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A Plan for the Commercialization of Solar Thermal Central Receiver Systems

M. J. Fish, L. D. Brandt

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A PLAN FOR THE COMMERCIALIZATION OF SOLAR THERMAL CENTRAL RECEIVER SYSTEMS

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ABSTRACT

Concepts for solar thermal central receiver plants have evolved through continuing research and development into designs that are projected to have higher efficiency and lower cost. Recent studies have combined these results with rising costs of fossil fired plants and fuels to show that solar central receiver plants can be a competitive alternative for large scale electrical production. Because of these findings, commercialization of the concept is now receiving increased attention by both government and private groups involved with development of the technology. This report recommends the elements of a government program to achieve successful commercialization by the early 1990's. The recommendations integrate utility requirements for demonstration and risk sharing with supplier needs for manufacturing process development. Program timing and costs are presented, and the effects of program modifications are briefly discussed.

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A PLAN FOR THE COMMERCIALIZATION OF SOLAR THERMAL CENTRAL RECEIVER SYSTEMS

Introduction

Commercialization of the solar thermal central receiver concept is receiving increased interest as a result of several recent studies assessing its potential (1-4). These studies indicate that: 1) solar central receiver plants using mass produced heliostats can compete with conventional coal fired plants for large scale electrical production over a wide range of fuel cost projections, as shown in the example result of Figure 1; and 2) the solar central receiver concept is often the preferred choice among solar technologies for a large number of thermal and electrical applications and plant sizes. Based on these findings, the Division of Solar Thermal Energy Systems and the San Francisco Operations Office of the Department of Energy have requested that Sandia National Laboratories, as technical manager for this program, recommend a plan identifying an appropriate government role to accelerate, if possible, the commercialization of solar central receivers for large scale energy production. This report presents those recommendations.

A useful way to view the thrust of a commercialization study for any new energy technology is through the simple overview of technology evolution presented in Table I. The phases of Table I are typical of the progression of a new technology from initial conception to the time it stands on its own in the commercial marketplace. Activities in one phase may significantly overlap activities in another phase(s), but the framework of Table I provides the starting point for understanding the role of any given program element and its interaction with other parts of the overall plan. Phase 1 centers on research and development in which the choices for implementing the technology are narrowed and pursued. Phase 1 results lead into a demonstration period (Phase 2) in which most of the uncertainties in the working of the integrated system in real operating environments are resolved. While technical acceptance should be accomplished in Phase 2, economic viability will probably not be achieved due to the lack of established stable design procedures and large scale manufacturing facilities. Phase 3 activities must attack the economic hurdles in order to insure that both private user and supply sectors are established. Finally, the technology is ready to move into Phase 4 in which it can compete on its own for large scale energy production. In the context of Table I this report presents a plan for getting to Phase 4 from current R&D activities. In particular, major government programs, their timing, and estimated costs in Phases 2 and 3 are identified.

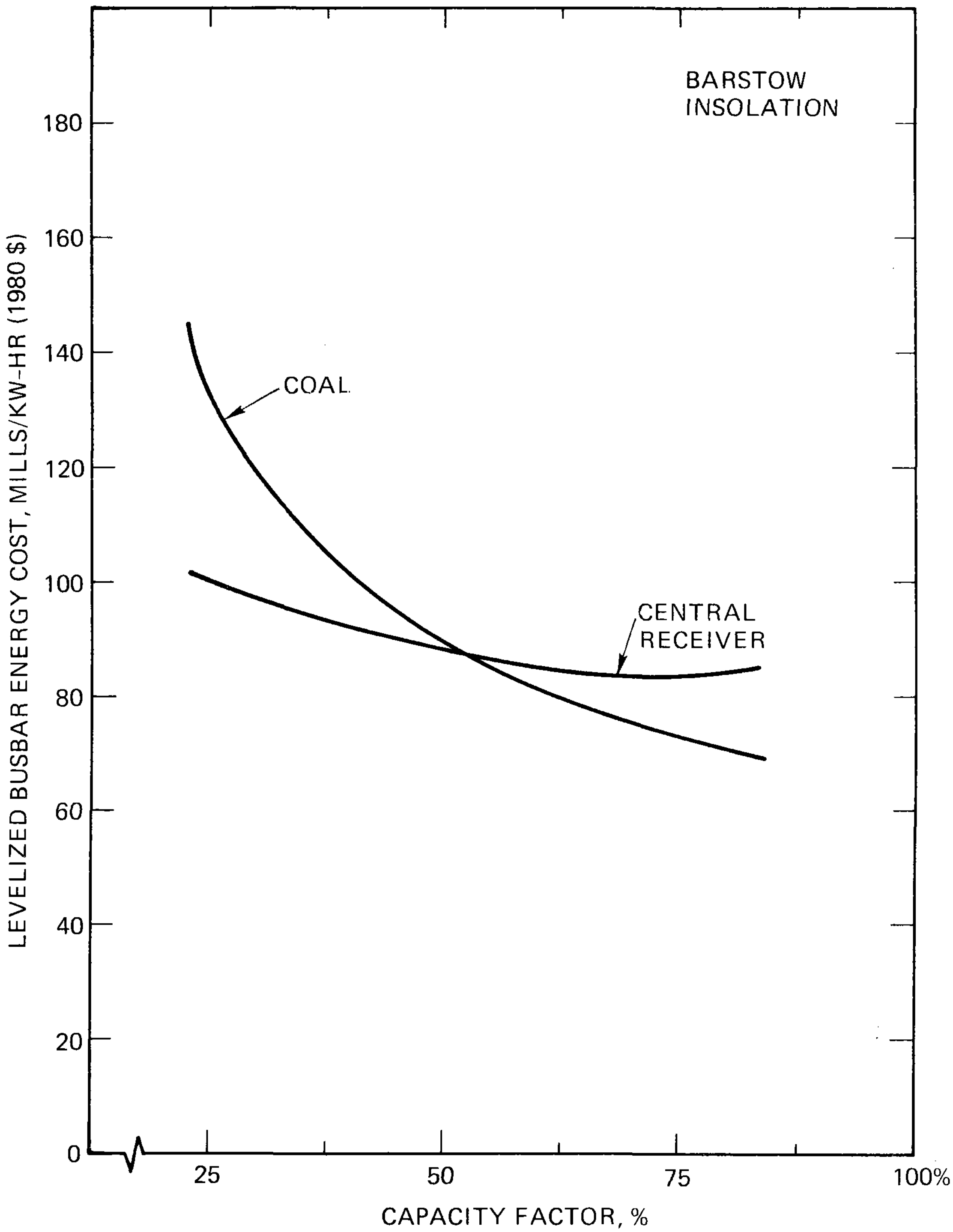


FIGURE 1. Energy Cost Comparison Between Solar Central Receiver and Coal Plants (cost and economic assumptions in Tables IX, X, XI in main text).

TABLE I

EVOLUTION OF NEW ENERGY TECHNOLOGIES

	Phase 1 Research and Development	Phase 2 Demonstration	Phase 3 Commercial Development	Phase 4 Commercialized Technology
Purpose	• Conceive and screen new ideas • Develop data base	• Resolve system technical uncertainites	• Establish private supply and market sectors	• Implement large scale energy production through user initiated projects

Approach

The two major but interconnected elements for successful commercialization are market acceptance and an established supply sector. Therefore, potential users and suppliers have been involved in formulating the plan recommended here. The particular programs discussed are aimed at integrating the needs of both sides in a compatible manner. Since the best characterized market for the technology to date is the electric utilities, and the major requirement on the supply side is achieving heliostat mass production, the authors have concentrated on identifying the major decision criteria of the utilities and potential heliostat manufacturers for committing to the central receiver concept. With respect to the balance of plant, it was felt that tower construction and steam turbine/generator systems were already well established technologies, and that receiver and storage systems would benefit most from continuing research and development activities rather than production economies of scale. Hence, the attention has been devoted to understanding how heliostat costs can be expected to change with time as a result of production process development.

The primary vehicle for identifying user and supplier requirements has been a series of meetings and follow-on exchanges with a number of southwestern U. S. utilities, both in and out of the current DOE program, and with several potential heliostat manufacturers currently involved in the program. The meetings were focused through a set of questions addressing concerns appropriate to the individual group with whom we were interacting. Although the number of potential users and suppliers interviewed was limited, it was felt that the major considerations for both were identified. The basis for this conclusion is that the views of the groups interviewed later in the process had already been expressed in earlier meetings with other groups. While this result might have been anticipated for the suppliers, it was also the case for the diverse group of users contacted. The utilities interviewed spanned a spectrum from innovative to very conservative with respect to their ability and/or desire to participate in the introduction of new technologies, and their levels of knowledge of the central receiver program varied widely. In spite of these differences, a consistent set of program recommendations evolved. The findings from these meetings are detailed in other reports (5,6); summaries are presented in Tables II and III.

The commercialization program elements discussed in this report result from the integration of user and supplier recommendations at a minimum level of government commitment to assure a high probability of success in a 10-15 year time frame.

TABLE II

SUMMARY OF UTILITY VIEWS

*On adopting central receivers for significant energy displacement

- Early plants would be designed for evaluating technology alternatives while minimizing system complexity
  - Receiver technology choice varies (no clear consensus for water/steam, salt, sodium)
  - Peaking applications (little or no storage)
- Later plants approach optimum solar application and technology
  - Higher capacity factors (intermediate to base load designs)
  - Most cost effective receiver technologies, as identified in early plants

*On the extent of demonstration (Phase 2, Table I)

- Barstow is necessary as the first technical integration step and as a clear sign of federal commitment to large scale technology development
- Larger demonstration(s) at 50 MW_e minimum are required
  - Minimum size for grid interaction
  - Intermediate size for scaling to full commercial
- Preferences vary for receiver/storage technology (salt, sodium, water/steam)
- 2-5 years reliable operation on a utility grid must be demonstrated

*On the government role in commercial development (Phase 3, Table I)

- Incentives are the desirable approach to overcome noncompetitive cost portion of first commercial plants
- Incentive policies must be in place early and approved for a substantial period of time (through early 90's minimum) to avoid unnecessary lags between demonstration and user commitment

*On the role of the state regulatory commissions

- New approaches for high risk capital intensive technologies are required

TABLE III

SUMMARY OF HELIOSTAT SUPPLIER VIEWS

* Competition is essential
  - Multiple supplier capability maintained beyond R&D
* Desirable path of each supplier to mass production proceeds through three steps
  - Design and prototype construction
    - 1-10 units
  - Continuous intermediate scale production
    - 2000 - 5000 units/yr
    - ~3 years
    - Some investment in tooling
  - Initial mass production
    - 15,000 - 30,000 units/yr
    - 5 years minimum
    - Dedicated manufacturing lines

Summary

The highlights of this commercialization plan are presented in Figure 2. The important points to be made about Figure 2 are summarized below. Detailed discussions can be found in the sections following.

1. Additional demonstration beyond Barstow to meet user requirements will also provide a market for heliostats produced at intermediate production levels (see Table III). This opportunity to satisfy critical user and supplier needs simultaneously is a cornerstone to achieving commercialization.

2. It is recommended that the noncompetitive cost fraction in the first commercial plants be overcome with properly structured federal incentives (e.g., added tax credits, accelerated depreciation allowances, financing of manufacturing facilities, etc.). Moreover, these policies need to be adopted by 1983 in order to minimize lags between demonstration and construction of the early commercial plants.

3. Utility commission policy revisions are an important complement to federal actions for implementing this technology. Suggested actions, such as capital recovery guarantees for the first plants, or combined stock holder and customer sharing of savings resulting from federal incentives, are discussed in the text.

4. The total costs to the government for the program presented here are estimated to be approximately $1.2 - $2.2 billion, depending on the cost of alternatives. This total includes approximately $340 million for program operating expenses, primarily for continuing research and development activities, $460 - $610 million for demonstration beyond Barstow, and $380 - $1200 million in incentives. These costs are spread over the 12 year period between now and 1992.

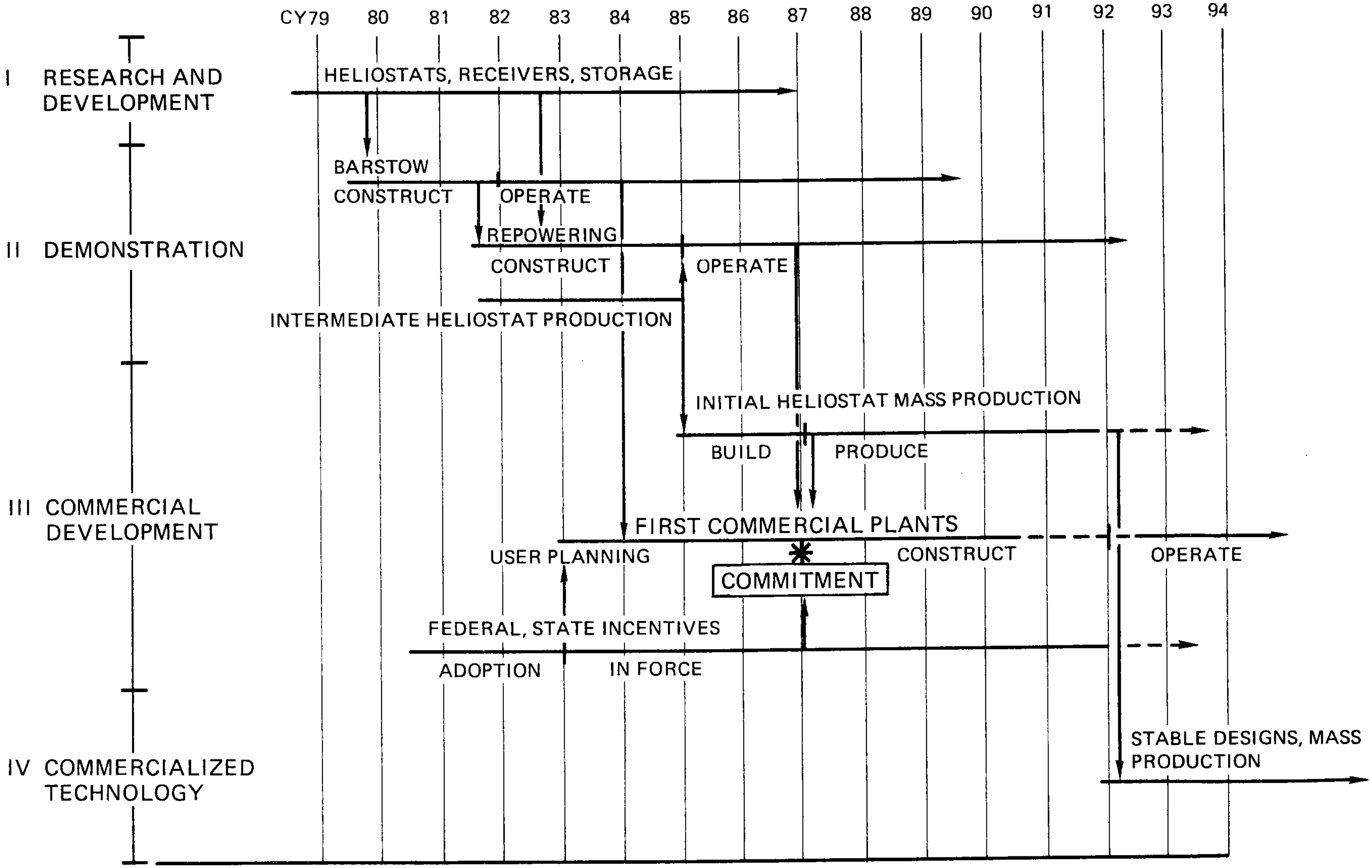


FIGURE 2. Highlights of the Commercialization Plan.

Program Elements for Central Receiver Commercialization

Retaining the structure of Table I, the goals of each phase in an evolving energy technology can be stated more specifically for solar central receivers as shown in Table IV. These goals are translated into recommended program elements in Table V. While these programs are far from the only choices, they do represent a minimum effort for successful commercialization based on both user and supplier requirements and preferences. The considerations behind the choices are discussed below.

Phase 1: Research and Development

The emphasis of the DOE program to date has been research and development (R&D). A number of conceptual and preliminary designs for the various subsystems are documented (see reference 7 for a review and bibliography). Both scale and full size hardware has been tested. Moreover, design iterations and component testing are ongoing and will continue as more experimental data and analytical capabilities become available. As a part of commercialization, continuing R&D efforts are essential to the evaluation of new technical options and applications as they arise. While the details of R&D integration with other activities are not the main concern of this study, routine and widespread dissemination of R&D results is very important for generating and maintaining interest in technology development.

Phase 2: Demonstration

As indicated in Table IV, the demonstration phase is aimed at both users and suppliers. The recommended program elements are designed to address a critical hurdle facing each side: adequate system demonstration for the users and continuous intermediate level heliostat production for about three years for the suppliers. With proper program planning, both barriers can be overcome simultaneously as discussed below.

Barstow--The 10 MW_e plant under construction near Barstow is a necessary first step to get the technology on a commercialization path. As the first operating integrated system, Barstow is expected by most utilities to have a number of start-up problems (5). After these are worked out, however, potential users will want to see the plant demonstrate 2-5 years of operating reliability comparable to more conventional options. This will qualify the project as a useful experiment from which estimates on operating and maintenance requirements can be made. This kind of information is important not only for economic assessments of the technology, but also as input to the next designs planned for construction. In addition, timely completion of the Barstow project is required as a clear sign to both users and suppliers of the government's commitment to develop solar as a viable option for large scale energy production.

100 MW_e Additional Demonstration--While Barstow is the required first step, it alone is not sufficient for attracting widespread utility interest. This is due primarily to the small size and experimental nature of the Barstow project and to a lesser extent, to the receiver/storage design for which more cost effective choices are now known. The demonstration projects in this part

TABLE IV

EVOLUTION OF SOLAR CENTRAL RECEIVERS

	Phase 1 Research and Development	Phase 2 Demonstration	Phase 3 Commercial Development	Phase 4 Commercialized Technology
Purpose	• Conceive and screen new ideas • Develop technology base	• Establish user confidence and support through adequate system demonstration • Provide small market for heliostats	• Provide economic incentives to build first commercial plants • Provide market for initial mass production of helio-stats	• Build full size commerical plants using estab-lished designs • Large scale mass production

TABLE V

MAJOR ELEMENTS FOR COMMERCIALIZATION

Phase 1 Research and Development	Phase 2 Demonstration	Phase 3 Commercial Development	Phase 4 Commercialized Technology
• Conceptual and preliminary designs • Component and subsystem testing -Heliostat prototype evaluation -Central Receiver Test Facility experiments -Storage, steam generator subsystem research experiments Applied research -Materials development • Information dissemination	• Barstow • Additional demonstration totaling 100 MW_e equivalent[1] - 50 MW_e plants - Salt, sodium, improved water/steam • Intermediate level heliostat production[1] -2K-5K units/yr - ~3 yrs minimum -2 suppliers minimum • Information dissemination	• Initial heliostat mass production -15K-30K units/yr -5 yrs stable production • Balance of plant designs -1st plant design and engineering • Federal government incentive program - Timing critical • Utility commission policy revisions	• No special programs or provisions for solar central receivers • Product improvement

[1]Can be satisfied with repowering program.

of the program are recommended as a move from experimentation at Barstow to technical demonstrations addressing two important commercial aspects of plant size and economic potential.

The recommendations for these follow-on projects are based on strong utility opinions (5). The groups interviewed generally agreed that demonstrations at 50 MW_e operated by utilities in their existing grid for 2-5 years would be the minimum acceptable effort to capture their serious attention. This size satisfies minimal requirements for grid interaction so that backup capacity requirements for solar plants can be characterized. In addition, component scaling limitations dictate an intermediate step at about this size in progressing from pilot plants such as Barstow to full commercial modules lying between 150 and 400 MW_e. Both of these points are important in the approach to commercial readiness.

Besides moving toward attractive commercial sizes, these demonstrations can utilize designs with improved economic potential and user acceptability. In the time since the Barstow design was selected, designs for heliostats and receiver/storage technologies of greater potential cost effectiveness have evolved (7). Heliostats currently under development have larger reflective areas and lighter weights per unit area, both of which lead to lower costs on a $\$/m^2$ basis. Receiver/storage designs with better cost and performance over the Barstow choice include improved water/steam, molten salt, and liquid sodium technologies. Based on their experience with conventional power generation to date, many utilities are leaning toward water/steam receivers as their early commercial choice. For a number of other utilities, however, the preference is with either salt or sodium because of the higher potential cost effectiveness of these technologies and the ease with which modern steam conditions, including reheat, can be produced. The choice of any of these technologies for demonstration at 50 MW_e might require an intermediate component development or pilot plant step between testing at the Central Receiver Test Facility and the 50 MW_e design if there are any serious material or equipment uncertainties in scaling. (An important function of the continuing R&D program is to evaluate the necessity of such activities.) Although this would be a conservative approach which might extend the time scale of the program, its lower risk may be justified for orderly commercialization (8).

The above considerations lead to the recommendation that total demonstration should be about 100 MW_e. At this level, two plants of 50 MW_e each could be built. These would satisfy minimum demonstration size requirements and allow the implementation of more than one receiver/storage technology. Given the diversity of preferences for receiver/storage designs and lack of test results and operating experience, multiple demonstrations are very important in order to attract a larger number of users to commit to the first commercial plants. While a number of the utilities view the early commercial plants in peaking applications (5), studies indicate that central receiver plant economics are enhanced at higher capacity factors, i.e., with the addition of several hours of storage. Hence, at least one of the demonstrations should include adequate storage to address the technical issues of operation from storage and to provide more data on solar plant capacity credit to the utility grid. This proposed level of demonstration will require ~10,000-15,000 heliostats. It is worth noting here that the draft repowering plan proposed by DOE/SAN in January, 1980, (9) would satisfy these demonstration needs.

Intermediate Level Heliostat Production--Potential heliostat suppliers interviewed in the course of this study agreed on the necessity of a stage of intermediate production at a level of 2000-5000 units/year for about three years (6). This transition step from prototype construction to mass production serves several vital functions. The heliostat design evolves to a mass producible version, and effective mass production processes are developed. Both these events can occur because investment in production tooling is at a small enough level to allow modifications. Moreover, the three year period makes field experience from the first units produced in this mode available for any necessary design modifications in later units. All these factors increase the certainty that an acceptable product can be consistently manufactured when the commitment to mass production facilities is finally made.

Only with strong assurance of a large potential market, however, will suppliers be willing to enter into this intermediate development stage on their own, and the market will evolve only with adequate demonstration as discussed above. By electing to demonstrate the technology to meet user requirements, the government can provide the market for intermediate level heliostat production, and moreover, the recommended scale of demonstration (10,000-15,000 heliostats) is large enough to support a minimum of two competitive suppliers. Maintaining competition during this early stage of production is important to promote cost reductions.

While these actions will not unconditionally guarantee the birth of a market and large supply industry, they will demonstrate the technology in a significant commercial market and provide the base for production of moderate cost heliostats. This opportunity to overcome simultaneously two major hurdles facing the technology, namely adequate demonstration for the users compatible with production levels to stimulate suppliers, is one of the key aspects of this plan for accelerating commercialization.

Information Dissemination--A dedicated effort to keep all parties, particularly the potential customers, informed of the progress of the program will become increasingly important in accelerating user decisions to commit to the technology. Mechanisms for routinely conveying important program findings in R&D and data from demonstration projects need to be developed by DOE. These activities might include widespread distribution of concise written summaries to users, suppliers, and state and federal government officials. In addition, individuals charged with marketing responsibilities in the program would be very effective for making personal contacts with a larger group of potential users unfamiliar with the status of the technology.

Phase 3: Commercial Development

Phase 2 activities bring central receiver systems to the point of technical readiness and offer the first step to economic viability by demonstrating receiver/storage systems of high potential cost effectiveness and by providing a market for heliostats produced in the intermediate manufacturing stage. Program activities in Phase 3 are aimed at completing the move to full economic competitiveness. Noncompetitive plant costs existing at the beginning of Phase 3 will be due to the small scale of mass production expected and the added expense in design and engineering of the first commercial plants. These conditions are expected to disappear by the end of Phase 3 resulting in competitive costs for central receiver systems.

Initial Heliostat Mass Production--Based on the continued involvement of two or more suppliers through intermediate heliostat production in Phase 2, it is anticipated that at least two suppliers will then be ready to move into mass production at a level of 15,000 - 30,000 units/year. Both scaling limitations from intermediate production levels (note similarity to utility practice) and uncertainties in the initial market size suggest this range as a maximum. The market uncertainties present at the beginning of Phase 3 will also cause suppliers to reduce their capital investment by purchasing readily available parts from outside manufacturers and to recover investment costs fairly rapidly, on the order of 3-5 years. These factors suggest that the Phase 3 heliostats will cost about $150/m^2$ (6). This is significantly higher than the competitive range of $75-$100/m^2$ estimated for mature mass production facilities, in which few parts are purchased and the capital recovery period is 8-10 years (10,11). Supplier commitment to this manufacturing strategy and to higher production volumes will occur as the market grows and more suppliers are attracted into the competition for a market share.

Balance of Plant Designs--The tower and turbine/generator subsystems of the central receiver plant are established technologies whose costs, in constant dollars, should remain at their current levels. However, the receiver and storage subsystems in the plants built in Phase 3 are expected to cost 50 - 100% above the estimates for stable "nth" plant designs. One contributing factor is the added design and engineering required to adapt the demonstrated technologies to the wide range of operating environments and specifications for commercial plants. As a result of this design evolution, suppliers of these components will find themselves in a corresponding evolutionary process of production development similar in nature to the intermediate heliostat production stage of Phase 2. Thus production tooling costs will be written off over relatively small numbers of installations. As more plants are built, receiver and storage design approaches will stabilize. Balance of plant costs can then be expected to approach "nth" plant estimates.

Federal Government Incentive Policies--As discussed above, full economic competitiveness is not likely to occur until after some period of initial heliostat mass production and after a few iterations on receiver/storage designs. In the interim, some vehicle for eliminating the cost/value differences to the users and/or suppliers must be provided in order to get plants built. The approach most favored by both the utilities and potential heliostat suppliers is the adoption of federal incentives to encourage the construction of the first commercial plants. The incentives might take the form of special investment tax credits, low interest loans, accelerated write-off periods, government funding of manufacturing facilities, etc. While each of these approaches has some merit, careful and immediate study by appropriate groups in DOE should be devoted to identifying the most effective ones. (Reference 12 provides an excellent starting point for this activity.) The incentives can be aimed at users or suppliers or both; e.g., additional investment tax credits can be offered to both those who will invest in production capabilities for solar equipment and those who buy and install it. The strong advantage of incentives is that the users are allowed maximum control in carrying out their projects, and the suppliers are encouraged to attract directly as many customers as possible for their product. Hence, the climate for normal commercial interactions is encouraged.

The effectiveness of this approach, however, is highly dependent on getting the incentives in place soon enough so that users and suppliers will be able to respond with little or no lag time after adequate demonstration in Phase 2. Because of anticipated long lead times for siting and licensing of the first plants for which procedures will not be well established, the utilities need incentives in place which will insure solar's economic attractiveness 2-4 years before construction is started. In addition, the suppliers require 2-3 years between the time a market is anticipated and the completion of a production facility. These facts point out the need to establish incentives as soon as possible, namely in the next year or two. Otherwise, gaps between demonstration periods and construction commitments by users can be expected.

Due to user and supplier planning requirements for commercialization by the early 1990's, the incentive program needs to be implemented rapidly and to remain in effect for a sufficient amount of time to insure the elimination of cost/value differences existing for the first commercial plants being built in Phase 3. This total time amounts to the sum of the planning and commitment times of users and suppliers (2-4 years) plus the required manufacturing investment recovery periods for the suppliers of the first plants (about 5 years). Two sets of incentives, one appropriate to the users and the other for suppliers, would help assure that both sectors will make their planning and commitment moves early.

Utility Commission Policy Revision--Current practices of most utility commissions tend to favor projects with lower initial capital investment even if operating costs are high. The up front project costs must be folded immediately into the rate base whereas increased operating costs can be added over time. Thus, higher initial investment costs mean higher near term increases in the rate base. This approach obviously favors fossil plants in comparison with solar. In addition, a new energy option, such as central receivers, whose reliability is not well characterized certainly offers higher risk to the customers whose interest are at stake. These considerations coupled with future economic uncertainties have made utility commissions reluctant to approve projects using unproven technologies.

In order to implement a new option such as the central receiver concept in the regulated utility environment, some commission policy revisions will be necessary. The utilities need encouragement that commissions will be receptive to new technology adoption and that they will allow some insurance against the risk of implementation. Effective actions might include: a guaranteed return on the investment in the event of premature shutdown before the end of the project's anticipated economic life; recovery of the investment starting in the construction period instead of when the plant comes on line; write-off of first of a kind plants as overhead (R&D) expenses; etc. In addition, changes in current practices regarding federal incentives are required in order that the federal incentive program recommended here be useful to the utilities. For example, typical commission policy is to pass through directly to the ratepayer, in the form of lower allowed charges, any favorable federal policy such as investment tax credits. The utilities need to share some part of these benefits in order to make financing of high risk projects attractive.

These actions on the state level are extremely important and may even be critical in accelerating commercialization of any of the new energy technologies. It is recommended, therefore, that the federal government establish a program to educate state policy makers and to implement, if necessary, regulations requiring utility commissions to evaluate new energy options in their state.

Phase 4: Commercialized Technology

At this point all special government programs or provisions can expire because the central receiver technology will be established as a competitive alternative for large scale energy production, in a position to compete using only those economic incentives enjoyed by other energy technologies. In the event of an established priority for accelerated penetration at this time, e.g., to achieve a 1 quad penetration goal by 2000, there may be some desire to keep or modify the special incentives adopted for the purposes of Phase 3. This topic, however, is not the focus of this report.

Timing of Programs

There must be substantial parallel development of the programs for each phase discussed in the previous sections in order to minimize the time to Phase 4. Figure 3 reorders the programs for commercialization listed in Table V in a time sequence. Starting times and durations for each program are based on points already discussed and on the current status of the program. Dashed lines imply uncertainty in activity starting and stopping times. When both user and supplier requirements are taken into account, and if the recommended actions are adopted, the technology can be competitive by 1992, assuming moderate coal price escalation rates.

Figure 3 also indicates interconnections between the various program elements based on the discussions in the previous sections. The Barstow project should move into startup and operation by the beginning of 1982. User requirements of reliable operation for two years minimum results in a 1984 to 1985 date at which the Barstow project becomes an influential factor in their planning activities. For the additional demonstration, the proposed scope of DOE's repowering program would satisfy both user needs for demonstration size and supplier requirements for intermediate heliostat production. This aspect plus the timeliness of the program recommend it as the choice for satisfying the purposes of Phase 2 beyond Barstow. The time required for selection, design, and construction of these projects restricts start-up of these plants to 1985 at the earliest. The need by the users to see these plants in operation for a minimum of two years results in a 1987 date when the earliest user initiated projects can be expected to begin. A slip in the repowering schedule will postpone this date. In addition, the two to four year user planning period prior to commitment means that users should be starting this activity as early as 1983 if they are to be in a position to start design and construction by 1987. At this early date, serious planning will take place only with the guarantee of the economic competitiveness of the solar plant in the late 1980's. In other words, the incentive program must be in effect by 1983 in order to minimize lags between demonstration and commitment.

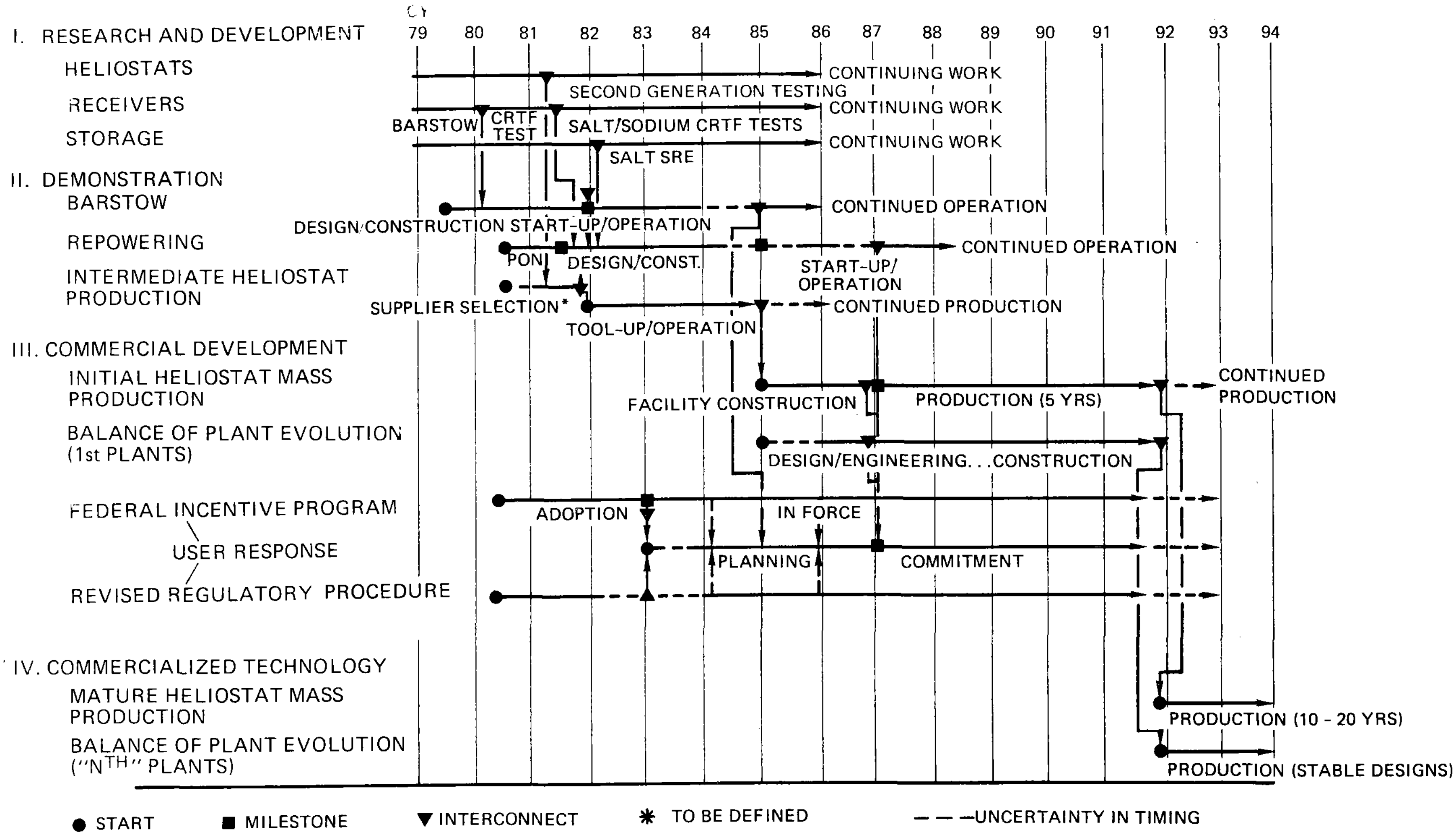


FIGURE 3. Program Timing.

The heliostat production development schedule also points out the necessity for a long term incentive program since the recommended production development path will not result in mature mass production until 1992. The intermediate production timing couples well with the design and construction schedule for repowering. There is also a fortuitous match between the user assessment period for operation of the demonstration projects and the time required for constructing initial heliostat mass production facilities. By about 1987 some users could be ready to commit, and the manufacturing capabilities should be available to meet the demand. Following about five years of initial mass production, a move to larger production facilities coupled to mature designs can be expected. Costs attain their competitive levels at this point, and the transition to the fully commercialized technology is then complete in the 1990's.

Roles of Participants

The general roles of the principal actors in each phase are outlined in Table VI. One can see in Table VI a shift from nearly exclusive government funding in Phase 1 to projects totally initiated and funded by the users in Phase 4. It is also important to note that some amount of user cost sharing is recommended as early as the Phase 2 demonstrations in order to indicate user, as well as governmemnt, commitment to developing the technology. This precedent has already been established for the Barstow plant. The additional demonstrations should include user commitment to the value of the solar plant in their application, taking into account both the costs of alternative technologies and the risks for central receivers. This is the most straightforward way to achieve serious user participation.

Table VII combines Figure 3 and Table VI to indicate major specific actions to be taken by each of the groups and the times at which they should be taken.

Since this plan is recommending that the federal government through DOE take the intiative in the early years, a more detailed breakdown of the near term activities of DOE are indicated in Table VIII. A 1983 date for implementing incentives at both the federal and state levels suggests that the formulation of these measures begin immediately. In addition, the three year plus construction period for repowering projects means that the funds for this activity need to be in place by fiscal year 1982. Again the groundwork needs to be laid as soon as possible. A slip in these early activities pushes user acceptance and supplier commitment further out in the later years and postpones the estimated 1992 date for full commercialization.

TABLE VI

GOVERNMENT, USER, SUPPLIER ROLES IN COMMERCIALIZATION

	Phase 1 Research and Development	Phase 2 Demonstration	Phase 3 Commercial Development	Phase 4 Commercialized Technology
Government	• Provide pioneering costs • Provide test facilities • Disseminate results • Plan for long term	• Provide most of funding • Assume most of risk • Exercise some control to assure projects meet long range goals • Remove government barriers	• Provide funding equal to cost minus value through financial incentives • Exercise minimum control	• Treat solar as any other developed technology
User	• Define potential applications	• Provide some funding • Assume some risk • Begin individual economic assessments	• Initiate and control most of project • Complete economic assessments	• Control projects completely
Suppliers	• Perform R&D • Develop data on present and expected costs	• Manufacture heliostats at intermediate production levels • Process development - Heliostats - Balance of plant	• Manufacture heliostats at initial mass production levels • Design and engineer first plants in detail	• Manufacture at high mass production volumes • Establish design and engineering procedures for balance of plant

TABLE VII

ACTIONS OF GOVERNMENT, USERS, SUPPLIERS IN COMMERCIALIZATION

Government

- Approve repowering projects - 1980
- Complete Barstow - 1981
- Adopt incentive polices - 1983
- Fund and complete repowering projects - 1982 → 1985
- Terminate special incentives - 1992

Users

- Begin planning activities - 1983
- Evaluate Barstow operation - 1985
- Evaluate repowering projects - 1987
- Commit to construction - 1987 →

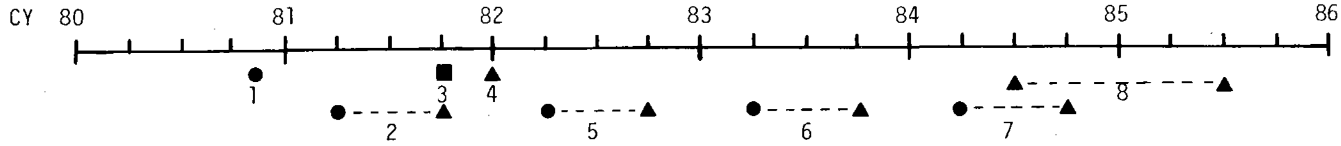
Heliostat Suppliers

- Produce at intermediate levels - 1982 → 1985
- Enter initial mass production phase
    - Begin facility construction - 1985
    - Begin production - 1987
- Move into large scale mass production - 1992 →

Balance of Plant Suppliers

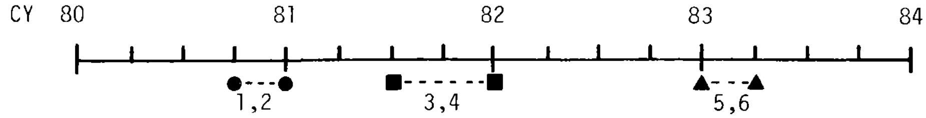
- Design and construct repowering plants - 1981 → 1984
- Design and construct first commercial plants - 1985 → 1992
- Enter stable component production phase - 1992 →

DEMONSTRATION PROGRAMS

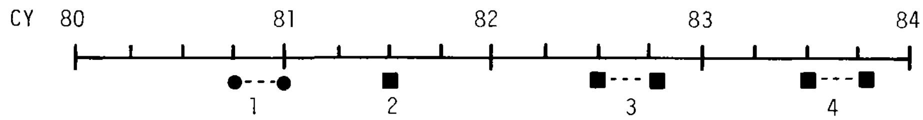


1. Issue PON for repowering.
2. Insure budget approval for repowering.
3. Select repowering construction projects.
4. Complete Barstow construction, begin operation.
5. Insure budget approval for remaining repowering funds.
6. Same as 5.
7. Same as 5.
8. Complete repowering project construction, begin operation.

INCENTIVE PROGRAMS



1. Begin federal incentive review.
2. Set up group to evaluate state policies, interact with PUC's.
3. Propose federal incentive package to Congress.
4. Propose actions affecting state level policies.
5. Secure federal incentives legislation.
6. Secure legislation (if any) affecting state policies.



1. Begin review of information transfer mechanisms.
2. Establish responsibility for information transfer.
3. Review information transfer programs, revise if necessary.
4. Same as 3.

●Start activity ■Intermediate goals ▲Completion points

TABLE VIII. Near Term DOE Activities.

Costs for Commercialization

In estimating program costs for demonstration in Phase 2 and incentive allowances in Phase 3, two factors must be considered. Obviously, the estimates on the solar plant costs in each phase provide the upper bound on expected program costs. On the other hand, the solar plant will have some value associated with it depending on the kind and amount of energy it displaces. As a baseline for estimating program costs, the value of the solar plant was bounded by the cost of a coal plant and fuel with the assumptions of Table IX. The solar plant cost assumptions are given in Table X, the economic assumptions in Table XI.

TABLE IX

COAL PLANT AND FUEL COST/PERFORMANCE ASSUMPTIONS

* Installed Plant Cost - \$925/kW_e (1980)[1]
* Delivered Coal Cost - \$1.50/10^6 BTU (1980)[2]
* Fuel Escalation - 1% above inflation thru plant life[3]
* Capacity factor - 50%[4]
* Heat Rate - 10,000 BTU/kw-hr

[1]Suggested from EPRI Technical Assessment Guide (13; late 1978 estimate escalated to mid-1980) and optimistic utility opinion.

[2]Typical of current new contract prices in the Southwest.

[3]Approximately equivalent to: 6% above inflation through 1985 followed by 0% real escalation throughout remainder of plant life.

[4]Average size for comparison with solar plant.

TABLE X

SOLAR PLANT COST/PERFORMANCE ASSUMPTIONS

* 50% capacity factor average

* Phase 2 - Demonstration Plants

  - Repowering application - no turbine/generator or land costs included
  - Optimal system design with improved receiver/storage technologies (i.e., salt, sodium, improved water/steam) -30% decrease in direct costs compared to Barstow
  - Government involvement similar to Barstow -60% distributables and indirects budget[1]
  - Heliostat costs from intermediate level production - $\$300/m^2$
  - Installed solar plant costs - $\$7600/kW_e$[2]
  - Plant efficiency ~22% (incident sunshine to electricity)

* Phase 3 - Early Commercial Plants

  - Small commercial plant diseconomies of scale ~10%
  - First plant design and engineering on balance of plant - 50% over nth plant costs
  - $\$200/kW_e$ for turbine/generator
  - Heliostat costs from low level mass production - $\$150/m^2$
  - Installed solar plant cost - $\$2,400/kW_e$
  - Plant efficiency ~22%[3]

* Phase 4 - Commercialized Technology

  - Installed solar plant costs - $\$1600/kW_e$

---

[1]Decreased government supervision, simplified procurement procedures, etc., compared to Barstow can greatly reduce this value.

[2]Consistency with repowering plan estimates (reference 9) discussed in reference 14.

[3]Poorer field performance in larger Phase 3 plants compensated for with more efficient balance of plant components to give about the same efficiency as Phase 2 plants.

TABLE XI

ECONOMIC ASSUMPTIONS

General Inflation - 8%
Capital Escalation - 8%
Discount Rate - 10%
Fixed Charge Rate - 17.75%
Interest During Construction - 25%
Plant Operating Life - 30 years

Based on these assumptions, the costs for commercialization can be estimated. A realistic scenario would suggest solar plant costs changing with time in a manner similar to the schematic illustrated in Figure 4. Costs for plants built in the five year period of Phase 3 should decline as design and engineering practices become better established. Some discontinuity can then be expected in the transition to the fully commercialized technology (Phase 4) as shown. This should occur as initial production facilities are paid off and/or larger production economies of scale come into effect. For the purpose of the first order analysis of this plan, however, the estimated average cost of the solar plants during each phase has been used. Figure 5 presents the equivalent costs of the solar and coal plants for each of the phases.

The total cost to the government is evaluated as the difference between the two cost curves in each phase times the total installed capacity. In Phase 2, the total is based on two heliostat suppliers producing 2000 units/year for three years; at 50% capacity factor, this amounts to an installed capacity of about 80 MW_e. In Phase 3, heliostat production is at 15,000 units/year from two suppliers for five years; at 50% capacity factor, this is 900 - 950 MW_e. Total program costs are $1.2 billion as shown in Table XII. This assumes user participation to the full value of the conventional coal plant alternative. A more pessimistic approach would acknowledge user reluctance to credit the demonstration and first commercial plants with full value due to the risk associated with the technology at that time. The extreme of no user cost sharing in the demonstration plants and no capacity credit (i.e., fuel displacement value only for the first commercial plants) results in the costs shown in parentheses. The Appendix presents the same analysis based on oil displacement rather than coal for comparison.

It is important to distinguish the nature of the various costs presented in Table XII. Both the operating (primarily R&D) and demonstration costs are direct government expenditures totaling $810-$965 M with most of it spent by 1985. Table XIII indicates the year by year profile. The remaining costs are in the form of incentives, which can limit government contributions to a cost effective level. Should the technology not be ready for widespread user acceptance by 1987 or if the incentives prove inadequate, then they will not

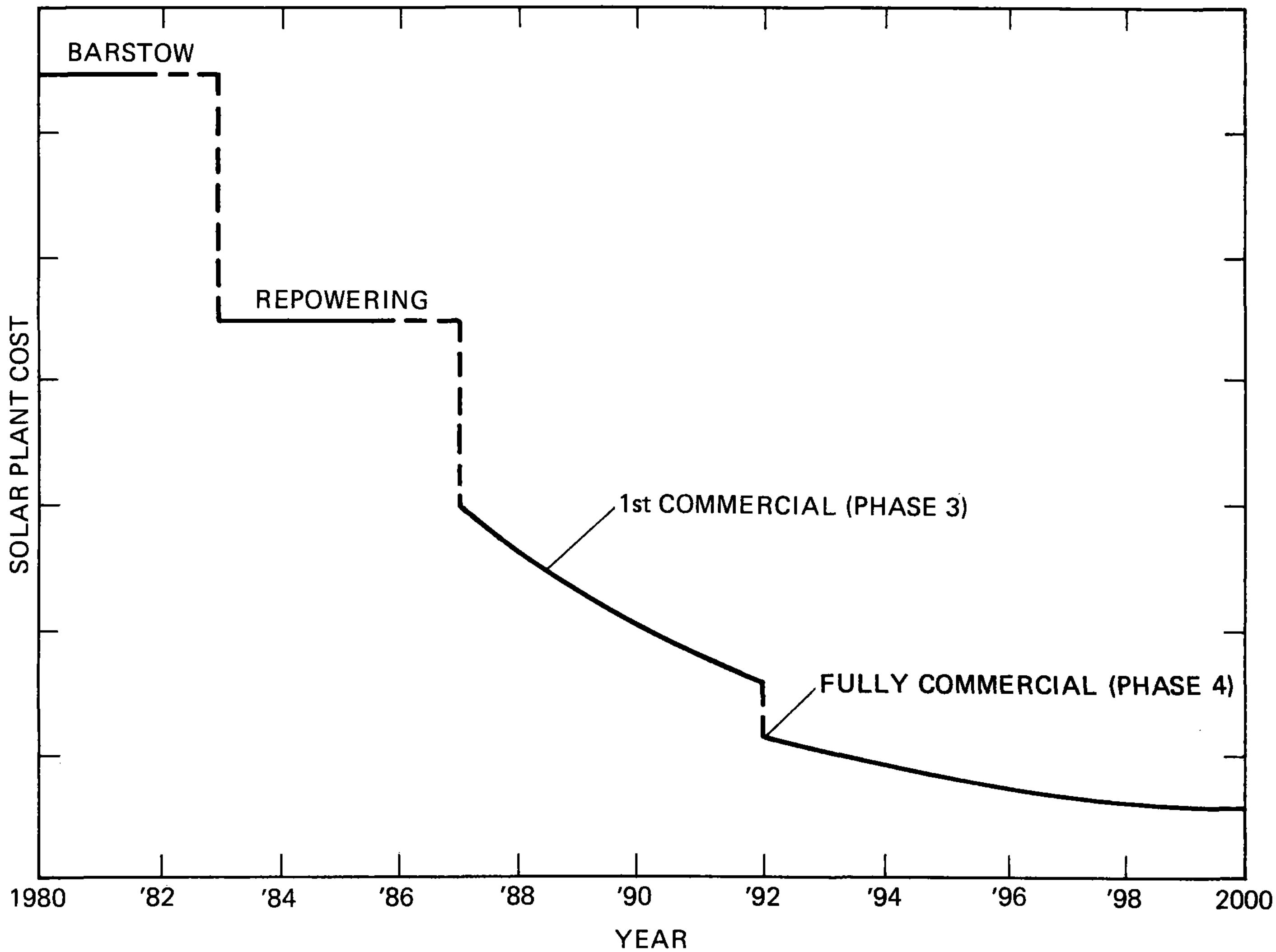


FIGURE 4. Schematic of Solar Plant Cost Variation with Time.

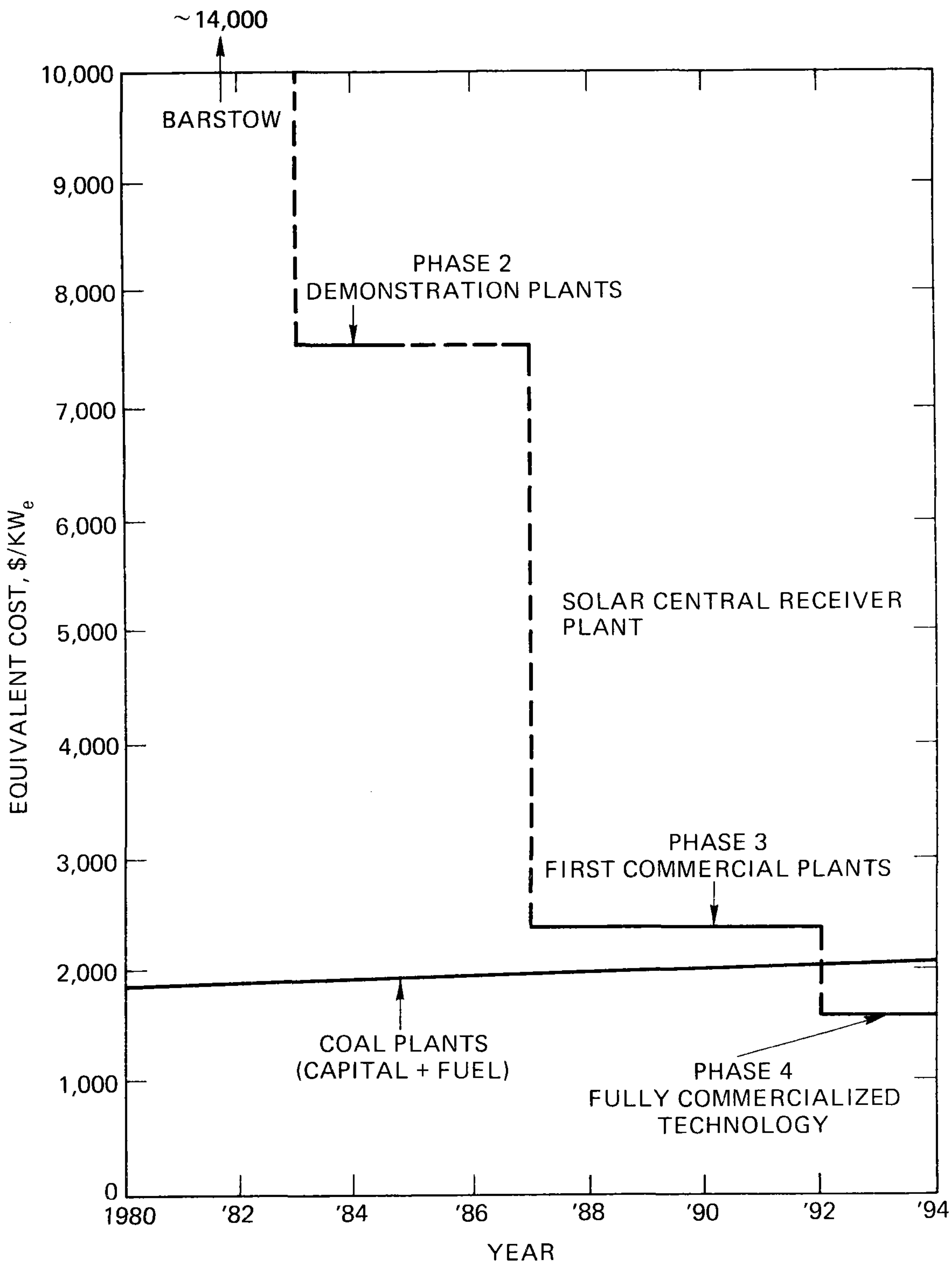


FIGURE 5. Equivalent Costs of Solar Central Receiver and Coal Plants.

TABLE XII

TOTAL PROGRAM COSTS TO THE GOVERNMENT (1980 $)

FY 1981 → FY 1992	
Demonstration Plants	\$467 M (\$623 M[1])
Incentives for First Commercial Plants	\$383 M (\$1215 M[2])
Operating Expenses (Continued R&D, demonstration project operation, capital equipment)	\$342 M[3]
TOTAL	\$1182 M (\$2170 M)

Installed Capacity ~ 1000 MW_e

[1]No user cost share; both figures include \$10 M for completion of Barstow in 1981.

[2]Solar plant value based only on fuel displacement only.

[3]From current Multi-Year Program Plan.

TABLE XIII

REQUIRED BUDGET AUTHORITY (1980$)[1]

FY	81	82	83	84	85	86	87	88	89	90	91	92	Cumulative
Total	65.0	171.5	277.4	199.8	55.6	32.5	25.5	19.5	14.2	13.0	11.0	10.0	895.0
Operating	35.2	50.5	49.4	36.8	34.6	30.7	23.7	18.0	13.0	12.0	9.0	9.0	322.9[2]
Construction	28.0	119.0	226.0	161.0	19.0	-	-	-	-	-	-	-	553.0[3]
Capital Equipment	1.8	2.0	2.0	2.0	2.0	1.8	1.8	1.5	1.2	1.0	1.0	1.0	19.1

[1]As of publication date.

[2]Includes R&D and operating expenses for Barstow and repowering (FY81-88) of ~$10 M/yr.

[3]Includes $10 M for Barstow (FY81) and assumes $70 M (12%) cost share for repowering projects (fuel displacement value).

be subscribed to the full extent of the $400-1200 M indicated here. Besides the lower risk to the government, incentives offer a lower cost approach than some form of direct government outlay because of the absence of the collection and budgetary approval steps associated with direct expenditures.

The average government expenditure per kW_e installed capacity is $1200-2200/$kW_e$.

Modifications to the Plan

A number of actions or different approaches to the plan recommended here can be proposed. Regardless of the particulars, any such modification will tend to either expand or narrow the scope of the proposed program. In discussing the effects of either, one should keep in mind certain points about the program recommended here.

The intent has been to provide a low risk path to commercial readiness regardless of the time required or the capacity displaced in the interim. As such, market penetration goals such as those set forth in the President's Domestic Policy Review may not be attained without a more ambitious program than outlined here. Such a program could include additional demonstration in non-utility applications in order to attract a wider market, and/or greater financial incentives early on to accelerate user commitment. The former is in fact a part of the repowering plan (9), in which industrial process heat projects, as well as utility projects, are included. Such actions, however, may require a larger government expenditure.

It should also be recognized that the recommendations presented here have been developed through an examination of the basic elements of the commercialization process. Thus, they represent a minimum effort for developing both user acceptance and supplier readiness in an orderly fashion. Changes to this plan which would compromise program elements at levels below those recommended run the risk of not developing the market and/or supply sectors as desired. For example, key elements for demonstration (Phase II) are not only user requirements, which dictate project size, but also intermediate heliostat production, whose essential characteristics include a minimum level and duration of production <u>plus</u> the competitive element. Sacrificing any of these could well postpone the availability of the fully commercialized technology.

While the program elements can be viewed as a conservative set with respect to risk to the users and suppliers involved, the proposed timing is optimistic. Significant overlap is recommended in anticipation of success of each activity, but a less optimistic phasing will postpone full commercialization past the twelve years suggested here. Some aggressive moves on the part of the government are called for, but the risk is minimized through the recommended approach of incentives for the transition from demonstration to the established technology.

Conclusions

The program for commercialization of solar central receivers presented here has incorporated the major requirements of both users and suppliers. The timing is dictated by user needs for planning and demonstration and by manufacturing requirements for design iteration and production process development. As such, the program can be viewed as a conservative approach in which the technology evolves through the normal steps which might occur in a totally private commercialization effort.

The importance of the government role, however, must not be underestimated. By providing funds for large scale demonstrations and incentives for the early commercial plants, the government is accelerating the pace at which the technology is implemented. The costs achieve competitive status with component production design maturity and high production levels. Only with government involvement at the approximate levels proposed here can this happen by the early 1990's.

Key points of this plan include: (1) the ability to resolve simultaneously two problems facing adoption of the technology, i.e., adequate demonstration for the users coupled with an intermediate level of heliostat production; (2) identification of incentives, in place of direct government expenditures, as the approach for getting the first commercial plants built; the timely adoption of and long term commitment to this approach is essential; (3) total costs to the government amount to $1.2 - $2.2 billion; of this total, $800-$950 M is in the form of direct expenditures for continuing R&D and additional demonstration.

There are several remaining areas for investigation. Foremost is the effect of an added market besides electrical. In particular, recent studies (2) indicate the attractiveness of many industrial process heat applications. Revisions to this plan, if necessary, will be made in the future as this additional market is better characterized. The other important follow-on activity is the identification of the most cost effective incentives to both users and suppliers.

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APPENDIX--PROGRAM COSTS BASED ON OIL DISPLACEMENT

The analysis in the main text on costs for commercialization is based on coal as the alternative for determining solar plant value, and as such, the results can be regarded as conservative. Arguments can be made that solar plants will actually be displacing oil or natural gas, particularly in repowering applications, and that these fuels should form the basis for determining solar plant value.

Assuming oil displacement as the criteria for solar plant value, the costs for commercialization can be determined as in the main text using the equivalent $/kW for the oil displaced instead of the coal plant and fuel cost. Figure A-1 is the analogous version of Figure 5 in the main text. The economic assumptions are the same as those in Table XI of the main text, with the current oil price assumed as $\$4.00/10^6$ Btu escalating at 1% above inflation. The heat rate used is 8500 Btu/kW-hr. The corresponding program costs are given in Table A-I.

Since the estimated costs for the first commercial plants (Phase 3) are very close to the value of the oil displaced, this analysis suggests that the government need only demonstrate the technology at the proper level and that no special incentives will be required in getting the first commercial plants built. However, for existing facilities being forced off oil and gas, the most economical alternative is coal, and moreover, new plants are likely to be coal fired because of its economic attractiveness over the alternatives. Hence, the analysis and discussion in the main text is based on coal.

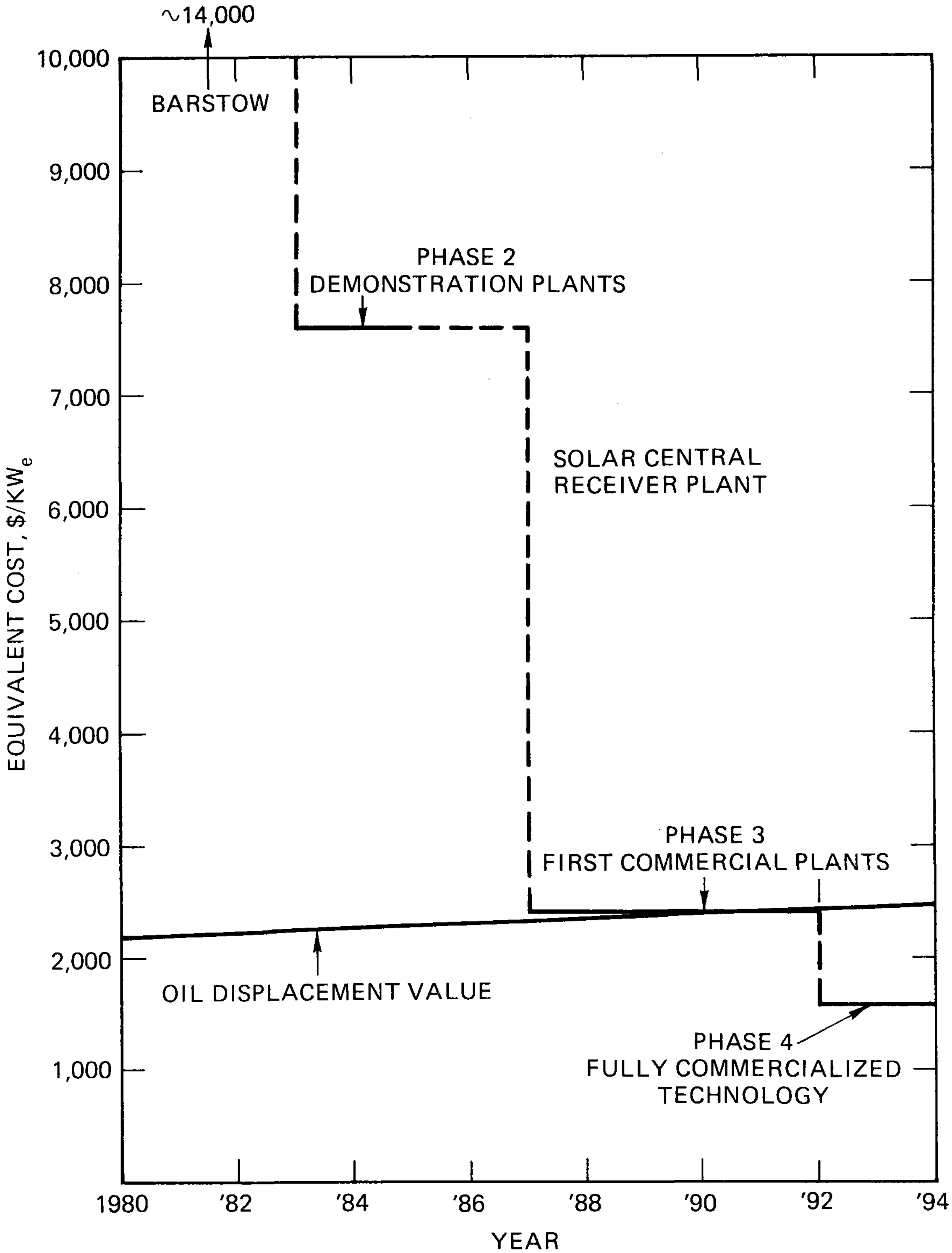

FIGURE A-1. Equivalent Costs of Solar Central Receiver Plants and Fuel Value in Oil Plants.

TABLE A-1

TOTAL PROGRAM COSTS TO THE GOVERNMENT (1980$)
OIL DISPLACEMENT

FY 1981 → FY 1992	
Demonstration Plants	$420 M ($623 M[1])
Incentives for First Commercial Plants	--
Operating Expenses	$342 M[2]
TOTAL	$762 M ($965 M[1])

[1]No user cost share; $10 M for completion of Barstow included.

[2]From current Multi-year Program Plan.

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R. Murraye Gordon
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Southwestern Public Service Company
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W. R. Esler
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J. B. Matthews
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Austin, TX 78767
Attn: R. L. Hancock

Brownsville Public Utilities
P. O. Box 3270
Brownsville, TX 78520
Attn: H. E. Hastings

West Texas Utilities Company
1062 N. 3rd St.
Abilene, TX 79604
Attn: R. E. Kennedy
Rick Stanaland

Garland Electric Department
P. O. Box 189
Garland, TX 75040
Attn: E. E. Krause
Bud Cariker

Denton Municipal Utilities
Municipal Bldg.
Denton, TX 76201
Attn: J. C. Little

Brazos Electric Power Coop.
P. O. Box 6296
Waco, TX 76707
Attn: J. E. Monahan
G. P. Lamb

Greenville Municipal Light and Power Department
P. O. Box 1049
Greenville, TX 75401
Attn: R. E. Nelson

South Texas Electric Coop.
P. O. Box 2485
Victoria, TX 77901
Attn: O. S. Roeson

City Public Service Board of San Antonio
P. O. Box 1771
San Antonio, TX 78296
Attn: J. K. Spruce
Don Snyder

Mendina Electric Coop.
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Hondo, TX 78861
Attn: M. D. Vajdos

Lubbock Power and Light Department
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Lubbock, TX 79414
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Topeka, KS 66612
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William Woellhof
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Kansas Gas and Electric Co.
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Kansas Corporation Commission
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Brian Moline
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Kansas Energy Office
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New York, NY 10001
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Marina del Rey, CA 90291
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American Public Power Association
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Washington, DC 20037
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Newark, NJ 07101
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Northrup Inc.
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