U.S. Department of Energy, *Geothermal Progress Monitor* (Washington, DC: DOE, 1983), Report No. 8; and testimony of Jon Wellinghoff (Consumer Advocate, State of Nevada), p. 5 in Subcommittee on Energy and Mineral Resources, *Geothermal Energy Development in Nevada Great Basin: Hearing to Examine the Current Status and Future Needs of Nevada's Geothermal Energy Industry,* op. cit., 1984.

[50] The 197o Geothermal Steam Act, however, does allow the Secretary of Interior to raise the statewide acreage limitation after Dec. 24, 1985. Indeed, in April 1985, the Department of the Interior proposed that the limitation be raised to 51,200 acres.

edly has slowed the rate at which resources can be assessed and at which development can occur. Second, primary lease terms are for 10 years; a leaseholder must develop the land within that period or lose the lease. This may inhibit commitments to develop particular geothermal resources.[51]

Utility Energy and Capacity Credits, and interconnection Requirements.—As with the other technologies discussed so far in this chapter low energy credits, low capacity payments, and stringent interconnection requirements discourage deployment by nonutilities. Even where the *possibility* exists that credits cou ld drop during the lifetime of a project, investment is discouraged. Also, any difficulties (such as delays) encountered in seeking to obtain favorable credits or interconnection requirements discourages non utility deployment.[52]

Transmission Capacity .—Like wind resources, geothermal resources often are located in areas which are not readily accessible or located near transmission facilities. Moreover, in some cases, the geothermal resources are far from the markets offering the highest avoided costs. The lack of adequate transmission facilities connecting the resources with markets and/or institutional mechanisms for wheeling power to these markets is considered a major impediment to the further deployment of geothermal technologies of any kind, especially in Oregon and Nevada.[53]

Leasing, Permitting, and Licensing Delays.– Where geothermal development is planned on Federal property, considerable delays may be occasioned in securing the necessary lease. Further delays also may result as the requisite licenses and permits are obtained from various public agencies.[54] Problems regarding water consumption and subsidence in particular may occasion delays, particularly in agricultural areas.[55] Together, these time-consuming steps may limit the amount of capacity which could be deployed in the 1990s.

Fuel Cells

History and Description of the Industry

The current major efforts to develop the fuel cell for grid-connected applications in the United States are split between natural gas and electric utilities. The electric utilities are pursuing the use of fuel cells in central station applications, while gas utilities have concentrated on relatively small, "onsite" fuel cells which would increase markets for natural gas.

As with photovoltaics, the initial commercial impetus behind fuel cell development in the United States was the space program in the 1950s and 1960s. Efforts to develop fuel cells for ter-

[51] See: 1) J. Laszlo, "Findings of U.S. Senate Hearings on Geothermal Development in Nevada, " *Proceedings: Eighth Annual Geothermal Conference and Workshop,* Altas Corp. (cd.) (Palo Alto, CA: Electric Power Research Institute, 1984), EPRI AP-3686, p. 6-16 through 6-20; 2) Vane E. Suter, "Who Will Develop the Governmental Resources?" *Proceedings: Seventh Annual Geothermal Conference and Workshop,* op. cit., 1983; 3) Subcommittee on Energy and Mineral Resources, *Geothermal Energy Development in Nevada Great Basin: Hearing to Examine the Current Status and Future Needs of Nevada Geothermal Energy Industry,* op. cit., 1984; *4)* Subcommittee on Energy and Mineral Resources, Senate Committee on Energy and Natural Resources, U.S. Congress, *Geothermal Steam Act Amendments of 1983* (Washington, DC: U.S. Government Printing Office, 1983), Hearing, May 2, 1983, S.Hrg. 98-392; and 5) James Ward, "Geothermal Electricity in California, " *Transitions to Alternative Energy Systems–Entrepreneurs, New Technologies, and Social Change,* op. cit., 1984).

[52] See J. Laszlo, "Findings of U.S. Senate Hearings on Geothermal Development in Nevada, " op. cit., 1984, and Subcommittee on Energy and Mineral Resources, *Geothermal Energy Development in Nevada's Great Basin: Hearing to Examine the Current Status and Future Needs of Nevada's Geothermal Energy Industry,* op. cit., 1984.

[53] See:, 1) J. Laszlo, "Findings of U.S. Senate Hearings on Geothermal Development in Nevada, " op. cit., 1984; **2)** C.J. Weinberg, "Role of **Utilities, Resource Companies, and Government: Discussion Group Report, "** *Proceedings: Seventh Annual Geothermal Conference and Workshop,* Altas Corp. (cd.) (Palo Alto, CA: Electric Power Research Institute, 1983), EPRI AP-3271, pp. 7-26 through 7-27; and 3) Subcommittee on Energy and Mineral Resources, Geo*thermal Energy Development in Nevada's Great Basin: Hearing to Examine the Current* Status *and future Needs of Nevada Geothermal Energy Industry,* op. cit., 1984.

[54] Included in *the* information required for facility licensing and permitting is baseline data on the environmental conditions at a site. For more information, see Alex Sifford, *Background Geotherma/ /formation for the 1985 Energy Plan,* op. cit., 1985.

[55] For a *discussion* of the water issue in the Imperial Valley, where considerable deployment of dual-flash and binary systems may occur in the 1990s, and where agriculture is very important, see: Department of Public Works, Imperial County, *Water for Geothermal Development in Imperial County: A Summarizing Report* (El Centro, CA: Imperial County, June 1984), special report, DOE Cooperative Agreement DE-FC03-79ET271 96.

restrial applications multiplied during the mid-1960s, but by the end of the decade most had ceased with one notable exception. In 1967 a group of gas utilities formed an organizations to develop equipment that somehow could counter the electric power industry's capture of the gas industry's markets. This and subsequent programs culminated in the current effort in which the Gas Research Institute (GRI), funded by the gas industry, and DOE are deploying and testing forty-six 40 kwe fuel cell cogeneration units. Several units of this size also were installed in Japan. Concurrently, GRI and DOE are funding a coordinated multi-year research project expected to yield an "early entry" onsite fuel cell system with an expected output of about 200 to 400 kWe.

Meanwhile, since 1971, fuel cell manufacturers, electric utilities,[57] the Electric Power Research Institute, the Federal Government and others have sought to develop and deploy multi-megawatt fuel cell power facilities. By 1978, a 4,5 MWe project was initiated in New York City. The New York unit suffered from delays in gaining local regulatory approval. These delays exceeded the storage life of the power section so that the unit could not be operated without refurbishment. As a result, the project was abandoned in 1984. Another similar, but improved unit was installed in Japan. That unit, made by the same manufacturer which produced the New York installation, has operated very successfully since April 1983. Currently, plans are being laid both in the United States and in Japan to first develop and deploy commercial demonstration units, and then to initiate commercial production of fuel cells late in the 1980s or early 1990s.

In the recent years a number of cooperative agreements between Japanese and U.S. firms have evolved, perhaps the most important of which is the joint venture between United Technologies and Toshiba. The two companies have agreed to cooperative electric utility commercial powerplant design and development activity. This alliance may lead to an agreement to construct a fuel cell production facility in the United States sometime in the near future.[58] The substantial capital and technological capabilities of these corporations enhance the prospects that the hurdles faced in early commercialization may be successfully and readily overcome.

Government involvement on both sides of the Pacific has been extensive. In the United States, Federal funding has been divided between military/space applications and support of civilian commercial uses. The support for civilian applications has emphasized the use of fuel cells in transportation and in electric power generation; this support has emanated from DOE and its predecessor agencies. The DOE program of greatest importance to the near-term commercial prospects of the fuel cell is the Phosphoric Acid Fuel Cell Program. The National Aeronautics and Space Administration (NASA) -Lewis Research Center has been designated by DOE as the lead center for the program.

DOE's funding for fuel cells is summarized in table 9-2. DOE's support peaked in 1984, when $42.3 million were spent on the technology. A very substantial portion of the funds has been dedicated to the phosphoric acid technology–which is the most promising technology for initial commercial penetration. While DOE spending on fuel cells dropped only slightly in fiscal year 1985, a substantial reduction to $9.3 million has been proposed for 1986. Under the latter proposal, support for the phosphoric acid technology is eliminated altogether.[59]

Although some fuel cell research and development took place in Japan during the 1960s and 1970s, the current Japanese fuel cell program did

[56]The Team to Advance Research on Gas Energy Transformation (TARGET).

[57]Electric Utility efforts in support of the fuel cell have been mediated in part through the Electric Utility Fuel Cell Users Group, an association established about 5 years ago. The group, now consisting of over 60 members, works closely with EPRI, fuel cell vendors and others to promote the use of fuel cells among electric utilities. For more information, see "Fuel Cell Users Group, " *EPRI Journal, vol.* 10, No. 1, January/February 1985, pp. 62-63.

[58]P. J, Farris, Business Planning Staff, International Fuel Cells (unpublished memorandum for OTA staff), June 18, 1985. For more information on these U.S.-Japanese efforts, see: Peter Hunt Associates, *Analysis of Equipment Manufacturers and Vendors in the Electric Power Industry for the 1990s as Related to Fuel Cells* (Alexandria, VA: Peter Hunt Associates, 1984), OTA contractor report.

[59]See Herbert Lundblad and Ronald R. Cavagrotti, *Assessment of the Environmental Aspects of DOE Phosphoric Acid Fuel-Cell Program* (Cleveland, OH: Lewis Research Center, 1983), DOEINASA–2703-3, pp. 7-20; and Fred Sissine, *Fuel Cells for Electric Power Production: Future Potential, Federal Role and Policy Options* (Washington, DC: Congressional Research Service, 1985).

not materialize until 1981. At that time, under the aegis of the Ministry of International Trade and Industry (MITI), the agency's "Moonlight Project" initiated a coordinated program directed towards the development of fuel cell technologies for various applications. Al I of the Japanese equipment manufacturers are working u rider this program, as are several Japanese utilities.

While the Japanese have in the past lagged behind the U.S. program, it appears that the current Japanese program has narrowed the gap. This results in part from the attentive observation of and participation i n U,S. efforts. The Japanese have learned from U.S. successes and mistakes, while providing their own refinements and modifications.

Industry Outlook and Major Impediments

The fuel cell industries in both the United States and Japan are positioning themselves for substantial commercial deployment of fuel cells in the 1990s. At the cost and performance levels which the fuel cells may achieve, extensive markets for both central station and dispersed applications could develop.

Deployment in Japan, fostered by the government (MITI), could be quite rapid. Particularly important in this regard is the close working relationship the Japanese fuel cell developers have with the country's electric power companies. This will ease the difficulties the manufacturers might encounter in the early stages of commercial transition. Over the next 15 years the well-coordinated Japanese effort probably will place that country's fuel cell manufacturers in a position comparable or perhaps superior to their U.S. counterparts barring significant increases in this country's efforts.[60] In Japan, fuel cells using primarily imported natural gas are expected to provide a few percentage points of total generating capacity by 1995, and could provide 7 to 8 percent of generating capacity at the beginning of the 21 st century.[61]

The rate at which fuel cells are deployed in the United States probably will be slow at first, until confidence among potential investors is built up. The length of this transitional period is a matter of speculation. It is likely that the first commercial units will not be erected until investors are convinced these early commercial systems will operate well, Since both the small (200 to 400 kWe) and large (multi-megawatt) demonstration units will not be installed until the latter part of the 1980s, operating experience sufficient to justify initial commercial orders probably will not develop until the beginning of the next decade. It is likely that the proposed termination of Federal funding of phosphoric acid fuel cell development will slow this process and perhaps weaken the industry's competitive status with the Japanese; but it is not clear how serious the effect will be.[62]

The potential market in the United States is very large. An EPRI study of the potential utility market suggests that fuel cells could provide as much as 65,000 MWe of generating capacity by 2005.[63] At the same time, circumstances favor non utility development too. Substantial advantages are associated with dispersed cogeneration applications under nonutility ownership. Investors, led by the gas utilities and perhaps the fuel cell manufacturers themselves, could stimulate rapid growth in nonutility applications in the 1990s.[64]

By the mid-l990s, total experience around the country and in Japan could be sufficient to trigger rapid growth in the technology in the late 1990s. With very favorable conditions, this growth could occur even sooner. Various impedi-

[60] Ernest Raia, "Fuel Cells Spark Utilities' Interest, " *High Technology*, vol. 4, No. 12, December 1984, pp. 52-57.

[61] N. Horiuchi et al., "Applications of Fuel Cell Power Plants in Japanese Utility Use, " 1983 *National Fuel Cell Seminar: Program and Abstracts* (Washington, DC: Courtesy Associates, Inc., 1984), Orlando, FL, Nov. 13-16, 1983, pp. 173-176.

[62] Robert L. Civiak, et al., *Impacts of Proposed Budget Cuts in Selected Energy Research and Development Programs* (Washington, DC: Congressional Research Service, 1985).

[63] Electric power Research Institute (E PRI), *Application of Fuel Cc//s on Utility Systems: Study Results* (Palo Alto, CA: EPRI, 1983), vol. 1, EPRI EM-3205.

[64] Peter Hunt Associates, *Analysis of Equipment Manufacturers and Vendors in the Electric Power Industry for the 1990s as Related to Fuel Cc//s,* op. cit., 1984.; Peter B. Bos and Jerome M. Weingart, "integrated Commercialization Analysis for New Power Generation Technologies, " *Energy* Technology X/, Applications *and Economics: Proceedings of the Eleventh Energy Technology Conference, Mar. 19-21, 1984,* Richard F. Hill (cd.) (Rockville, MD: Government Institutes, Inc., August 1984), pp 188-205; and "Industrial, Commercial Sites Eye Fuel Cells, " *Coal Technology Report,* Jan. 23, 1984, p. 2.

ments, however, could delay extensive commercial deployment until after the close of the century. These impediments are listed below.

Equipment Cost and Performance. -As was discussed in chapter 4, current evidence suggests that it is possible to mass produce fuel cells, to sell them at acceptable prices, and to operate them without excessive problems. However, this is by no means certain. Demonstration plants are necessary to reduce the uncertainty to a level more acceptable to investors. Further research and development, aimed at incremental improvements in the equipment, would increase the possibility that cost and performance will fall within the necessary ranges in the 1990s.

Perhaps the most important impediment facing the fuel cell is the lack of an initial market sufficient to justify mass-production. Without a sizable initial market, only small numbers of relatively expensive fuel cells can be manufactured. These must be sold at high prices–thereby inhibiting demand—or the manufacturer must, in the short term, operate at a loss. The time it takes to overcome this problem will, perhaps more than any other factor, determine the rate of commercial application of fuel cells in the 1990s.

Technology Demonstration.–The successful demonstration of both small and large fuel cells will be of critical importance to stimulating investment in the technology. Demonstration units will be needed to encourage the initial round of orders,

Utility Energy and Capacity Credits, and interconnection Requirements.–As mentioned above, a major market for fuel cells lies outside the electric utilities. Like other grid-connected, nonutility applications initiated under PURPA, low energy credits, low capacity payments, and stringent interconnection requirements discourage deployment by nonutilities. Even where the possibilityty exists that credits could drop during the lifetime of a project, investment is discouraged. Also, any difficulties (such as delays) encountered in seeking to obtain favorable credits or interconnection requirements discourages nonutility deployment.

Licensing and Permitting De[ays.–In the long term, licensing and permitting delays are likely to be minimized by virtue of the technology's relatively low environmental impacts. However, other circumstances might lengthen delays. The technology will in many instances be installed in areas where powerplants have not been traditionally sited and in highly populated areas where safety considerations are likely to be heavily emphasized. Moreover, the technology is new and regulatory officials are not well acquainted with it. The 4.5 MWe facility which was installed in New York was the subject of many unexpected delays; similar problems could develop with future plants.

Integrated Gasification/Combined= Cycle Plants

History and Description of the Industry

The integrated gasification/combined-cycle plant (IGCC) is a relatively new combination of components—gasif iers, gas turbines, and steam turbines—which themselves have been around in some form for a long time. Steam turbines have been used to generate electrical power since 1930 in the United States, and now are used to generate more electrical power worldwide than any other technology.[65]

Gas turbines were not used for commercial generation of electric power in the United States until 1961. Spurred by the need for fast-starting generating capacity and encouraged by the short lead-times typical of gas turbines, utilities in the 1960s and early 1970s deployed many of these units.[66]

Coal gasifiers were being used commercially by the early 1800s. By 1930, there were about 11,000 coal gasifiers in the United States. These were used to produce gas for both light and heat in cities as well as for industrial uses. From the 1930s through the mid-l950s, development con-

[65] Based on telephone conversation between Bruce W. Morrison, V.P. Atlantic Region, Westinghouse Electric Corp., and OTA staff, May 16, 1985.

[66] Ibid.

tinued, especially in Germany and the United States. The basic design of large commercial gasifiers which today form the basis for IGCC developments originated during this period.[67]

With the availability in the United States of low cost, reliable supplies of natural gas in the late 1950s and the 1960s, activity involving coal gasification in the United States was maintained at only a very low level, though it continued to be important in the steel industry. Greater interest continued overseas, however, where circumstances favored the technology's development.

The 1970s brought renewed interest in gasification for various applications, including electricity generation. The use of coal gasifiers in electricity generation offered some important advantages. It allowed for greater reliance on domestic coal resources, less dependence on oil or gas, and its environmental impacts were less severe than those of more conventional coal-fired equipment. In addition, coupling a coal gasifier to a combined-cycle system appeared to meet the growing demand for highly efficient generation.

But the economic use of gasifiers in electricity production required technical improvements over earlier commercial technologies, In response to this need, advanced gasifiers have been developed. Several prime candidates for application in IGCC systems for the 1990s have emerged; these gasifiers have either been used commercially in some application, or are in advanced stages of development. Each has specific advantages and disadvantages. The principal corporations developing gasifiers included Texaco, Inc., Shell, the Allis Chalmers Corp., Dow Chemical, the British Gas Corp. (BGC), Kellog Rust (the KRW gasifier), and Lurgi Gesellschaften. The latter two corporations have cooperated in the development of a single gasifier design known as the BGC/Lurgi gasifier.

The current status of gasification systems being developed by these corporations is summarized in table 9-4. Activities directed towards the development and commercial deployment of the gasifiers have not been directed just to IGCCs but to a considerably broader range of applications.

Among the major gasifier systems which had operated in nonelectric applications in the United States by mid-l985 were the Illinois Power Co. 's Wood River facility, which used a KILnGAS gasifier developed by the Allis Chalmers Corp. primarily for IGCC applications; and Tennessee Eastman Co. 's gasification plant in Kingsport, Tennessee, which used Texaco gasifiers. Other important gasification plants have been operated by the Tennessee Valley Authority; and by the Great Plains Gasification Associates in Beulah, North Dakota. Many of these projects have received Federal support through DOE or the Synthetic Fuels Corp. Coal gasification meanwhile has been pursued overseas as well.

Only one type of gasifier, developed by Texaco, had by mid-1985 been deployed in an IGCC installation in the United States—the Cool Water Project, the world's first demonstration of an IGCC using commercial-scale components. Conceptual studies and other activities concerning this plant began in the mid-l970s and in 1979 Southern California Edison and Texaco signed an agreement which formally initiated the project.

The effort later was joined by EPRI, Bechtel Power Corp., the Japan Cool Water Program Partnership, the Empire State Electric Energy Research Corp. (a group of New York State utilities), SOHIO, and General Electric. Sizable loans were provided by banks in the United States and Japan. EPRI has made the greatest funding contribution to the program.

As the project progressed, oil prices dropped. Avoided costs, the basis for the purchase price of power produced by the plant, consequently would not be as high as was originally anticipated by the project sponsors. They were compelled to obtain price support guarantees from the Synthetic Fuels Corp. These amounted to a maximum of $120 million, to be provided during the plant's demonstration period, running through June 1989.[68]

[67] Synthetic Fuels Associates, Inc., *Coal Gasification Systems: A Guide to Status, Applications, and Economics* (Palo Alto, CA: Electric Power Research Institute, 1983), EPRI AP-3109.

[68] Paul Rothberg, *Synthetic Fuels Corp. and National Synfuels policy* (Washington, DC: Congressional Research Service, 1984), Issue Brief Number IB81 139.

Table 9-4.—Status of Developing Gasification Technologies

Process	Value of technology for electric power production	Number of units in design, construction, or operation in June 1985			
		Small pilot units (< 50 t/d)	Large pilot units (100-300 t/d)	IGCC units (demonstration/commercial) (>600 t/d)	Other large-scale demonstration or commercial units
Texaco	High	[2] • Texaco (Montebello) (2 gasifiers)	[2] • Ruhrkohle/Ruhrchemie Oberhausen (1 gasifier) • TVA-Muscle Shoals (1 gasifier)	[2] • Cool Water (2 gasifiers)	[9] • Tennessee Eastman (2 gasifiers) • UBe Ammonia (4 gasifiers) • Ruhrkole/Ruhrchemie (1 gasifier) • Lunan (China) (2 gasifiers)
BGC/Lurgi	High	[1] • British Gas (Midlands) (1 gasifier)	[1] • British Gas (Westfield) (1 gasifier)	[4] • Detroit Edison/ Consumers Power (4 gasifiers)	[1] • British Gas (Westfield) (1 gasifier)
Shell	High	[1] • Shell (Amsterdam) (1 gasifier)	[2] • Shell (Harburg) (1 gasifier) • Shell (Deer Park) (1 gasifier)	• Northeast Utilities (1 gasifier)	
Dow	High	[2] • Dow (Freeport) (1 gasifier) • Dow (Plaquemine) (1 gasifier)	[1] • Dow (Plaquemine) (larger than 300 t/d) (1 gasifier)	[1] • Dowsyn (Plaquemine) (1 gasifier)	
KRW (Westinghouse)	Moderate-high	[1] • Westinghouse (Waltz Mill) (1 gasifier)		❑ • Keystone (Johnston, PA) (2 gaslflers)	China (1 gasifier)
Allis-Chalmers	Moderate	[1] • A-C (Oak Creek) (1 gasifier)			❑ KILnGAS (Wood River) (1 gasifier)

❑ Represents total number of gasifiers within any category.

SOURCE M Gluckman, Electric Power Research Institute personal communication, June 1985

Another IGCC unit soon will be under construction in Plaquemine, Louisiana. Designed by Dow Chemical, the plant is expected to begin operating in 1987 with a substantial contribution from the Synthetic Fuels Corp.–$62O million in price guarantees. Most recently, three U. S. utilities—the Potomac Electric Power Co., the Virginia Electric Power Co., and the Detroit Edison Co.–have initiated the steps which could lead to the deployment of three IGCC units during the 1990s.[69]

As suggested above, the development of gasification technologies has generally depended heavily on Federal support through the Synthetic Fuels Corp. In addition the Federal Government has supported the development of gasification through DOE and its predecessor agencies. Most of this DOE support has been for research, development; and demonstration of surface coal gasification.[70] As indicated in table 9-2, this support peaked in 1978 at $208 million and has declined since to a proposed $15 million for fiscal year 1986.

Efforts in the private sector on behalf of the IGCC have emanated mainly from the equipment developers in the private sector, interested utilities and EPRI. The vendors of both the turbines and the gasifiers are large corporations which have funneled considerable capital into the research, development, and demonstration of their products, While the investments sometimes are

[69]For details on Potomac Electric Power co. 's (PEPCO) plans, see: Steven M. Scherer, "PEPCO's Early Planning for a Phased Coal Gasification Combined Cycle Power Plant," paper presented at the EPRI and Kernforschungsanlage Julich Conference on Coal Gasification and Synthetic Fuels for Power Generation, San Francisco, CA, April 1985.

[70]Surface coal gasification is distinct from underground coal gasification. The latter involves technologies which are very different from those considered here and are not candidates for IGCC systems in the 199os.

directed primarily toward the application of the equipment to the IGCC (as was the case at the Cool Water Plant), they usually are intended to advance the technologies over a wider variety of applications.

EPRI has devoted a large portion of its budget towards the development of the IGCC, both through numerous studies and through its funding of the Cool Water Plant. EPRI also parented the Utility Coal Gasification Association (UCGA), a group of utilities interested in the IGCC. Formed by early 1983, the association collected and disseminated information on the technology and its applications, and otherwise encouraged its deployment. The early commercial users of the IGCC probably will be among the association's members.

In addition to participation in the UCGA, some utilities have been considerably more involved in the technology. Southern California Edison, for example, invested heavily in the Cool Water project and has been very active in promoting the IGCC.

Industry Outlook and Major Impediments

Three primary criteria must be met if the IGCC is to make a sizable contribution to generating capacity in the 1990s. First, a number of utilities must be convinced the technology will perform as required over its entire 30-year lifetime. Second, the combination of cost, performance, and risk will have to be superior to that of both conventional and other developing technologies—including atmospheric fluidized-bed combustion (AFBC), Third, projects probably must be initiated no later than late 1993 if they are to come online within the 1990s.

Taken together, these elements suggest that additional utilities indeed may step forward over the next 3 to 8 years and initiate IGCC plants. However, the current evidence suggests other factors--the most important of which are discussed below–may weigh against initiation of many projects during the short time available. Consequently, there is a possibility that only a few–perhaps a half-dozen or less–IGCCs will be operating in the United States by the end of the century.

Equipment Cost and Performance.–Many of the individual components of the IGCC have been commercially applied for many years. Among available components is equipment which either already is adequate for IGCC applications or probably will be in the near future. Other components, though, are relatively new and in fact may be unique to the IGCC. Evidence from the Cool Water plant experience to date and from other sources indicates that these components will perform adequately and will not involve excessive cost, However, experience with IGCCS is still limited, and while the Cool Water performance has been very good, many utility investors may still lack sufficient confidence in component cost and performance estimates. Consequently, even if cost reductions or performance improvements are not in fact necessary, uncertainty about equipment cost and performance may be a serious impediment to timely investment.

Cost and Performance Data/Technology Demonstration.—An important concern about the IGCC in the eyes of investors over the next 5 to 7 years will be the lack of demonstrated experience with the entire system, and hence the lack of proven integrated cost and performance data. The Cool Water plant and the Dow facility probably will be the only IGCCS to which investors may turn for a reference point, It is perhaps for this reason an EPRI in mid-1984 told a congressional subcommittee that the deployment of at least one or two additional IGCC demonstrations in the United States, using perhaps the BGC or Shell gasifiers, was a very high priority in promoting clean coal utilization in the 1990s,[71] others too have cited the need for further demonstrations.[72]

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[71] Dwain Spencer, Electric Power Research Institute, testimony presented in hearings held by the Subcommittee on Energy Development and Applications, House Committee on Science and Technology, U.S. Congress, *The Status of Synthetic Fuels and Cost-Shared Energy R&D Facilities* (Washington, DC: U.S. Government Printing Office), No. 106, June 6, 7, and 13, 1984, p. 203.

[72] See: 1) "Firms Plan CGCC Plant in Michigan, *Synfuels* Week, vol. 6, No. 13, Apr. 1, 1985, p. 1. 2) "Va. Power Plans 400 MW CGCC Plant, " *Synfuels Week, vol. 6, No. 12,* Mar. 25, 1985, pp. 1-2. This article discusses the plans of Virginia Power Corp. to "repower" an existing powerplant with a gasification system, and a combined-cycle system to form a "coal gasification/combined cycle" unit or CGCC. The utility has proposed that the Federal Government subsidize the project. It reported that even without Fed-

Utilities, of course, will examine their own experiences and those of others with gas turbines, steam turbines, and combined-cycles, and will scrutinize gasifiers operating both here and abroad in nonelectric applications. The favorable experience with those components certainly will help to reduce the risks perceived by investors, but they are unlikely to fully offset the lack of experience with the IGCC itself.

Note that as experience with the Cool Water plant accumulates, experience with AFBCs will be accumulating much more rapidly as both demonstration and commercial plants come online under both utility and nonutility ownership and under different operating conditions. It is likely that the AFBC, with its larger number of operating plants and its favorable cost and performance, will pose a formidable challenge to the IGCC for initial utility commitments.

Licensing and Permitting Delays.–A major source of delay for IGCCs could lie in the licensing and permitting process. Though the environmental impacts of the IGCC will be less severe than those of its conventional competitors, it nevertheless does have significant impacts on the environment. Concern over the impacts could result in delays, particularly if the potential environmental impacts are not precisely known by egulators, or where important regulatory issues regarding the technology have not been satisfactorily resolved,

For example, very little data are available on the long-term leaching characteristics of gasification ash/slag. Furthermore, the analytical tools necessary to adequately determine the possible impacts of the solid waste in a specific environment, and to properly develop or assess measures to mitigate those impacts, are lacking. Yet such data and methods are required to properly determine whether or not the solid waste should be treated as hazardous or nonhazardous, and in evaluating specific plant proposals .73

Certainly measures can be taken by government authorities to expedite the IGCC's progress through regulatory channels. 'd Regulatory bodies may provide an IGCC technology with special treatment, as was the case in California with the Cool Water project, Under such circumstances, delays may be reduced substantially. More importantly, constructors of initial plants can work closely with regulatory bodies to ensure efficient resolution of potential concerns. If either of these paths are followed, the amount of IGCC capacity by the year 2000 could be substantially higher than would otherwise be the case. If such is not the rule, however, delays could result because of the newness of the technology that could seriously impede the ability of project promoters to bring IGCCs on-line before the end of the century.

Stringency of Environmental Regulations.–A major advantage of the IGCC over its conventional competitors is its potential to operate with lower nitrogen oxide and sulfur oxide emissions, at incremental costs lower than those associated with equivalent emission reductions in a conventional coal plant. Where emissions are severely limited, the IGCC is able to capitalize on this advantage. Where such limitations are lacking, however, the IGCC is less able to successfully compete with the more conventional alternatives. The lack of stricter regulations which require lower emissions consequently may reduce incen-

eral support, it would install the combined-cycle portion of the plant and operate it beginning in 1993. But the gasification portion of the project would be delayed without Government support; the system would employ natural gas instead of gas produced from coal. Referring to the gasification portion of the system, officials of the utility reportedly stated that "the technology is unproven and the utility decided that privately financing its early introduction in the marketplace would be 'an unreasonable risk to (Virginia Power) ratepayers and stockholders. ' " A company official was quoted as saying: "We are a risk averse industry. Without some Government help to defray the risk, our implementation of the gasification technology would just have to wait. " According to the utility, without Government assistance, the "conversion to coal gasification could be subsequently pursued when the technology and economics become favorable about ten years later or 2003. "

[73]Masood Ghassemi and **George** Richard, "Regulatory Requirements for Land Disposal of Coal Gasification Waste and Their Implications for Disposal Site Design, " *Energy Sources, vol.* 7, No. 4, 1984, pp. 357-376. The authors state that ". . . environmental issues involving disposal of these wastes may constrain the commercial development of gas supply technologies" (p. 358).

[74]See: 1) Masood Ghassemi and George Richard, "Regulatory Requirements for Land Disposal of Coal Gasification Waste and Their Implications for Disposal Site Design, " op. cit., 1984. 2) Arturo Gandara, "Environmental Considerations in Siting Alternative Fuel Generating Facilities, " *California Energy Commission News and Comment, No. 13,* spring 1984, pp. 4-18 (reprint of testimony presented to the Advisory Committee on Federal Assistance on Alternative Fuels, Oct. 31, 1983).

tives to more extensive deployment of IGCCs in the 1990s.

Fuel Use Restrictions.–An IGCC plant typically will require access to natural gas. If the installation is built in stages, the gas turbines can be installed first and can use natural gas as an interim fuel until the gasifiers are completed. Also, natural gas can be used during the lifetime of the plant to replace or supplement the synthetic gas produced by the gasifiers. As explained earlier, the Fuel Use Act prohibits the use of natural gas under certain conditions. An exemption would be required from the Federal Government which would permit the use of natural gas in an IGCC. This could cause delays in a project, and denial of an exemption may even lead to project abandonment.

Atmospheric Fluidized-Bed Combustors

History and Description of the Industry

In the early 1920s, fluidized beds were applied for the first time in Germany to produce combustible gases from coal. Subsequent development led to their use in "cracking" the heavy fractions of petroleum, first in 1942 and extensively thereafter. Further efforts led to their application to other industrial uses and eventually to produce steam. The first commercial fluid ized-bed boiler began operation in France in 1955. Serious development of fluidized-bed boilers did not begin in the United States until 1965.[75]

By 1976, DOE was funding the construction of the first industrial-sized AFBC boiler in the United States–a 30 MWe pilot plant in Rivesville, West Virginia. Several more small industrial AFBCs were built in the late 1970s and early 1980s as the technology progressed rapidly and small AFBCs became competitive with conventional options in the marketplace. Coincident with the emergence of small AFBCs during this period was the implementation of PURPA, which set the stage for a rapid increase in the deployment of AFBCs in cogeneration applications.

By early 1985, over 2,200 AFBCs were operating in China, and between 200 and 300 were operating or under construction elsewhere in the world, mostly in Western Europe, Japan, and the United States. Most of those outside China were small industrial units. Over 40 small AFBCs were operating or under construction in the United States by early 1985, and by mid-1985, over a dozen privately financed commercial AFBC cogenerators were being built in the United States. Unit sizes of these U.S. plants range from 15 to 125 MWe; none of these fully commercial units is owned by an electric utility.[76]

The electric utilities are, however, showing a growing interest in the technology. The thrust of utility-sponsored R&D has been the development of AFBCs with capacities in excess of 100 MWe for retrofit to existing powerplants or for entirely new plants. Toward this end, three demonstration projects are currently under construction. Two are retrofit units being incorporated into existing plants.[77] The third is a 160 MWe demonstration unit at the Tennessee Valley Authority's (TVA) Shawnee Steam Plant in Paducah, Kentucky. The retrofit units will begin operating in 1 to 2 years; the TVA unit is expected to be fired first in 1989.

Central to the utility efforts has been the Electric Power Research Institute. By 1977, EPRI had built a 2 MWe pilot plant. This was followed by a 20 MWe plant which began operation in 1982. EPRI now is partly funding all three of the above mentioned demonstration projects.

[75] Shelton Ehrlich, "History of the Development of the Fluidized-Bed Boiler," *Proceedings of the 4th International Conference on Fluidized-Bed Combustion, Dec. 9-11, 1975* (McLean, VA: MITRE Corp., May 1976), Publication M76-36, pp. 15-20; and A.M. Squires, "Contributions Toward a History of Fluidization," *Proceedings of the Joint Meeting of the American Institute of Chemical Engineers and the Chemical Industry and Engineering Society of China, Sept. 20-22, 1982* (New York: American Institute of Chemical Engineers, 1983), pp. 322-353.

[76] For a comprehensive review of the current status of AFBC's, see: Bob Schwieger, "Fluidized-Bed Boilers Achieve Commercial Status Worldwide," *Power,* vol. 129, *No. 2,* February 1985, pp. S-1 through S-16.

[77] These are the Colorado Ute 100 MWe Nucla unit, scheduled to begin operating in 1987; and the Northern States Power Co.'s 125 MWe Black Dog Unit 2, expected to be in operations in 1986. Note that one small retrofit unit already has operated. This *is* the Northern States Power Co.'s French Island Plant, Unit #2. The 15 MWe retrofit began operation in 1981.

The Federal Government too has supported the technology with a program which first led to the construction of the Rivesville plant in 1976 and subsequently to a series of pilot and demonstration facilities. Federal support peaked in 1980 at almost $30 million and has dropped sharply since. By far the largest portion of Federal funding for the AFBC now is channeled into the TVA 160 MWe demonstration plant–$30 million of the $22o million required for that project.

The industry which supplies AFBCs is large and well established. About 50 companies sell the industrial-sized boilers worldwide. Often, these are the same companies which sell conventional technologies. The adoption of the AFBC by these firms is likely to facilitate its deployment in the United States.

Industry Outlook and Major Impediments

Four applications of the AFBC may be important over the next 15 years: grass-roots electric-only plants, retrofit electric-only plants, cogeneration installations, and nonelectric systems. The electric-only units are likely to be deployed by utilities, whereas the cogeneration and nonelectric units probably would be built and operated by nonutility investors.

Current evidence suggests that the electric-only retrofit units, and cogeneration plants and nonelectric facilities financed by non utilities may very well dominate the AFBC market in the 1990s. The rapid accumulation of operating experience with these units and their short lead-times—substantially shorter than those which wou Id characterize large 100 to 160 MWe grass-roots, electric-only units' B—makes their near-term prospects very bright.

The small AFBCs are being deployed extensively and many are expected to be initiated over the next decade. The market appears to be vigorous and growing, and suppliers abound. No barriers unique to these small units are expected to impede deployment, though some problems common to nonutility technologies—such as the adequacy of PURPA avoided cost payments—may develop.

A substantial utility retrofit market has also been identified; strong evidence indicates that numerous powerplants in the United States are candidates for AFBC retrofits. Most are small (less than 200 MWe), old units which are configured so as to allow a retrofit. Retrofit units probably will dominate early utility involvement with the AFBC. By the 1990s there will be more operating experience with retrofit units than with large grass-root units. Such retrofits appear to offer utilities a low cost option for improving existing capacity; they also require less time to deploy than the grass-roots plants. Commercial retrofits therefore could begin coming on-line before 1995, and large numbers may commence operating before the close of the century.

By the early 1990s, experience with the large utility demonstration units, expected to begin operating in the late 1980s, as well as experience with the smaller AFBCs outside the utility industry, may foster both technical improvements and utility confidence. The prospects appear to be good that extensive utility orders of large, commercial, grass-roots plants could begin at that time;[79] these plants could provide substantial amounts of electricity by the late 1990s. Delays of any kind, however, may limit the potential of AFBC grass-roots plants within this century. Such delays could be occasioned by problems or uncertainties associated with the performance of the larger AFBC units, or by difficulties in the licensing or permitting process.

Compressed Air Energy Storage

Industry Description, History, and Outlook

Major efforts in the United States on behalf of compressed air energy storage (CAES) began in the latter half of the 1970s, stimulated by the Federal Government, the Electric Power Research institute, interested utilities, and others. Most

[78]Retrofit u nits i n many cases involve very little regulatory delay, as they are deployed at preexisting plants. Cogeneration units and nonelectric units commonly are very small, are not owned by utilities, and are not subject to the same extensive regulatory delays which characterize large utility owned projects.

[79]See Robert Smock, "Utilities Look to Fluid Bed as Next Step in Boiler Design, " *Electric Light and Power, vol. 62, No. 7,* July 1984, pp. 27-29; and Taylor Moore, "Achieving the Promise of FBC," *EPRI Journal,* vol. 10, No. 1, January/February 1985, pp. 6-15.

important to these early efforts were three preliminary engineering-design studies, completed in 1981, which investigated the utility-specific application of CAES to the three major storage media (hard rock, salt, and aquifer CAES). Shortly before these studies were finished, in November 1980, the Soyland Power Cooperative, Inc., in Decatur, Illinois, formally committed itself to building the first U.S. CAES plant.

As these events unfolded in the United States, the world's first CAES plant was built in Huntorf, West Germany; it began operating in December of 1978. Since that time, the 290 MWe Huntorf unit has operated nearly 7 years without serious problems. Furthermore, a smaller 25 MWe CAES unit recently was completed in Italy. Despite the successful operation of the German plant, the construction of the Italian plant, and efforts in the United States to deploy CAES plants here, this country still is without even a demonstration plant. The Soylands plant was canceled, and since then no U.S. utility has initiated construction of a CAES plant.

Federal support rapidly declined after peaking in 1978-79. Beginning with fiscal year 1983, DOE has provided no support to the technology (see table 9-2). Others, however, have continued promotional efforts. Although no CAES plants are now being constructed, EPRI and a private firm are currently performing an initial screening analysis of CAES on 10 utility systems. EPRI also is planning to provide funds in support of initial plant siting studies with interested utilities and in support of the installation of two or more so MWe "mini-CAES" plants.[80] Additionally, four consortia of architect/engineering firms, turbomachinery suppliers and cavern builders have been formed to supply initial plants.[81]

These developments suggest that several mini-CAES units could be initiated and built by the early 1990s. There are, however, no strong indications that a maxi-CAES plant (with a capacity of several hundred megawatts) will be initiated in the next several years and will be on-line within the first few years of the 1990s. Since a maxi-CAES plant will require a lead-time (including licensing and permitting) of approximately 5 to 8 years, plans to build any commercial maxi-CAES units must be underway no later than the end of 1994 for contribution to generating capacity within this century. Current evidence suggests that utility orders wou Id be unlikely without a U.S. demonstration plant.

The prospects for mini-CAES plants in the United States appear to be much brighter. A mini-CAES plant requires a lead-time of approximately 4.5 to 6.5 years. If several are initiated by the end of 1986, they could be on-line by mid-l 990. If extensive mini-CAES capacity is to be on-line by the year 2000, however, plans to build such plants should be initiated no later than mid-l990. This would allow approximately 5 years for the demonstration units to operate and for a substantial market demand to develop.

Such rapid growth in demand is possible, given the favorable levelized cost which might characterize CAES units (see chapter 8), and given the fact that many of the components are conventional and commercially available. Furthermore, the appropriate geology underlies 75 percent of the United States, so the market is potentially large and varied. EPRI estimates that CAES technology has the potential of supplying 4 to 8 percent of peak demand by the year 2000.[82]

To accomplish this will require that lead-times be kept short, and that other impediments be successfully cleared. The major impediments are discussed below. Unless these are effectively and speedily eliminated, demand is more likely to increase gradually, with large numbers of orders unlikely before the latter half of the 1990s.

Major Impediments to the Commercial Deployment of CAES Systems

The major impediments to *high* deployment levels for CAES by the end of the century are outlined below.

[80] David Rigney, Electric Power Research Institute, "Notes on Compressed Air Energy Storage," provided to Brian E. Curry, Northeast Utilities, March 1985.
[81] Ibid.

[82] Robert B. Schainker, *Executive Overview: Compressed Air Energy Storage (CAES) Power Plants* (Palo Alto, CA: Electric Power Research Institute, August 1983), mimeo.

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Uncertainty Regarding Plant Cost and Performance.–As discussed above and in chapter 4, while all of the individual above-ground components with the exception of the recuperative heat exchanger have been employed in other commercial applications, the performance of integrated assemblies coupled to specific geologic reservoirs is still unproven in the United States.

A principal area of concern is the impact of daily variations in pressure, humidity, and temperature on the reservoirs; these at present are not precisely known.ss The prime concern is leakage of the air from the reservoir. Until one or more units have been installed and operated for at least several years, uncertainty will still trouble investors and is likely to strongly inhibit investment in CAES.

Licensing and Permitting Delay s.–As discussed in chapter 4, several regulatory problems cou Id delay deployment of a CAES plant. These plants employ a gas- or oil-fired combustion turbine. The operator of the plant must obtain an exemption from the Powerplant and Industrial Fuel Use Act of 1978. Other delays might result from environmental impacts; regulatory problems might arise regarding atmospheric emissions, well drilling and construction, water consumption and contamination, and cavern excavation. The relative inexperience of all concerned parties with CAES could further complicate the licensing and permitting process.

Batteries

Industry Description, History, and Outlook

Batteries first appeared in the 19th century and were quickly applied to railroads, telephones, and lights, Near the beginning of this century, the all-electric automobile appeared using batteries, but it was not until 50 years later that utilities used batteries to level loads in urban areas. For example, batteries were used in Chicago to compensate for the effects on the direct-current (DC) electric system of elevators and lights in large downtown build ings.[84] As the use of DC power systems declined in the 1930s, the use of batteries by utilities declined as well.[85]

Over the past dozen years, however, batteries for stationary applications have been the subject of renewed interest and development. Rapid technical progress has been made and batteries may eventually be used extensively in grid-connected applications to enhance peak load capacity.

At the forefront of battery development have been manufacturers in Western Europe, Japan, and the United States. Often closely affiliated with these R&D programs have been parallel efforts to develop batteries for mobile applications. Efforts directed towards stationary applications in the United States have been led by DOE, EPRI, and interested utilities, as well as by battery manufacturers themselves.

DOE and EPRI together have funded the construction and operation of the national Battery Energy Storage Test (BEST) Facility in New Jersey as a national center where prototype battery modules are tested and evaluated, along with other related equipment. The facility first began operating in 1982. By May 1985, both advanced lead-acid and zinc-chloride batteries had been tested in the facility. Sodium-sulfur (or beta) and zinc-bromide batteries are expected to be installed around 1989 or 1990.

The Japanese meanwhile have vigorously developed batteries under the auspices of MITI's Moonlight program since fiscal year 1980. The goal of the program is to demonstrate two 1 MWe, 8 MWh battery installations by 1990. As is the case in the United States, both utilities and their customers have been identified as prime markets.[86] Already the batteries are being used by utility customers in Japan; the Japanese National Railways, for example, has installed a Japanese-

[83] Decision Focus Inc., *Compressed-Air Energy Storage: Commercialization Potential and EPRI Roles in the Commercialization Process* (Palo Alto, CA: Electric Power Research Institute, 1982), EPRI EM-2780.

[84] Jenny Hopkinson, "The New Batteries, " *EPRI Journal, vol. 6, No. 8,* October 1981, pp. 6-13.

[85] Peter A. Lewis, *Elements of Load-Leveling Battery Design for System Harming,* paper presented at the International Symposium and Workshop on Dynamic Benefits of Energy Storage Plant Operation.

[86] Y. Ariga, et al., Central Research Institute of Electric power Industry (Japan), "Optimum Capacities of Battery Energy Storage System for Utility Network and their Economics, " *Advanced Energy Systems–Their Role in Our Future: Proceedings of the 19th Intersociety Energy Conversion Engineering Conference, Aug. 19-24, 1984* (San Francisco, CA: American Nuclear Society, 1984), paper 849050, pp. 1075-1080.

made lead-acid battery system .[87] Western European manufacturers are very active as well. indeed, West Berlin became the location of the world's first large, modern, grid-connected battery installation. After operating a small prototype facility, the city's utility decided to build a 17 MWe, 14.4 MWh facility. Plant construction began in early 1985.[88]

The battery technologies favored for widespread deployment in the 1990s are advanced lead-acid and zinc-chloride batteries. Both types of batteries have been successfully tested at the BEST Facility, The EPRI, vendors of both types of batteries, and others are laying the groundwork for the subsequent step for commercialization: multi-megawatt demonstration units within the next 5 years.

Early markets for the stationary batteries could reside with both utilities and non utilities. Utilities can use batteries to level loads, shave peaks, regulate systems, or for spinning reserves. Non-utilities—commuter railways, for example—may use batteries to avoid the high cost of electricity during peak periods and to take advantage of lower prices during base periods. Recent analyses suggest that in some cases batteries could present very attractive investment opportunities.[89]

The strongest segment of the battery industry is concentrating on the lead-acid battery. About a half-dozen companies, primarily producers of automotive batteries, consider the large load-leveling batteries as a technology with considerable promise and have active R&D programs. go

Lead-acid batteries are strong contenders, in part because the precipitous drop in lead prices resulting from Government-mandated removal of lead from paint and gasoline has drastically reduced raw-material costs. In addition, the lead-acid battery industry is strong and well-established. However, while the industry is considered capable of financing the construction of a mass production facility, and though stationary markets have interested all the major battery manufacturers, to date they have been reluctant to make major investments. Apparently, they perceive the stationary market to be too unpredictable—particularly when compared to the automotive market. A major uncertainty lies with the effect changing gas and oil prices would have on the technological choices between batteries and conventional generating technologies in meeting the need for peaking capacity. [91]

Meanwhile, the development of the zinc-chloride battery has been shouldered mainly by one firm, Energy Development Associates (EDA) .92 The company has introduced a large, prototype commercial module, known as the "FLEXPOWER" commercial load-leveling battery. It is rated at 2 MWe, 8MWh. It plans to deploy the system in four stages, with the ultimate goal of commercially deploying the technology by the late 1980s or early 1990s.[93] Its design was "heavily influenced by the desire to meet both electric-utility and customer side-of-the-meter markets with similar hardware. "[94] The demonstration phase for the system will include installation and operation of a system by an industrial customer.

Major Impediments to the Commercial Deployment of Batteries

The major impediments to the widespread commercial deployment of batteries in the 1990s are discussed below.

Technology Demonstration.–The successful testing of both lead-acid and zinc-chloride battery modules has provided encouraging evidence in favor of the batteries. Commercial-scale mu ki-megawatt installations are required, however, which will demonstrate the capabilities of the systems on a commercial scale, over extended peri-

87 Glen n Zorpette, "High-Tech Batteries for Power Utilities, " *IEEE Spectrum, vol. 21, No.* 10, October 1984, pp. 40-47.

88 Glen n Zorpette, "High-Tech Batteries for Power Utilities, " op. cit., October 1984.

89 Bechtel Group, Inc., *Updated Cost Estimate and Benefit Analysis of Customer-Owned Battery Energy Storage* (Palo Alto, CA: Electric Power Research Institute, January 1985), EPRI EM-3872.

90 Arthur D. Little, *Commercialization Strategy for Lead-Acid Batteries in Utility Load Leveling Applications* (Cambridge, MA: Arthur D. Little, Inc., 1980), DOE/ET) 26934-l.

91 Ibid.

92 A subsidiary of Gu lf+ Western I nd ustries.

93 B D. Bruin met, et al., *Zinc-Chloride Battery Systems for Electric-Utility Energy Storage,* paper presented at the 19th Intersociety Energy Conversion Engineering Conference, Aug. 19-24, 1984, San Francisco, CA.

94 BD. Brummet, et al., *Zinc-Chloride Battery Systems for Electric-Utility Energy Storage,* op. cit., 1984.

ods, and under the variety of conditions expected of actual commercial plants. Until such demonstrations have taken place, extensive investment is unlikely.

Equipment Cost and Performance. -Until demonstrations have been completed, and experience has accumulated, it will be difficult to precisely identify cost and performance impediments to commercial applications of batteries. A key variable affecting the future of lead-acid batteries will be the price of lead; low prices will be required to maintain acceptable costs.

For zinc-chloride batteries, the major variable probably will be the level of demand for the large stationary batteries. Low costs will depend on mass production; mass production in turn will require a sizable market. Vendors will be reluctant to invest in manufacturing capacity without strong indications that the market will absorb the quantities produced; yet the market is unlikely to develop until mass production drives prices down. This "chicken-or-the-egg" dilemma may be the least tractable of the impediments confronting developers of the zinc-chloride battery in the 1990s. This problem is considerably less serious with the lead-acid battery because many of the lead-acid battery's components can be produced with existing facilities dedicated to pre-existing markets. Lead-acid battery prices therefore are less sensitive to initial demand for the large stationary units.

Utility Rate Structures.—The price customers pay for the use of utility-generated electric power during peak periods may differ from the price paid during off-peak periods, A demand charge may be imposed based on a customer's peak demand (cost/kWe). Or, the energy charge (cost/kWh) may be higher during peak periods than during other times of the day. Hence, there is an incentive for the customer to shift consumption away from peak periods. One way of doing this is with batteries. With low demand and energy charges or no incentive pricing, however, a battery may not be justified. Or, even if the charges are high at present, the possibility that they may decrease (relative to off-peak rates) discourages customer investment in batteries. Current evidence indicates that both low charges and uncertainty over charges could be major impediments to customer investments i n batteries.[95]

Licensing and Permitting.–Generally, the installation and operation of a battery unit will cause impacts far less serious than those associated with most competitors. In most cases, few regulatory delays are likely to result. But for zinc-chloride batteries, serious licensing and permitting delays might occur as a result of the possibility that large volumes of chlorine or bromine might be released accidentally from a proposed battery installation. Consideration of the possible problems is not likely to stop deployment in any particular instance. But difficulties, particularly with regulatory officials not well acquainted with the the technology or where the site is in a densely populated area, could arise and cause lengthy delays.

95 Bechtel Group, Inc., *Feasibility Assessment of Customer-Side-of-the-Meter Applications for Battery Energy Storage* (Palo Alto, CA: Electric Power Research Institute, 1982), EPRI EM-2769; and Electric Power Research Institute, *Utility Battery Operations and Applications* (Palo Alto, CA: Electric Power Research Institute, 1983), EPRI-2946-SR.