Chapter IV

ONSITE ELECTRIC-POWER GENERATION

Chapter IV.—ONSITE ELECTRIC-POWER GENERATION

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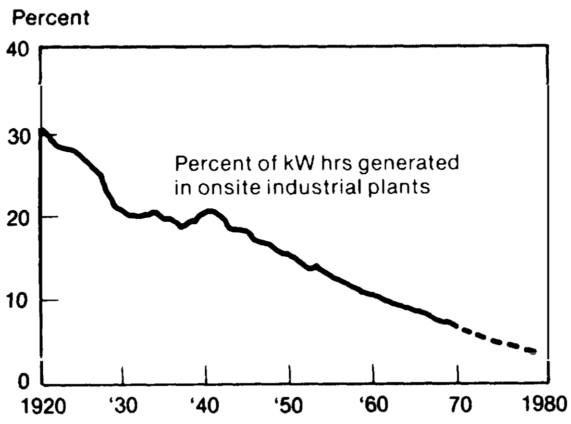
Chapter IV
Onsite Electric-Power Generation

BACKGROUND

While most electricity generated in the United States originates in large, centralized facilities owned and operated by electric utilities, the number of onsite generating plants has declined steadily and the average size of utility generating plants has steadily increased. Figure IV-1 shows, for example, that onsite generating equipment represented nearly 30 percent of all U.S. generating capacity in 1920 but only 4.2 percent in 1973. [1] The percentage of electricity generated in plants with a capacity greater than 500 MW, however, increased from 40 percent in 1965 to 56 percent in 1974.[2]

Since many of the benefits and problems of onsite solar equipment are shared by on site generating devices of all types, an examination of the potential market for the solar equipment must determine whether any of the economic and institutional circumstances which produced the trend toward centralization might change during the next two decades. There are two reasons for undertaking an examination of this rather fundamental issue. The most obvious is that the ways in which energy is produced and consumed around the world will need to change dramatically during the next three decades, if only because reserves of inexpensive oil and natural gas will vanish during this period. These changes will require a reevaluation of all conventional assumptions about energy. Secondly, the prospects for onsite generation may be improved by newly developed technologies—especially solar energy equipment. The solar resource is inherently distributed and economies of scale are often difficult to identify.

Figure IV-1.—Trend in Self-Generation



SOURCE: Edwin Vennard "A Study and Forecast of the Electric Power Business," *Report for the Charles T. Main Engineering Co.*, Nov. 1, 1973.

[1] Federal Power Commission News Release, May 6, 1975, p. 4.

[2] Federal Power Commission, *Statistics of Privately Owned Electric Utilities in the United States, 1974*, p. XLII.

There are a number of explanations for the trend toward centralization:

- Larger equipment tended to be less expensive per unit of installed capacity
- Larger plants tended to be more efficient in their use of fuel and had lower maintenance costs per unit output, since a relatively small number of trained operators could reliably maintain large generating plants.
- Larger plants could be installed in remote locations, simplifying siting problems and ensuring that pollutants would be released at a distance from populated areas.
- In recent years, a major advantage of large plants was their ability to use coal instead of oil and gas as a fuel. The delivery of coal to a large plant, using a dedicated rail facility, could significantly reduce the effective cost of coal fuel.

- Onsite facilities were frequently unable to compete with "promotional" rates charged during the periods when utilities were enjoying declining marginal costs. Under those circumstances, all utility customers benefited from increased sales, since average rates declined as utility sales expanded.
- Many companies were reluctant to invest in onsite equipment because they were unable to finance a large fraction of the equipment with their own equity, They were forced to turn instead to debt financing, which had the effect of increasing company vulnerability during periods of economic hardship, This meant that greater returns were expected of onsite generating equipment than were expected of investments in product-oriented areas.
- There was a fear that a failure of onsite equipment could have disastrous effects on the operation of a business, and a feeling that the headaches of electricity production should be left to the utilities, whose primary business was energy.
- Electric utilities have frequently opposed the installation of onsite generating facilities by industry and have often been reluctant to own such equipment themselves.
- Many onsite facilities have been poorly designed and have received inexpert maintenance, and reports of failures have frightened prospective investors.
- Onsite generating equipment has tended to be of somewhat archaic design.
- Federal and industrial research has concentrated almost exclusively on the development of improvements in large centralized equipment rather than in systems optimally designed for onsite generation.
- Onsite equipment in some installations has created problems of noise and local pollution, and some owners have encountered difficulties in expanding generating facilities.

One of the major objectives of this study is to determine whether there are or will be circumstances under which the advantages of onsite energy equipment, particularly solar energy equipment, can outweigh this rather impressive set of traditional reasons for avoiding onsite equipment. It is interesting to observe that many nations which have experienced higher fossil fuel prices than the United States make far greater use of onsite electric power. For example, 29 percent of the electricity generated in West Germany is produce d by onsite industrial plants.[3]

Onsite equipment can offer a number of advantages:

- Location of equipment "onsite" greatly increases the design opportunities and makes it easier to match energy equipment to specific onsite energy demands. In particular, it should make it easier to use the thermal output of solar collectors and the heat rejected by electric generating systems which is typically discarded (often at some environmental cost) and wasted by central generating facilities. There is a considerable amount of overlap between equipment being developed for energy conservation and onsite generating devices, and onsite designs are usually most successful when integrated into a coherent plan encompassing both energy demand and supply.
- The basic solar energy resource is available onsite whether it is captured or not. Integrating the equipment into the wails or roof of a building or into the landscape around a building can reduce the land which must be uniquely assigned to solar energy. Onsite generation of energy can reduce the cost of transporting energy and reduce the losses and environmental problems

[3] R Sukhuja, et al (Thermo-Electron Corp), *A Study of Inplant Electric Power Generation in the Chemical, Petroleum Refining, and Paper and Pulp Industries,* June 1976, pp 1-4

associated with transmission. (The extent of these savings can be difficult to compute, and this topic is treated with greater care in chapter V.)

- Onsite equipment can reduce investment risks, because it can be constructed rapidly and additional units can be installed quickly to meet unexpected changes in demand.
- Onsite equipment can be made as efficient as centralized equipment, even if no attempt is made to use thermal energy exhausted by generating devices, If this heat is applied usefully, overall efficiencies as high as 85 percent are possible.
- High-efficiency energy use, possible with combined electric and thermal generation, can result in a reduction of polluting emissions produced by onsite devices burning conventional fuels.
- Onsite equipment can be manufactured, installed, and maintained without major changes in the way energy-related equipment has been handled in the past. It would not require novel approaches to financing, new types of businesses, major new categories of labor skills, or major participation by the Government.

In addition, there may be social, strategic, or political reasons for trying to reverse the trend toward increasing centralization of energy production in the United States which have no direct connection with the economic merits of the case. Some of these issues are discussed in chapter VI 1.

In assessing the relative merits of large and small equipment, it is necessary to judge both as a part of an integrated energy system. Reviewing the performance of units operating in isolation can be very misleading.

In particular, it is necessary to distinguish between the advantages enjoyed by large energy systems, which result from economies of scale in individual devices, from the advantages resulting from the fact that the large systems meet a demand relatively free of the sharp demand peaks which characterize individual energy customers. The smooth demand results from combining many customers into a single diverse load, and this advantage could be enjoyed by small generating centers able to buy and sell energy from a large energy transmission and distribution system.

Since the primary objective of improving an energy system is to reduce the net price paid for energy by all consumers, it is necessary to try to show how each component will affect the overall price of meeting real fluctuating demands for energy throughout the year. This clearly is not a simple undertaking, particularly since so many changes can be expected in the way energy will be generated and used during the next few decades. Many new technologies will undoubtedly emerge in generating, storage equipment of all sizes, and in the technology of energy transport.

Energy can be transmitted in electrical, thermal, or chemical form, for example, and stored as mechanical, thermal, or chemical potential energy Energy can be generated at a central facility and sent for storage in onsite units (it is common in Europe, for example, to store electricity which will be used for space heating in the form of heated bricks), and energy generated locally could be sent to a central facility for storage

optimizing the combination of onslte and central energy devices will be difficult because of the many variables and uncertainties, but the outcome of this analysis can profoundly affect perceptions about the relative value of different types of equipment and it can affect the designs chosen for onsite systems These issues are treated in more detail in the next chapter

CAPITAL COSTS

The only satisfactory technique for comparing the cost of onsite and centralized power generation is to undertake the detailed comparison of life-cycle costs of integrated systems which is undertaken in detail in volume 11. It is interesting to notice, however, that there frequently is no clear correlation between the size and the unit cost of generating and storage components. Comparisons between different sizes of equipment based on the same basic design can be misleading; it is important to compare the costs and performance of devices selected to perform optimally at the size range selected.

GENERATING PLANTS

Table IV-I indicates that the initial costs of onsite generating equipment may actually be less than the cost of larger plants per unit of generating capacity.

Table IV-1.—1985 Generation Costs as a Function of Plant Size (1975 dollars)

Plant type	Initial capital cost dollars/kW	Fuel cost mills/kWh heating value	Efficiency (%)	Fuel cost (mills/kWh)	Operating & maint. costs (mills/kWh)	Capital charges (mills/kWh$_e$)	Total cost (mills/kWh$_e$)
New central station baseload plant*							
100 MW coal plant	400-800	3.24	38	8.5	1.3	9-27	(19-37)
Transmission and distribution	300-400	-	91	0.8	1.4	14-19	(16-21)
Other central station costs	8.5	-	-	-	2.0	0.1	(2.1)
Total central plant costs	908-1208	3.24	35	9.3	4.7	23-46	37-60
Industrial Plants							
10 MW combined cycle (oil)	360	5.5	48	12	3	8-12	23-27
10 MW combined cycle (oil prices triple)	360	16.5	48	36	3	8-12	47-51
10 MW gas turbine w/waste heat boiler	350	5.5	68	8	3	8-12	19-23
Small Generating Equipment							
100 kW diesel w/waste-heat boiler (oil)	400	10	56	18	5-10	17-28	40-56
5 kW gasoline engine	280	17	12	141	10-20	9-16	160-177
Possible Future Systems							
100 kW Phillips-type Stirling (mass-produced)	50-200	10	40	25	5-10	1.7-6.8	32-42
5 kW Ericsson device (mass-produced)	50-200	10	50	20	1-10	1.7-6.8	23-48
5 kW inverted gas turbine with waste-heat boiler (mass production)	50-200	10	68	15	1-10	1.7-6.8	18-32

*NOTE: The delivered cost of energy will be higher than the costs computed here since some energy must be provided from relatively expensive peaking plants or storage facilities.

Assumptions
— capital charges 0.15% annually
— oil costs utilities and industry \$1.60/10^6 Btu and individuals \$2.80/10^6 Btu
— coal costs \$0.95/million Btu
— gasoline costs 60¢/gallon
— plant-load factors 0.5–0.75 (large and intermediate)
0.3–0.5 (small systems)
— transmission and distribution system-load factor 0.35

SOURCES: Central station costs based on *Statistics of Privately Owned Electric Utilities: 1974*, Federal Power Commission. Pages XXXV, XXXVI, XXXVII, XXXIX, XLII, XLIII. 1976 fuel prices, and generating and transmission efficiencies are assumed. Other costs based on estimates documented in later sections of this chapter.

Review of Electrical *World's* Steam Station Cost Surveys for the past 22 years[4] showed that, from 1965 to 1975, there was no significant decline in capital costs of steam plants of all types as their size increased. Figure IV-2 shows costs per unit of generating capacity as a function of plant size for steam plants completed from 1965 to 1977 Only the 1977 survey gives any inclination of economies of scale, and the limited number of plants in that summary compared to previous surveys makes it very difficult to conclude that economies Of scale may again be valid.

Another trend determined in this review is that unavailability frequently increases as size increases, resulting in higher effective capital costs (figure IV-3). It should be noted that the stations reviewed in these surveys are new, and the availability problems may result in part from breaking in the new plants

While small units manufactured in small numbers may be substantially more expensive per unit output than large systems, the cost of small systems can be substantially reduced using mass production techniques unsuitable for larger devices. Moreover, investments in large generating facilities are so substantial that very conservative design practices must be used. Smaller systems permit greater experimentation, and, in many cases, innovations can be introduced into the market more rapidly, Conservative design practices, however, play a large role in determining which device will be selected for mass production

STORAGE DEVICES

It is difficult to generalize about the economies of scale of storage since the value of storage is a strong function of the cost of transporting energy and the strategy of its use Many types of storage are constructed from modular units and do not show strong economies of scale.

In most cases, low-temperature thermal energy can be stored much less expensively in large systems than in small storage tanks, This is because the ratio of the surface area required for a vessel containing a heated fluid to the volume of the fluid stored decreases as the volume increases. A low ratio means that less material will be required for the storage vessel and that the area over which heat can be lost to the environment per unit of energy stored is reduced.

In some very large systems, no insulation will be required other than dry earth. The advantage of large-scale storage of hot water would be increased significantly if techniques for storing hot water in aquifers can be developed. Taking advantage of this opportunity requires a piping network capable of delivering fluids to the central point.

Systems for storing energy at high temperatures (e.g., above 300 OC/5720 F) typically consist of a large number of relatively small modules, and large devices do not show economies of scale. In many cases, the storage must be located close to the site where the energy will eventually be used. For example, electricity can be “stored” in bricks, heated to high temperature, which are used to provide space heating for buildings during periods when electric rates are high. Such devices must be located in the buildings they serve.

No clear pattern of cost emerges for devices capable of storing energy at intermediate temperatures.

Most of the techniques which have been proposed for storing electricity in mechanical form (in hydroelectric facilities, for example) are only feasible in relatively large units, although it may be possible to use the numerous small dams which already exist around the country for small amounts of storage. Battery systems now available for

[4] 10th through 19th Steam Stat Ion Cost Survey, *Electrical World,* Oct 7, 1957, p 115, Oct 5, 1959, p 71, Oct 2, 1961, p 69, Oct 7, 1963, p 75, Oct 18, 1965, p 103, Oct 16, 1967, p 99, Nov 3, 1969, p 41, Nov 1, 1971, p 39, Nov 1, 1973, p 39, Nov 15, 1975, p 51

Figure IV-2.—Data From Steamplant Surveys, 1965-77

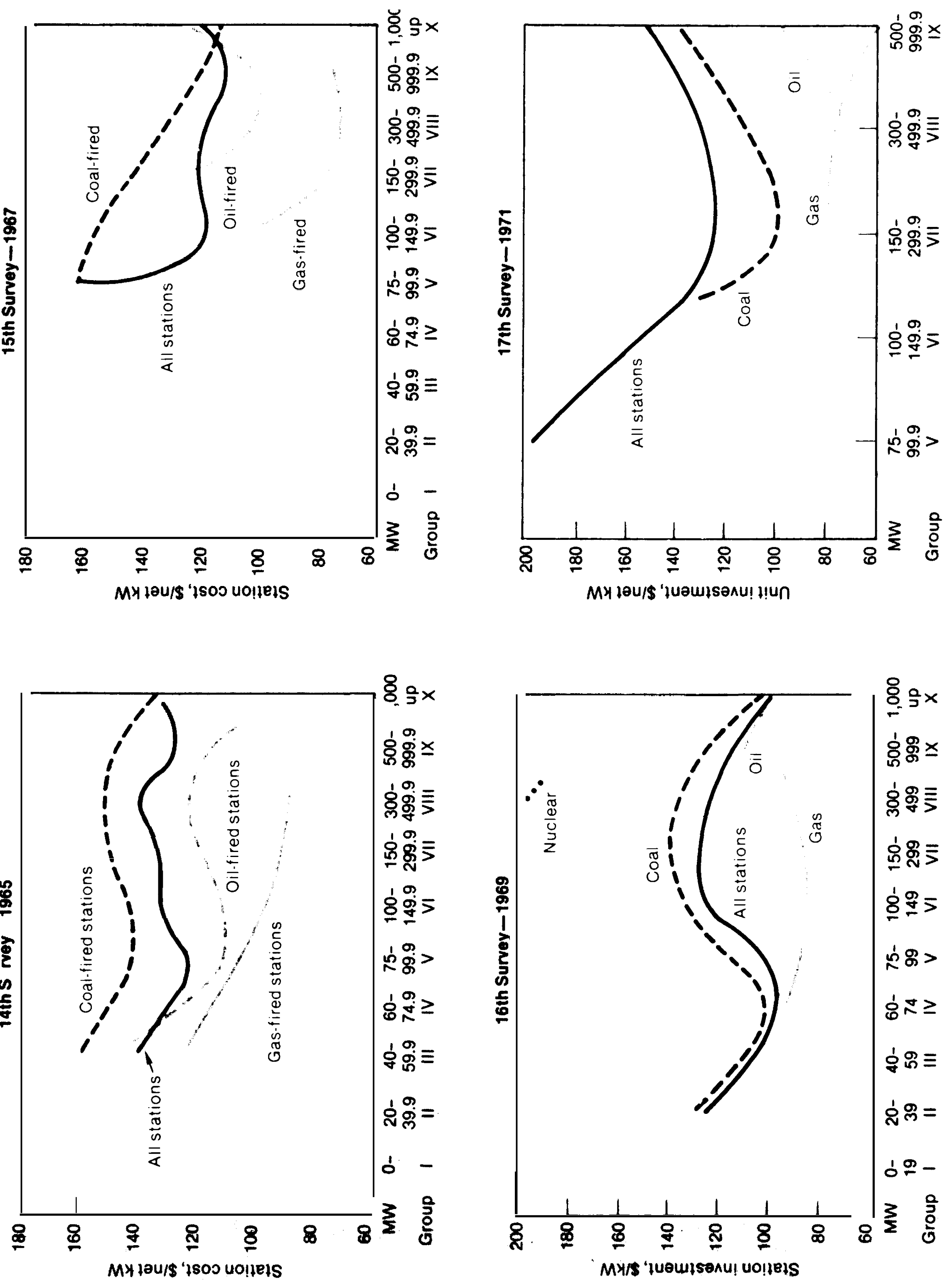
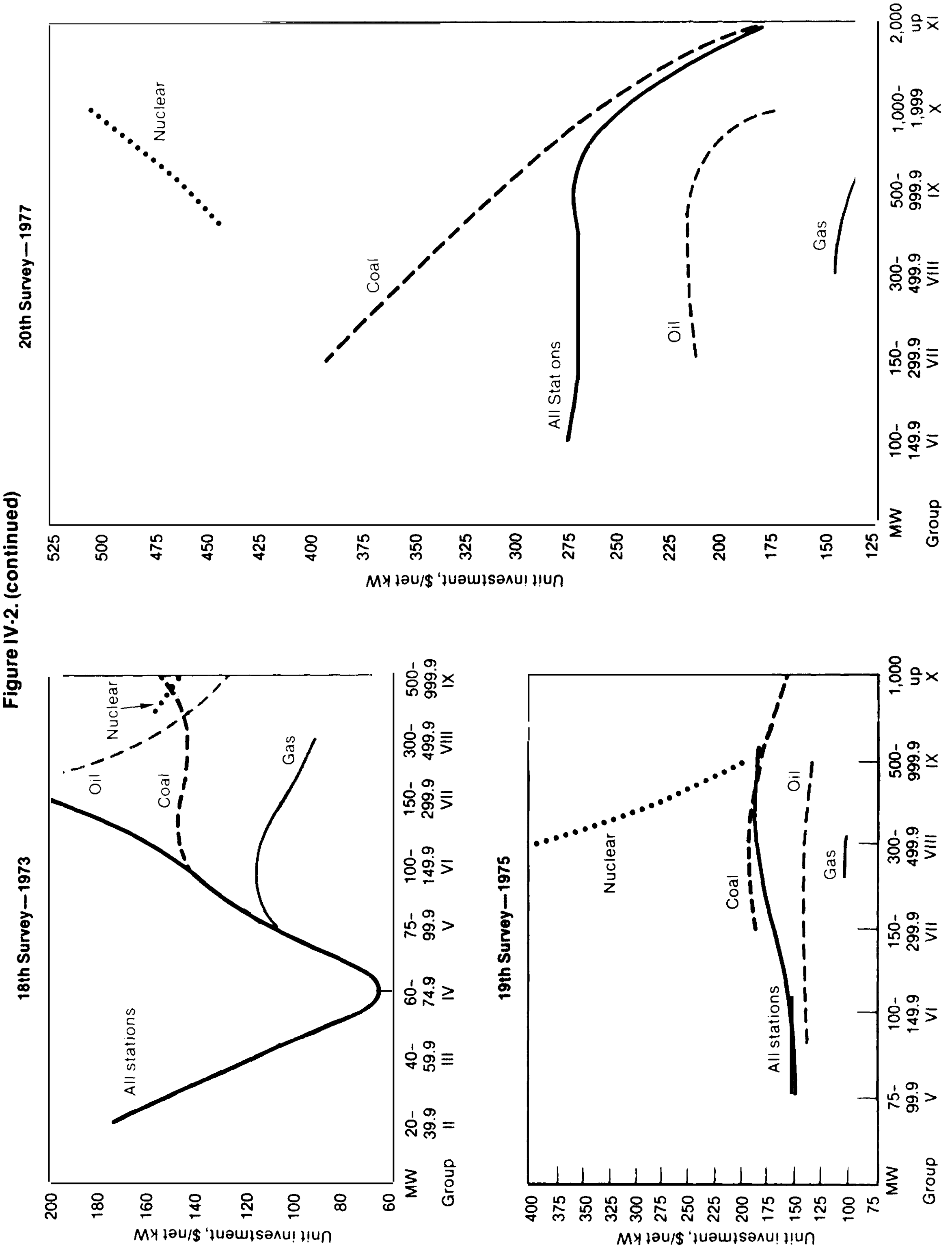


Figure IV-2. (continued)



SOURCE: *Electrical World*. Data from steamplant surveys from 1965 to 1977 showing unit investment versus size for steamplants of all types completed during the survey period.

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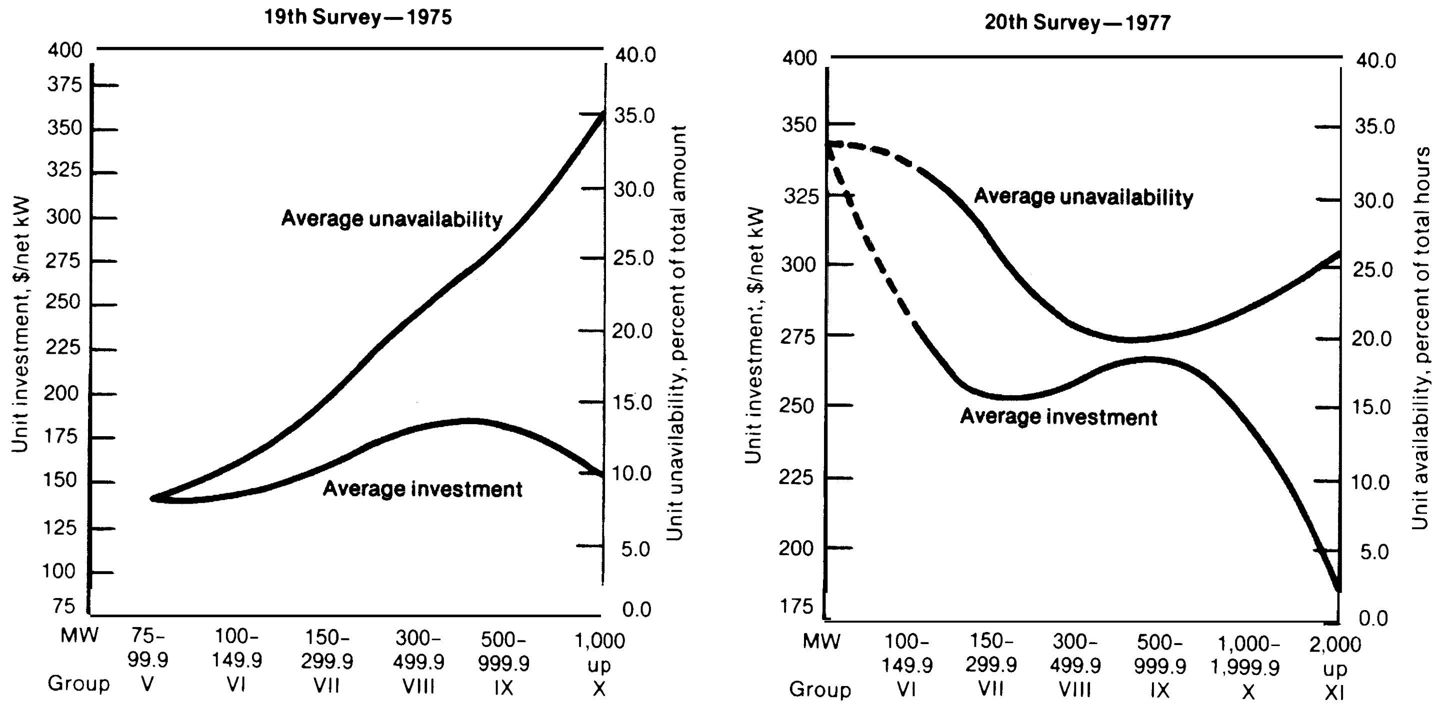
Figure IV-3.—Steamplant Survey Results Showing Average Unavailability Versus Size for Plants Completed During the Survey Period



SOURCES: "19th Steam Station Cost Survey," *Electrical World*, Nov. 15, 1975, p. 51.
"20th Steam Station Cost Survey," *Electrical World*, Nov. 15, 1977, p. 50.

storing large amounts of electricity for utilities are more economical in relatively large units (several megawatt hours), although economies of scale disappear long before capacities equivalent to those of large hydroelectric storage facilities are reached.

In the future, however, it may be possible to develop low-cost batteries for which there is no particular advantage in designing units larger than a few hundred kilowatt hours. This cannot be said for most other types of chemical storage systems. Large-scale storage of hydrogen or other gasses, for example, can probably be best accomplished in large underground chambers.

The economies of scale of storage devices is discussed in detail in chapter XI.

Onsite or regional storage facilities also offer a number of other advantages which are not directly reflected in initial costs of the systems. Table IV-2 summarizes the benefits of centralized and decentralized energy storage devices identified in an exam i nation of alternative techniques for storing electricity for utility use.

SOLAR COLLECTORS

Since most types of solar collectors consist of arrays of individual devices with individual areas less than 30 square meters (m’), there is no clear economy of scale for most types of collector arrays. An optimum size for a heliostat central receiver system will probably be established as the costs of these systems are better understood, but it is not clear whether a large penalty will have to be paid if the system is not at the optimum size. Similarly, a system which requires piping to connect a series of distributed thermal collectors will probably have an optimum size since these plumbing costs will become large for large systems.

Pond collectors and several other specialized collector designs may also show some economies of scale up to 2,000 to 3,000 m^2, but again, the penalty for building a smaller system may not be large. Much more must be known about the economics of collector devices before confident statements can be made in this area.

Table IV-2.— Impacts of Energy Storage on Electric Power Systems

	Impacts	Economic benefits*
Central energy storage	Improved baseload capacity factor	Low-cost charging energy
	Conservation of oil, natural gas	Reduced fuel costs
	Reduction of spinning reserve	capital cost credit ($20-40/kvv)
	Higher reliability/reduced reserve margin	Capital cost credit (to be determined)
	More efficient load folowing	Capital cost credit (to be determined)
Dispersed energy storage	All of the above, plus:	All of the above, plus:
	1. Deferral of new transmission and distribution lines	Capital cost credit ($50-100/kW)
	2. Deferral of substation reinforcement	Capita l cost credit ($30-60/kW)
	3. Misc. (transmission and distribution loss, volt-ampere reactive control, short circuit)	Capital cost credit ($10-20/kW)
	4. Increased security of supply/reduced reserve	Capital cost credit (to be determined)
	5. Rapid installation (factory built)	Reduced interest during construction
	6. Modular/incremental capacity growth	High capacity factor of storage

“Probable ranges; actual benefits depend on specific conditions in individual power systems.

SOURCE: F. R. Kalhammer, *Impacts of Energy Efficiency on Electric Power Systems,* American Nuclear Society Meeting, San Francisco, November 1975.

OTHER ASPECTS OF CAPITAL COST COMPARISONS

The cost of equipment purchased for a largeplant will always reflect the advantage of discounts resulting from large purchases. These savings occur because the manufacturer's marketing costs and other overhead costs are lower for large sales than for a number of small purchases. Larger systems may also benefit because there is no need to perform detailed engineering for each installation, as may be the case for some onsite energy systems.

Taking advantage of the ability to best integrate an onsite generating system with the climate and demand pattern at each site could, however, add to the engineering cost. Contractor overhead charges tend to be slightly higher for smaller systems. Generalizations are difficult, however, since it may be possible to develop standardized designs for small systems.

Ease of rapid construction of small generating and storage facilities reduces the interest paid during construction —charges which represent about 18 percent of the cost of new electric-generating plants capable of generating 1,000 MWe. [5] Rapid construction also means that the effects of inflation are easier to assess. Inflation occurring during the construction of a 1,000 MWe generating plant which would come online in 1983 is expected to represent about 30 percent of the total value of the plant.[6]

Short construction times can also provide much greater flexibility in meeting new demands.

This advantage is particularly significant when rapid fluctuations in the growth of demand make predictions difficult. Plants which require only a month to construct require predictions to be accurate only a month into the future. Moreover, a mistake in forecasting is far less costly if the investment is limited. The economic benefits of large plants which require many years to construct depend heavily on the accuracy of demand predictions covering periods of a decade or more. Utilities can react to unexpectedly low demand by delaying or deferring plant construction, but this process can be costly–with the cost depending on the amount of capital invested before the deferral. Forecasting mistakes can mean plants in operation which are badly underutilized, yet inaccuracies are inevitable given uncertainty about the future of energy supplies, costs, and demands.

In the period 1973-75, demand did not rise as rapidly as expected. Demand has fallen far below the predictions and, as a result, many utilities had far more capacity available than they could profitably employ. The disastrous effect of inaccurate predictions on the growth of electrical demand made during this period was reflected in the decline in load factors and a rise in gross peak margins (see figure IV-4). Both features indicate a serious underutilization of installed capacity, Utility commissions increased rates to permit these companies to remain solvent (although in many cases the utilities argued that these rulings still preclude profitable operations).

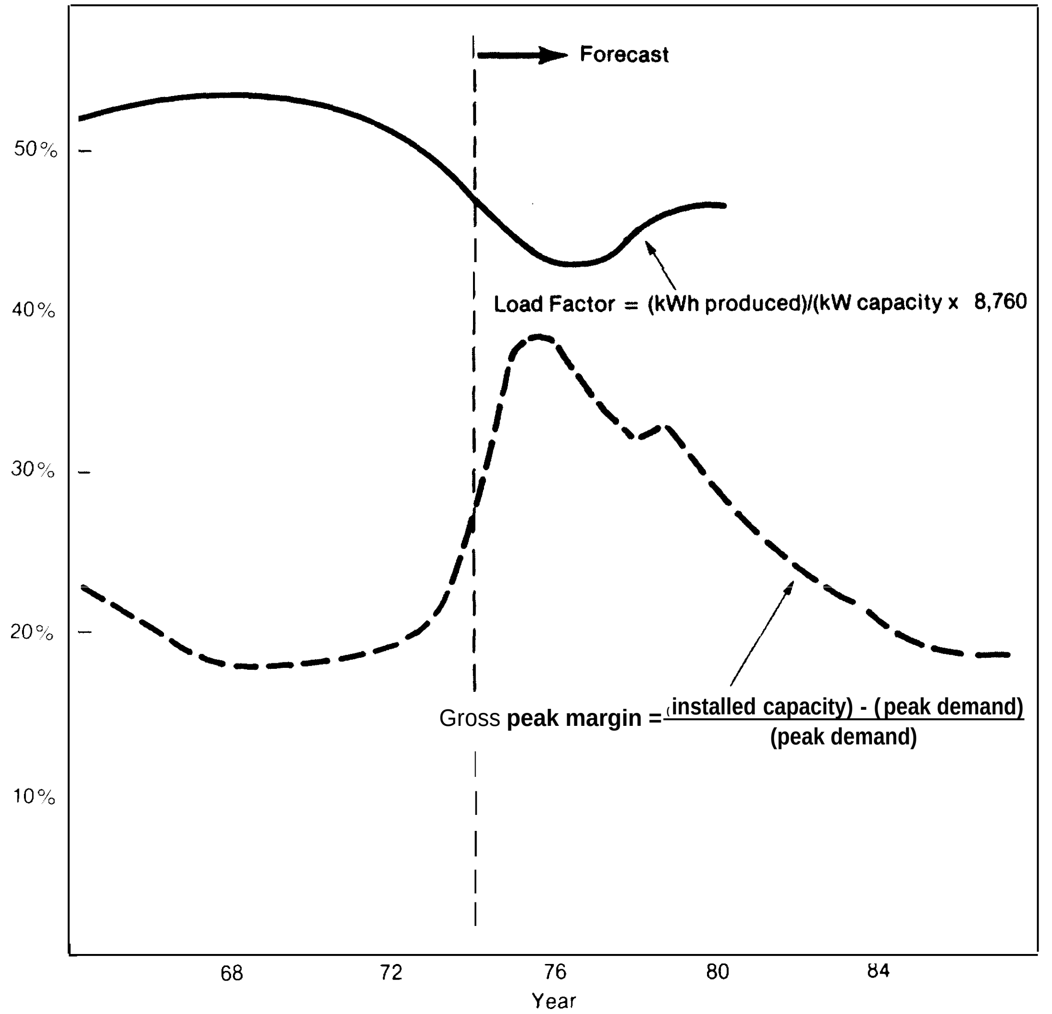
Load factors for small systems (defined to be the peak output potential of the generating system divided by the annual average output) vary widely because of the erratic nature of onsite energy demands. While many large industries operate at virtually full capacity throughout the day (and thus have relatively constant electric and thermal demands), small industrial plants, commercial buildings, and residences can have very uneven demands.

The irregular demands lead to relatively poor utilization of the generating equipment. The problem usually diminishes as the size of the total demand increases since large loads typically are an aggregation of a number of small loads. Unless the small loads all change in unison, peak individual demands will not all occur at the same time and the ratio of peak to average demand

[5] WASH-1230 Revised

[6] Ibid

Figure IV-4.— Historic and Projected Load Factors of Utility Generating Facilities



SOURCE 26th Annual Electrical Industry Forecast, ' *Electrical World*, September 15, 1975, p 46

will be less (This can be seen by noticing that the load factors shown in table IV-3 increase with the size of the buildings served.) Since the improvement is greatest when the largest possible number of loads are connected, utility load factors are almost always higher than onsite load factors, It is important to notice that this advantage is attributable to the size of the grid interconnection and not to the size of individual generating facilities.

WASTE-HEAT UTILIZATION

One major advantage of onsite generation of electric power is that an opportunity is provided for making use of thermal energy usually wasted by central electric-generating facilities. From 60 to 80 percent of the energy consumed by conventional generating equipment is lost into the atmosphere or nearby bodies of water, causing thermal

Table IV-3.—Load Factors for Typical Buildings

	Albuquerque	Boston	Ft. Worth	Omaha
1. Single Family House				
—gas heat, h.w. & a/c	28.3	25.5	26.6	28.1
—gas heat, h.w. & electric a/c	24.7	15.5	26.6	21.9
—electric resistance heat & h.w. & electric a/c	18.3	21.9	17.0	20.1
—heat pump, electric h.w. & a/c	14.5	16.8	15.8	16.3
2. Single Family House with Extra Insulation				
—gas heat, h.w. & a/c	26.1	25.3	26.4	25.9
—gas heat, h.w. & electric a/c	28.6	21.2	29.0	23.5
—electric resistance heat & h.w. & electric a/c	16.7	20.1	18.6	18.9
—heat pump, electric h.w. & a/c	14.5	17.7	19.0	16,9
3. High Rise Apartment				
—gas heat& h.w.,central elec, a/c	32.7	18.9	30.1	23.$
—electric resistance heat & h.w., central electric a/c	25.5	27.5	28.4	26.5
—electric resistance heat & h.w., window a/c	24.1	26.8	26.0	25.5
4. Shopping Center				
—gas heat & h.w., central electric a/c	40.2	—	36.9	35.1
—electric resistance heat & h.w., . . electric a/c	44.7	—	39.1	36.2
5. Industry				
—one shift	22	22	22	22
—three shifts	67	67	67	67

NOTE: The characteristics assumed for the buildings and heating and cooling equipment used by the buildings are described in detail in chapter IV of volume IL In computing the load factors for industry, it was assumed that the facility operated at 70 percent of peek capacity during active shifts and that the plant was shut entirely for 2 weeks during the year.

pollution in areas close to these plants. Approximately 17 percent of the energy consumed in the United States in 1972 was wasted in this way and estimates show that this fraction will rise to 25 percent by 1985, when the United States is expected to be more heavily dependent on electricity. [7]

At the same time, enormous amounts of steam are generated for space conditioning and industrial processes. These applications are inefficient uses of the fuel consumed because the end requirement is generally for a much lower grade of heat than the fuel utilized is capable of providing. The heat exhausted by electric-generation prime movers can be used for many commercial and industrial applications to produce an overall efficiency of energy use in the range of 70 to 85 percent. The implementation of this technology could both reduce demands for fuel and the demand for new capital in the electric utility industry. (Both commodities are in short supply.) It has been estimated that if large-scale industries gen-

[7] *ERDA-48,* Vol 1, appendix B

erated all of their own electric-power requirements by 1985 and served their process-heat requirements with waste heat, where possible, the Nation would save 1,45 Quads* per year [8]

Systems which make use of this "waste heat" are conventionally called "total energy" or "cogeneration" systems. A typical system is shown in figure IV-5. Equipment for total energy plants has been available for many years, but use of such systems has declined In 1972, only about 0.2 to O 3 percent of the U. S electric- generating capacity made use of waste heat. [9] This decline has resulted both from an overall reduction in onsite power and from the fact that electric sales have been more profitable than steam sales [10] The use of large, remotely located, electric-generating plants has, of course, made thermal distribution unfeasible in many cases. Total energy systems are still widely used in Europe and the Soviet Union.

There is an enormous demand for thermal energy in forms which are available from total-energy systems In 1973, for example, nearly 14 percent of the energy consumed in the United States went into space heating, and 23 percent into industrial process heat. [11]

Analysis of the economic attractiveness of both solar and nonsolar total-energy systems depends on whether the overall cost savings (e.g. , the amount by which the savings in electricity or fossil-fuel costs exceed the cost of owning and operating heat-recovery units) will result in an acceptable rate of return to an investor, In both cases, the issue depends crucially on the balance between thermal and electrical loads.

Total energy is not commonly used in residential applications because of the large daily and seasonal variation in thermal loads, In spring and fall, for example, there is a far smaller demand for thermal energy than during the winter and summer months. In the high-rise apartment studied in this assessment, for example, the ratio between energy required for electricity and the energy required for heating and hot water varied from 0.21 in January, when the heating load was maximum, to 1.5 during the spring and fall, when the primary requirement for thermal energy was hot water. Only about 5 percent of the 550 total energy plants operating in the United States in 1972 were installed in residences. The Department of Housing and Urban Development (HUD) is, however, conducting a large field experiment (MI US) with a total energy system serving a mixture of residential structures and commercial facilities.

Total energy or cogeneration systems are likely to be relatively more attractive in sites where there is a consistent demand for heat. Buildings such as laundries, hospitals, and the food, paper, refining, and chemical industries are prime candidates. Most of the large factories can be expected to operate on a three-shift schedule, permitting maximum utilization of the generating facilities, Many of the industries described use electricity in ratios amenable to cogeneration and can use steam at temperatures which can be conveniently supplied with cogeneration systems. The precise demands of buildings and industries of various types are discussed in greater detail in the section on "model building and industrial loads. "

Some care should be exercised in using the ratios which are developed for contemporary buildings and industries, since the thermal and electrical demands could change dramatically as the result of conservation techniques and new technologies. Widespread use of electric automobiles, for

* A Quad is defined as 1 quadrillion Btu's

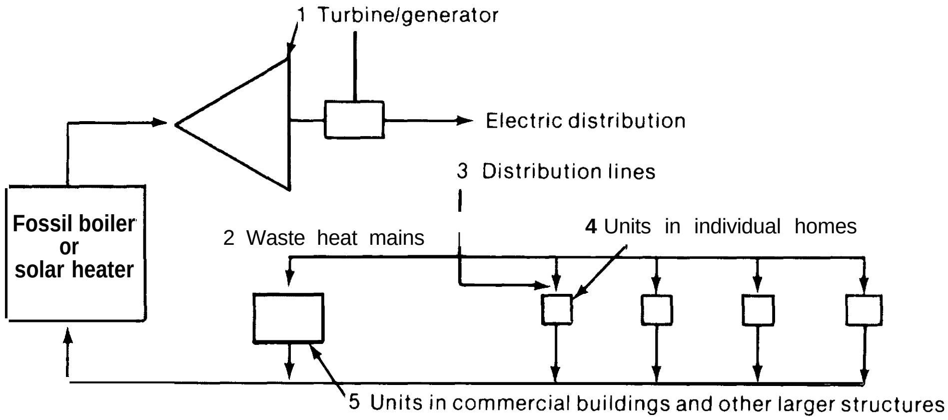
[8] Energy Industrial Center Study, op cit , pp 6, 7

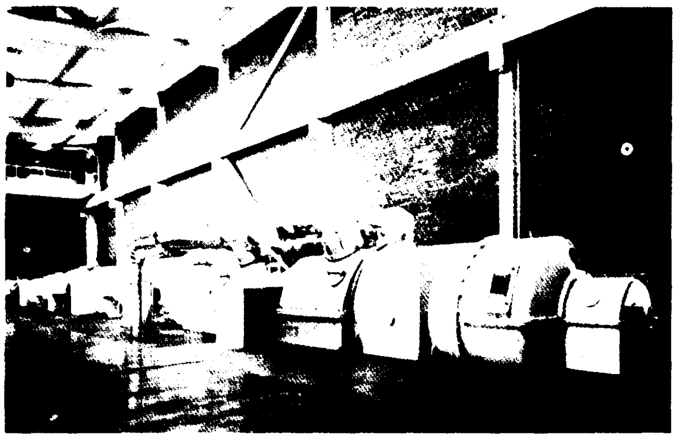
[9] P R Achenback and J B Cobel, *Site Analysis for the Application of Total Energy Systems to Housing Developments*, presented at the 7th Intersociety Energy *Convention* Engineering Conference, San Diego, Calif, Sept 25-29, 1972, p 5

[10] Energy Industrial Center Study, op cit , p 21

[11] M H Ross and R H Williams, *Assessing the Potential for Fuel Conservation*, The Institute for Public Policy Alternatives, State University of New York, Albany, N Y , July 1, 1975, p 19

Figure IV-5.—Components of a District Heating System in Sweden

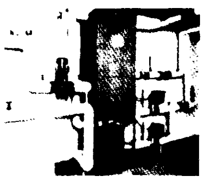




(1) District heating turbine plant delivered by STAL-LAVAL

(2) Installation of district heating mains out to Kallerstad, a new industrial area

(3) b) Plastic pipes (PEMX) with factory-added cellular insulation in corrugated polyethene protection pipe (Granges Essem)



(4) Consumer service unit for private house

(5) Large substation in a school

SOURCES Figures (1)(2),(4), and (5) from "District Heating" Tekniska Verken I Linkoping AB [Sweden) Figure (3) from Margen, P H (Manager Energy Technology Division, AB Atomenergi, Studsvik R&D center, Sweden), "The Future Trend for District Heating, " page 68, presented at the Swedish Symposium on Combined District Heating and Power Generation Feb 2528, 1974 example, would increase the ratio of electric to thermal demand in residential buildings, and heat recovery units could reduce thermal demands,

OPERATING COSTS

Concerns about operating costs have been a major barrier to onsite equipment in the past, and badly designed systems have been plagued by expensive maintenance. Reliable data about the cost of operating small systems designed for continuous-power output are extremely difficult to obtain because of the small number of installations in most of this size range. A summary of information from a variety of sources is shown in table IV-4.

The greatest variation in the data occurs in the small size ranges, where some of the numbers are based on estimates made by designers, some represent attempts to operate systems designed for "backup power" operation in a continuous operation mode, and some are averages of widely varying operating experience. For example, the military standard for generator sets shows an engine life of 2,500 hours for 15 kW units and 4,000 hours for 100 to 200 kW units. [2] Daimler-Benz reports up to 20,000 hours of engine life for its 10 kW engine.[13] Operating cost will depend strongly on the installation, the skill of the operators, and the system design. In most cases, it will be extremely difficult to predict operating costs until some experience has been obtained with the particular application.

There is considerable variation in operating costs of larger powerplants (see figure IV-6), and it is difficult to choose a single number for comparative purposes. This is particularly true for nuclear plants, where experiences vary greatly and statistics on long-term operating costs are cliff i cult to obtain. It is interesting to note, however, that over half of the operating expenses of coal-fired plants are due to the cost of operating the boilers. Presumably, these costs would be eliminated in a solar system that did not rely on fossil backup, although the cost of maintaining the collectors would probably compensate for this savings.

RELIABILITY

Concerns about reliability have been a major impediment to onsite power generation. Onsite installations can, in principle, be made as reliable as utility power—or more reliable if enough redundant units are purchased or great care is taken in design and manufacture. In fact, redundant onsite power systems are occasionally used to provide realiable power when utility power is not sufficiently reliable. Achieving high reliability with redundancy is, of course, expensive (see table IV-5). It is possible, however, that a simple, mass-produced heat engine could be designed to operate with the reliability of a household refrigerator (which is a simple heat engine operating in reverse). Designers working on a variety of different onsite systems feel that this is not

[12] Military Standard, Electric Power Engine Generator Set, Family Characteristic Data Sheets, Mil-Std-633 A(MO), Oct 8, 1965 (Data provided OTA by the Aerospace Corporation)

[13] Mercedes-Benz Diesel and Gas Turbine Catalog, Vol 36 (Data provided to OTA by the Aerospace Corporation)

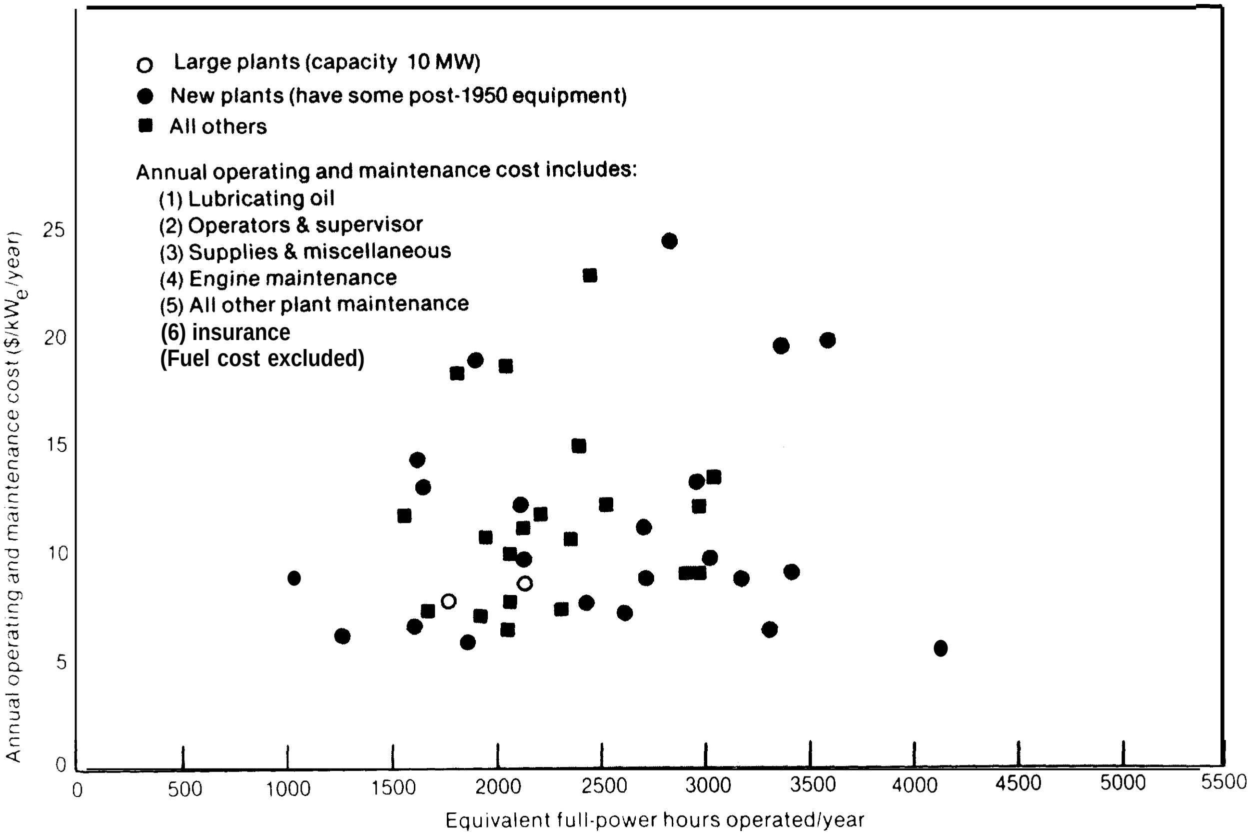
Table IV-4. —Operating Costs of Various Systems

Design type	operating and maintenance cost (c/kWh)	reference
A. Small systems (5-50 kW)		
—gas turbine	1.25	1
— diesel engine	0.4-2.4	2
— Stirling engine	0.74	3
—free-piston Ericsson	0.10	4
— air-conditioners	2-4	5
B. Intermediate systems (50-1,000 kW_e)		
—gas turbine	0.1-0.3	6
—gas turbine	0.25-0.4	7
—diesel engine	0.23	8
—diesel engine	0.27-0.55	9
—diesel engine	0.4	10
— gas engine	0.2-0.4	11
C. Larger systems (1 MW and larger)		
— large diesel plants	0.33	14
— new coal-fired turbines	0.12	13
— new nuclear plants	0.3	13

Notes for Table IV-4.

1. International Harvester, Sofar Division, private communication, March 1976.
2. Based on 2,500-10,000 hours between overhauls (estimate based on combination of data from Allis Chalmers, Detroit Diesel, and Daimler-Benz) assuming 30 percent of initial cost ($400/kW) is revested in each overhaul,
3. *JPL Program Review;* "Comparative Assessment of Orbital and Terrestrial Central Power Systems"' (Interim report), March 1976, p. 31. (Assumes a 15-year life and 1 man-hour every 3 months.)
4. Estimate by Glen Benson of Energy Research and Generation Corp., private communication, November 1976. (Assumes 1 mart-hour per year for maintenance.)
5. Based on maintenance contracts on 2-ton air conditioners which are assumed to operate at peak load--2 ,000 hours per year. Such contracts are sold by Sears for $60-$120/year (depending on the age of the system). It is assumed that an air-conditioning cycle, operating m reverse as a heat engine, is 17-percent efficient.
6. MIUS Technology Evaluation: "Prime Movers ORNL-HUD-MIUS-1 l,"' April 1974, p. 14.
7. International Harvester, Solar Division, private communication, May 1976.
8. *Diesel Engineering Handbook,* 1966(inflated by 6 percent for 10 years)
9. "MIUS Prime Movers," *op. cit.*, p. 21.
10. Assumes 30 percent of capital cost (assumed to be $300/kW) is invested for each 30,000 hours of operation.
11. "MIUS," *op. cit.*, p. 14.
12. '<Statistics d Privately Owned Electric Utilities in the United States," 1974, *FPC*, pp. 36, 37, and 21.
13. "20th Annual Steam Station Cost Survey," *Electrical World*, November 15, 1977, p. 46.
14. Morgan, Dean T. and Jerry P. Davis, "High Efficiency Decentralized Electrical Power Generation Utilizing Diesel Engines Coupled with Organic Working Fluid Rankine-Cycle Engines Operating on Diesel Reject Heat," 1974, pages 5-45, (Assuming a 60 percent load factor.)

Figure IV-6. —Annual Operating Costs Versus Equivalent Full-Power Hours of Operation for Baseload Plants



SOURCE: *Thermo Electron Corporation*

Table IV-5. — Engine Requirements for Systems Designed to Provide Reliability Equivalent to Utility Power Reliability

(Approximately 5 hours of outage per year, including failures in generating, transmission, and distribution equipment)

Number of engines in system	Fraction of peak load which can be met by each engine	Reliability required of each engine	Relative cost'
1	100%	0.999	1
2	100%	0.976	2
3	50%	0.986	1.5
4	50%	0.947	2
5	25%	0.992	1.25
5	33%	0.960	1.67

'The figures shown in this column may underestimate the added cost of multiple systems since smaller engines usually cost more per-unit-output than larger devices and more complex control systems would be required for multiple units

an unrealistic expectation. Photovoltaic devices, of course, are capable of extremely high reliabilities so long as adequate attention is paid to environmental protection in the initial installation.

Statistics on the reliability of onsite equipment are difficult to obtain and even more difficult to interpret since performance depends so heavily on the quality of the system's design, the skill with which the system is maintained, and local operating conditions. The situation is further complicated by the fact that most onsite generator systems are not designed for continuous operation and are meant only to provide emergency backup power. Some available data is summarized in table IV-6. A recent survey found that piston-engine generator sets used by the U.S. Army, for ex-

Table IV-6. — Reliability of Onsite Equipment

Engine type	Forced outage rate (%)	Scheduled outage rate (%)	Overall avail-ability	Mean time between failures	Average repair time (hrs)	Refer-ence
Diesel and gas turbines	1	3	.96	-	-	1
Piston engines	-	-	-	500 hrs	2.5	2
750 kW gas turbine	-	-	-	700 hrs	6.4	2
5 MW gas turbine	-	-	-	1.8 yrs	23.5	2
Large marine diesels	-	-	(more than .96)	-	-	3
Large diesels	1-4*	-	-	1.2-1.3 yrs	-	4

*Assuming an average repair time of 100 hours.

References

1. MIUS Technology Evaluation: Prime Movers, ORNL-HUD-MIUS-11, April 1974, pp. 57-60.
2. R. W. Parisian, Power *114*(1), 45-27, January 1970.
3. F. M. Swengel, Power Engineering 72(3), 38-40, March 1968.
4. Gamze, *ibid.*

ample, have a "mean time between failures" of about 500 hours,[4] Diesels and gas turbines, in the range of 50 kW to 1 MWe, however, average 1.2 years between failures.[15 16] Gas turbines typically operate 20,000 hours (2.3 years) without overhauls, even in installations where they must operate unattended, and 40,000 hours between failures have been experienced on some systems. " prototype Stirling engines have operated 10,000 hours without failures in bench testing.[18] Free piston Ericsson-cycle devices, if designed properly, should be able to operate with very high reliability because of their inherent simplicity, the small number of moving parts, and the fact that no seals around rotating shafts are required. The reliability of diesel equipment depends on whether the system has been designed for continuous operation and on the revolutions-per-minute (r/rein) of the device. Low r/rein systems which are designed for continuous operation can typically require one relatively inexpensive overhaul, costing about 10 percent of the initial investment each 10,000 operating hours, and a major overhaul costing 20 percent of the investment each 20,000 operating hours. Almost all reliable data deals with systems larger than 50 to 200 kWe and little data exists for very small systems.

Standards for reliability cannot be measured in any systematic way. Requirements will differ from customer to customer. Some industries, for example, would face catastrophic losses if they lost power for an extended period (say several hours), while residential customers might not be willing to pay a premium for extremely high reliability. One of the disadvantages of providing power from a centralized utility grid is that all customers must pay for a high system reliability whether they need it or not. Onsite generation would permit much greater flexibility in this regard.

Utilities currently try to maintain enough capacity to ensure that failure of the generating plant will curtail power for no more

[14] M/US Technology E valuation: Prime Movers, OR NL-HUD-MIUS-ll, April 1974, pp 57-60

[15] Ibid

[16] M Gamze "A Critical Look at Total Energy Systems and Equipment, " Proceedings, the 7th Annual I ECEC Conference, San Diego, Calif , Sept 25-29, 1972, p 1266

[17] Robin Mac Kay, "Generating Power at High Efficiency, " Power, June 1975, p. 87

[18] R C Ullrich (North American Philips Corporation), private communication, October 1976

than 2.4 hours per year. (This is a typical working figure, but standards vary. Southern California Edison Company, for example, uses a standard of 1 hour in 20 years)[19] It has been argued, however, that this standard for generating reliability is too high, and that the last few hundredths of a percent of reliability are enormously expensive, 20 particularly since the transmission and distribution system is usually less reliable than the generating plant The effect may not apply to all utilities, however, and optimal expansion plans may well result in maintaining very high reliabilities in some instances.

Analysis of the requirements of different types of customers in this regard is almost nonexistent It is difficult to anticipate how much different customers would be willing to pay for reliability If they were given a choice The costs of providing high-reliability service could be reduced, for example, if the customers were wi l l Ing to accept lower reliabilities during predictable periods — such as during peak-demand hours — or during maintenance cycles

The requirement for providing high reliability with onsite equipment can be relaxed considerably if the utility grid can be used to provide complete ''backup' when failures occur or when systems are disassembled for routine maintenance The impact of providing this backup power on utility costs is a complex issue and cannot be treated in detail in this paper

It is clear, however, that a small number of customers requiring backup would not have a major impact on utility operation, and that a large number of customers with small backup requirements would not pose a problem since failures would be distributed at random, Some correlation with peak-demand periods could be expected (Solar outages due to variations in sunlight would, of course, be correlated, but failure of equipment should be similar to other types of onsite failures,) A small number of very large users would, however, pose a serious problem if they depended on utilities for complete backup. I n such cases, provision would have to be made for drastic reduction of onsite demands whenever the onsite generating equipment failed. The presence of electric storage, either onsite or in the utility grid, could do much to alleviate the problems of unanticipated equipment failure

I t seems, therefore, that onsite equipment can provide any desired level of reliability If a premium is paid, if the utility is used to provide backup power, or if the optimistic expectations of system designers are realized, Existing equipment can provide a very high level of reliability without redundancy, although the exacting standards of utility power cannot be matched, The seriousness of this f a i l u re wou ld have to be judged o n a case-by-case basis, Unfortunately, there is little operational experience for most promising onsite equipment, and basic long-term concerns are unlikely to be finally resolved before an adequate base of experience with these systems has been developed

SITING PROBLEMS

In recent years, many utilities have experienced major problems in finding suitable sites for generating facilities A large number of new regulations and requirements have greatly increased both the cost and the time required to justify a proposed site. In most cases, lengthy environmental impact statements must be filed. A great

[19] Jerry Braun, Southern California Edison Company, private communication, May 1977.

[20] Michael L. Tolson, "The Economics of Alternative Levels of Reliability for Electric Power Generation Systems," *The Bell Journal of Economics*, Vol 6, No 2, Autumn 1975, p 697

variety of local and nationally based groups have legal standing orders to contest siting plants and rulings.

Most small plants would be required to go through many of the procedural steps required of the larger plants, and less effort may be required to justify the installation of a single large plant in a remote area than to justify several small facilities in areas where local protest would be likely to develop. On the other hand, the onsite generating equipment might face far fewer objections than the large sites for a variety of reasons:

- Each plant would be relatively small, and the impact on the local environment would usually be slight.
- In the case of cogenerat ion and total energy systems, energy would be required onsite for heating and industrial applications, even if no electricity were generated onsite, and thus the incremental impact of equipment and emissions traceable to electric generation wou Id be small,
- It could be plausibly argued, in most cases, that the impacts of alternatives to onsite generating facilities would be more severe than those imposed by the on site design.
- Onsite facilities would not require a major dislocation of populations, no construction camps would be required, no new roads or new waterways would be necessary, etc.

Large solar-electric systems, which require large amounts of land in a single area for collectors, could also face serious siting problems. Smaller onsite solar systems, which could be integrated into the buildings or immediate region being served with solar energy, would undoubtedly face far fewer objections,

MISCELLANEOUS OPERATING PROBLEMS

A major constraint to onsite power generation has been the reluctance of owners and managers of companies other than utilities to accept the burden of owning and operating complex electrical generating facilities; there has been great apprehension about maintenance costs, reliabilities, personnel requirements, and other technical uncertainties.

Operators of most commercially available generating equipment require extensive training, and in many jurisdictions, local codes set specific standards. For example, the District of Columbia requires operators of high-pressure steam systems, capable of generating more than 55 kW of thermal power (equivalent to about 15 kW of electric power) to hold a "second-class steam engineer's license. " Obtaining such a license requires 3 years of experience with steam-plants having pressures greater than 15 psi and passing a special examination.[21]

Thus, qualified operators are difficult to find and they command high salaries. Several steam-system owners have indicated fear about their vulnerability to losing a chief engineer with unique experience.

Equipment has also been a problem; the market for onsite equipment is so small that little new design work has been done, Existing onsite generating installations are nearly all "one-of-a-kind" designs; they are often installed by engineers who do not have much experience in the area, and they frequently use equipment in ways not originally contemplated by the manufacturer. As a result, performance has often been disappoint ing.[22]

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[21] "Operation and Maintenance of Boilers and Engines and Licensing of Steam Engineers, " District of Columbia Register, Washington, D C

[22] Maurice G Gamze, "A Critical Look at Total Energy Systems and Equipment, " Proceedings, the 7th Annual IECEC Conference, San Diego, Calif , Sept 25-29, 1972, p 1266

In some areas, suitable equipment of modern design is difficult to find. Most new boilers installed by industry, for example, are low-cost gas "package boilers" which are not compatible with the requirements of onsite electric power generation.[23] Small heat engines tend to be of older designs.

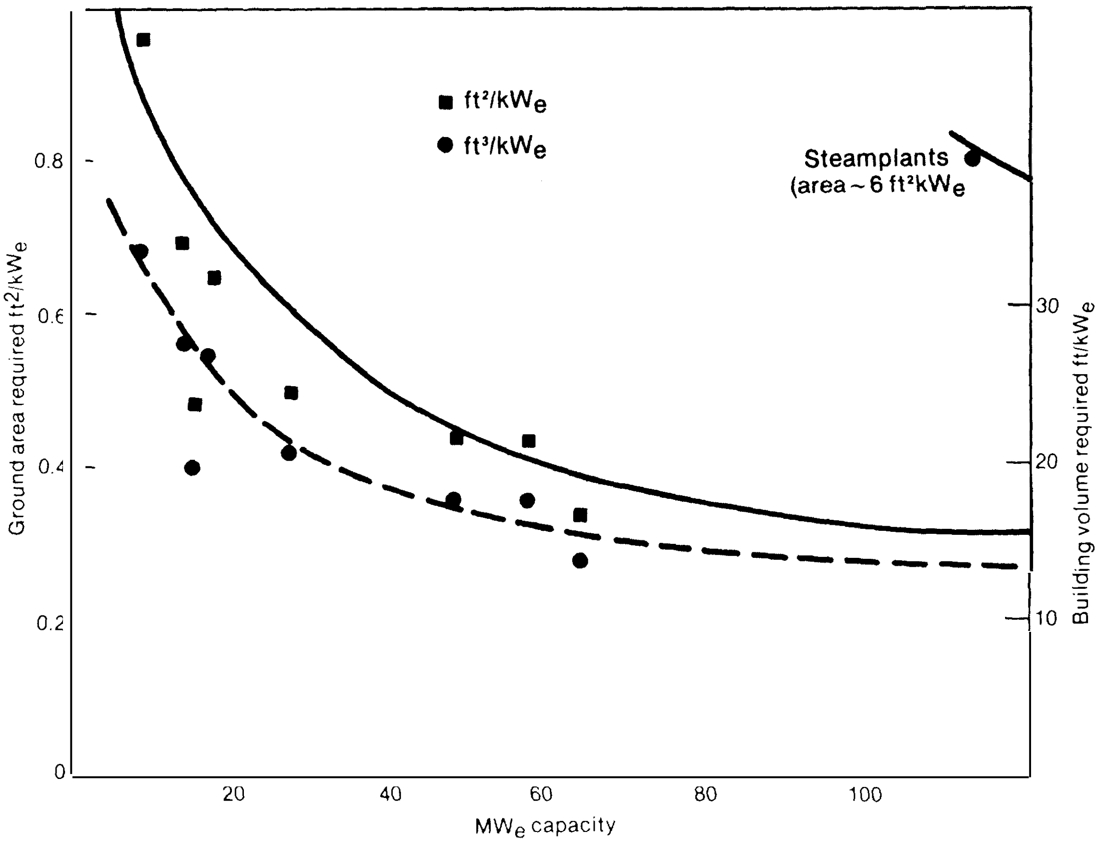
Building space may impose additional limitations (see figure IV-7). Electric-generating equipment would nearly double the space required for conventional heating and cooling equipment in a typical installation. The space requirements also make it difficult to expand capacity when requirements for electricity expand.[24]

The use of solar energy to operate onsite devices eliminates one of the major impediments to conventional onsite equipment — their use of relatively expensive liquid and gaseous fuels Table IV-1 indicated that fuel costs dominate the cost of providing power from small generating equipment even at current fuel prices In many cases, however, it may be attractive to try to provide backup for a solar-powered facility by burning a fuel during periods when solar energy sources are not available. It may be possible to develop boilers for small devices compatible with coal, waste products, and other "biomass" fuels The development of fluidized-bed boilers of various sizes may be particularly attractive for such an application. The development of such systems would, of course, also increase the attractiveness of onsite generating devices operating entirely from energy sources other than direct solar energy

[23] Edward J. Mitchell and Peter R. Chaffetz, *Toward Economy in Electric Power*, December 1975, p. 9.

[24] Gamze, op. cit., p. 1268.

Figure IV-7.—Space Requirements of Typical Combined-Cycle Plants



NOTE: 200 MW steamplants typically require 30-35 ft³/kW3 and 6-8 ft/kW.

SOURCE: Thermo-Electron Corp., "High-Efficiency Decentralized Electrical Power Generation..." New 1974 NSF Grant TE4186-27-75, p. 3-171.
"20th Steam Station Survey," *Electrical World*, Nov. 15, 1977, p. 58.