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HEAT AND ELECTRICITY FROM THE SUN USING PARABOLIC DISH COLLECTOR SYSTEMS*

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ABSTRACT

This paper addresses point focus distributed receiver (PFDR) solar thermal technology for the production of electric power and of industrial process heat, and describes the thermal power systems project conducted by JPL under DOE sponsorship. Project emphasis is on the development of cost-effective systems which will accelerate the commercialization and industrialization of plants up to 10 MWe, using parabolic dish collectors. The characteristics of PFDR systems and the cost targets for major subsystems hardware are identified. Markets for this technology and their size are identified, and expected levelized bus bar energy costs as a function of yearly production level are presented. Finally, the present status of the technology development effort is disccussed.

INTRODUCTION

The solar thermal power systems work at JPL is sponsored by the Department of Energy, Thermal Power Systems Branch, for the purpose of developing systems capable of competitive-priced thermal and electric energy for utility, industrial, and isolated applications. Program responsibility resides with DOE Headquarters and project management with JPL, with engine and power conversion support provided by NASA Lewis Research Center.

Three principal configurations for thermal power systems being developed by DOE are the central receiver (CR), the line focus distributed receiver (LFDR), and the point focus distributed receiver (PFDR). The JPL work is based on a PFDR system with paraboloidal dish and integral receiver. This technology is expected to be initially applied to relatively small power systems (up to a few megawatts) made up of identical modules (each a few tens of kilowatts in capacity). Each module is capable either of generating electricity, or of supplying heat for industrial purposes, depending on the type of receiver used. A representative dish configuration is shown in Figure 1.

For electric applications the module consists of three subsystems: the concentrator, the receiver, and the power conversion unit. An automatic control system enables each module to track the sun. In the simplest configuration of the system, the power conversion unit is located atop the receiver, at the focus. The optical portion of the concentrator is a parabolic reflector, although lens concentrators are also being considered. To produce thermal energy for industrial, commercial, or agricultural applications, the power conversion unit is replaced with an appropriate receiver having flexible lines to conduct the working fluid to a heat transfer network on the ground.

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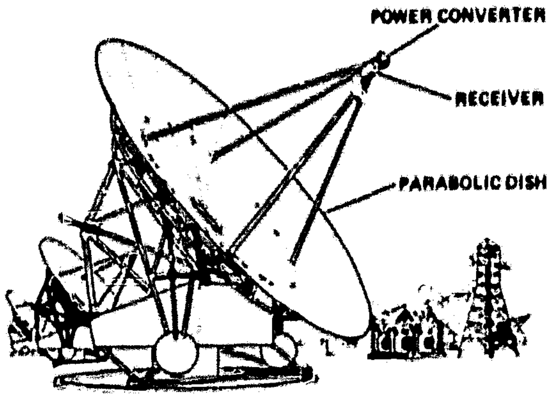

Figure 1. Dish Concentrator with Power Converter at the Focus

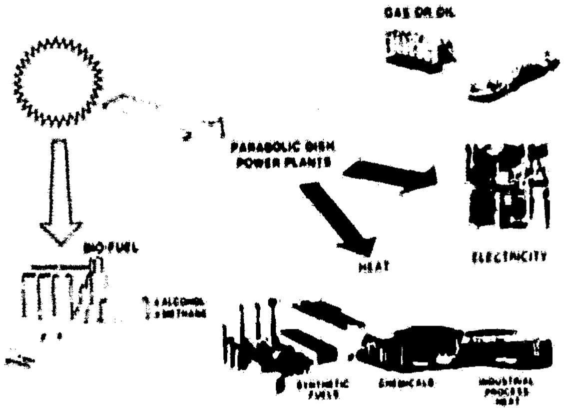

Figure 2. Versatility of Parabolic Dish Power Plants

POINT FOCUS DISTRIBUTED RECEIVER (PFDR) ADVANTAGES

The principal advantages of dish solar concentrators are (1) the high temperatures attainable, (2) the inherent modularity of dish collectors, (3) the ease of collecting the power output of each dish in electrical form, and (4) the high percentage of the available solar insolation which is collected. The high temperatures available from dish systems results from their inherently high concentration ratio.

The attractiveness of the high temperature characteristic of dish systems arises from both the higher conversion efficiency achievable from heat engines as the temperature of the working fluid is increased and the wide range of temperatures achievable for thermal applications.

The ready adaptability of dishes to two-axis tracking insures maximum utilization of the direct beam radiation at near maximum efficiency from sun up to sun down. Two-axis tracking combined with the high geometric concentration ratio provides high temperatures at the focus, which in turn allows high efficiencies to be derived from Brayton or Stirling heat engine power converters. PFDR systems offer broad applicability, including both small and large utilities, power for remote sites, agriculture (especially pumping), and a wide range of industrial and commercial process heat applications.

Versatility as shown in Figure 2 is a key attribute of solar thermal systems, especially of dishes because of their high temperature potential. Versatility can be illustrated in terms of the end product produced: electricity, process heat, steam, chemicals and fuels.

Dish systems can readily be designed to provide for hybrid operation in which conventional fuels provide heat on a transient or steady state basis to compensate variations in insolation. Along with the hybrid operational capability, there is the potential for using numerous conventional fuels. A potentially attractive hybrid mode is the coupling of the solar plant to a biomass system to supply it with low Btu biogas produced by a digestive process. The most appropriate fuel would be selected for each application.

PROJECT GOALS

The primary goals of the project are (1) to produce electricity or heat at a cost competitive with conventional alternatives, and (2) to develop the technical and economic readiness of cost-effective PFDR technology necessary to accelerate market penetration of small power systems. Market penetration requires a mature technology coupled with favorable preconditions within the commercial and industrial infrastructures which govern the effectiveness of supply and demand forces. To facilitate the establishment of preconditions increasingly more favorable to market penetration, the project will attempt to enter market areas of high-cost energy first and to enter large markets with corresponding lower energy costs later. Figure 3 displays this overall market strategy. The projected size of the isolated load market (a near-term, relatively high-cost energy market) in the 1990-2000 time period is 300 to 1000 MW/year. Although this market is small in comparison to the grid connected utility market, the graph also indicates that by assuming only a 20% market penetration, up to 10,000 power modules per year would be required to meet this need.

In addition to the electric market, both grid and non-grid connected, there exists a large market for a combination of both thermal and electric power. Industrial process heat is a typical application in this category.

In summary, it is clear that to build manufacturing volume most expeditiously, the high cost, isolated load markets should be penetrated first. To compete in the low cost grid-connected market will require both experience and production volume which can result from the successful prior pursuit of the higher cost, isolated markets.

CONCEPT OF FIRST AND SECOND GENERATION TECHNOLOGY

From a technology standpoint, the project strategy is to first develop hardware suitable for entering the near-term isolated load market. First-Generation equipment, based on gas turbine technology, will entail less developmental risks and permit the early introduction of solar plants into the marketplace. Satisfying the demands of the near-term market will help to mature all the infrastructures essential to solar power plant sales, especially with regard to collectors. Just as importantly, this strategy will also make solar power plant technology more visible and thus encourage its large-scale use in other applications.

To meet the long-term goal of the project (i.e., entering the grid-connected market with baseload coal-steam and nuclear plants), improved system efficiency is needed. This will be achieved through use of advanced engine (second generation) technology. Additional cost reductions are expected from continuing improvements in dish collector design, and through increased production.

Solar power plants produced from first generation technology have system goals of 100 to 120 mills/kW hr. Such plants can compete with conventional systems in the near-term isolated load market, and in the oil-fired, intermediate-peaking, grid-connected market, but will need to be improved for the baseload grid-connected power plant market. The main attraction of these plants is that they will enter the near-term market, develop the required infrastructure and require only a modest R&D investment by the government to mature.

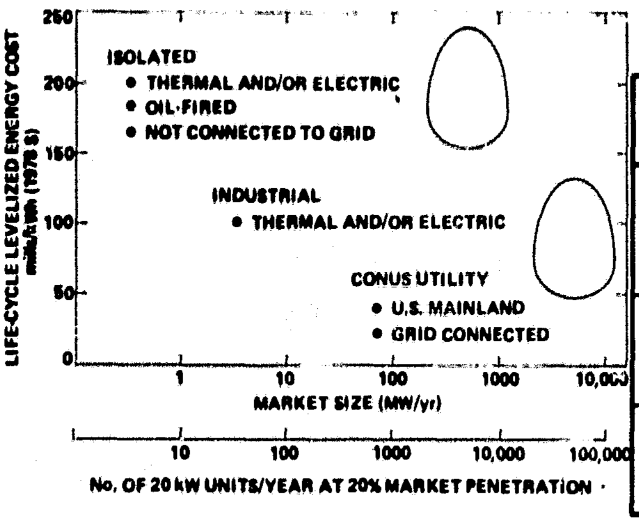

Figure 3. Energy Cost and Market Size

Table 1. Cost and Performance Targets for Electric Power Generation (1978 Dollars)

SUBSYSTEM	PARAMETER	TARGETS FOR FY	
		1ST GENERATION (1982)	2ND GENERATION (1985)
CONCENTRATORS	COST IN MASS PRODUCTION*	\$100 – 150/m²	\$70 – 100/m²
	REFLECTOR EFFICIENCY	90%	92%
RECEIVERS	COST IN MASS PRODUCTION*	\$40 – 60/kWe	\$20 – 40/kWe
	EFFICIENCY	80%	85%
POWER CONVERSION	COST IN MASS PRODUCTION*	\$200 – 350/kWe	\$50 – 200/kWe
	EFFICIENCY	25 – 35%	35 – 45%

* RANGE OF 1ST GENERATION PRODUCTION: 5,000 - 25,000/YEAR.
* RANGE OF 2ND GENERATION PRODUCTION: 10,000 - 1,000,000/YEAR.

Power plants using second generation dish technology will require more time to bring on line (3 to 4 years of additional technology development) and consequently will require more resources to develop. Work on second generation systems has already begun. These plants have system cost goals of 50 to 60 mills/kWh, which are clearly competitive with coal and nuclear systems in the grid-connected market. Utilizing the above costs for electricity, cost targets have been developed for both first and second generation subsystems hardware. These are shown in Table 1.

PROJECTED POWER PLANT BUS BAR ENERGY COSTS

Estimates of levelized bus bar energy costs from dish-electric power plants have been made based on projected component performance and costs. The results of these studies are presented in Figure 4 as a function of the number of dish power modules (~25 kWe peak) produced per year. Information is presented in this fashion since power module cost is a strong function of the collector and engine costs which are in turn affected by the production rate. Figure 4 also indicates the assumed costs for the basic module components (concentrator, receiver and engine) in various production rates, and the assumed balance of plant and O&M costs. At a production rate of 25,000 units/year and assuming no energy storage, levelized bus bar energy costs of 75 mills/kWeh are projected (1979 dollars). These numbers are based on what is believed to be a conservative estimate regarding engine-generator conversion efficiency (40%) for the 1990 time period. With a more optimistic estimate of efficiency (i.e., 45%), the bus bar cost decreases to about 67 mills/kWeh. At very large production rates (400,000 modules/year), the costs decrease to 58 mills/kWeh. Clearly such costs permit penetration of the grid- connected utility market.

PROJECT STRATEGY AND STATUS

The TPS project goal is to demonstrate technical, operational, and economic readiness of PFDR technology for electric and thermal power applications. To reach this goal in a timely manner, the project has three parallel but complementary activities or elements: Advanced Development is R&D oriented, with emphasis on feasibility testing and component and materials development.

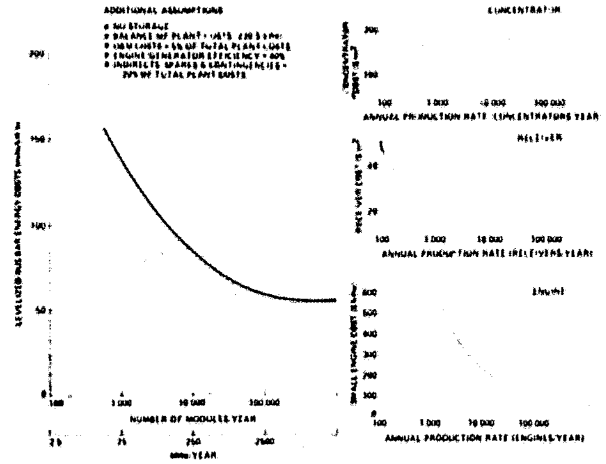

Figure 4. Effects of Mass Production on BBEC

Advanced designs from this activity are utilized by the Technology Development element which does the detailed engineering and fabricates and validates (tests) a complete module (concentrator, receiver and engine). The third element of the project, Applications Development, is responsible for developing complete power plant systems and demonstrating the technology through a series of engineering experiments sited in a variety of potential user environments. The status of each of these three project elements is described below.

Technology Development

The present thrust of this project element is to develop first generation subsystems (including concentrators, receivers/transport and power converters) which can be utilized in the Applications Development element for engineering experiments. The major products of this project element are proven hardware and acceptably low capital equipment and production costs (Ref. 1).

First generation hardware emphasizes proven gas turbine technology for the power conversion equipment, and an injection molding process for fabrication of the plastic petals or gores for the dish concentrator structure. This manufacturing technique already exists and is used in the production of a number of commercial products such as refrigerator doors. It should facilitate the attainment of mass-producible, low-cost concentrators. A first-generation dish concentrator proposed by General Electric and configured for injection molding is shown in Figure 5. Similarly, existing small gas turbine technology, very much like that developed for automobile turbochargers, cruise missiles, torpedoes, and auxiliary power units, is being studied for the eventual mass production of power conversion subsystems. The first-generation engine and receiver, presently being developed by Garrett Corporation, is shown in Figure 6.

Design, fabrication and test activities for both first- and second-generation hardware lead to two key events: a Brayton module on test in mid CY 1981, and a Stirling module on test early in CY 1984. The subsystems involved are concentrators, receivers, and power convertors. Second generation subsystems will be selected for incorporation in the Technology Development element of the project on the basis of the status of competing concepts emerging from the Advanced Development element of the project

Testing and evaluation of these dish power modules are performed at the JPL desert test site shown in Figure 7. Evaluation of early dish hardware is already taking place at this site. A 6-meter diameter dish module purchased

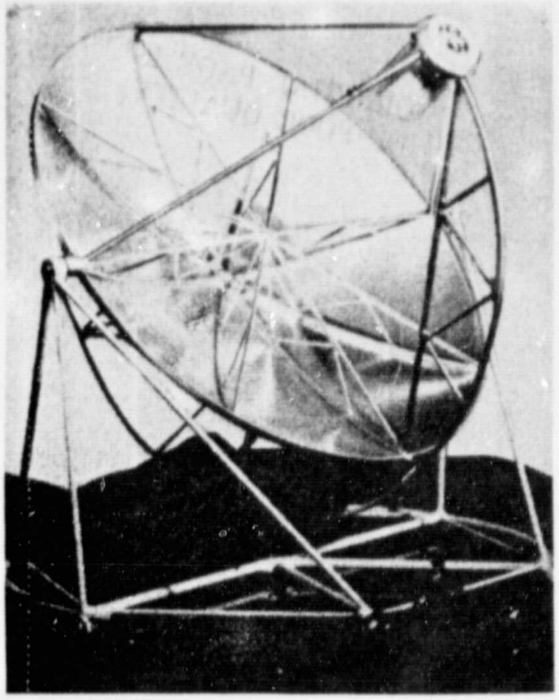

Figure 5. General Electric Low-Cost Collector Concept

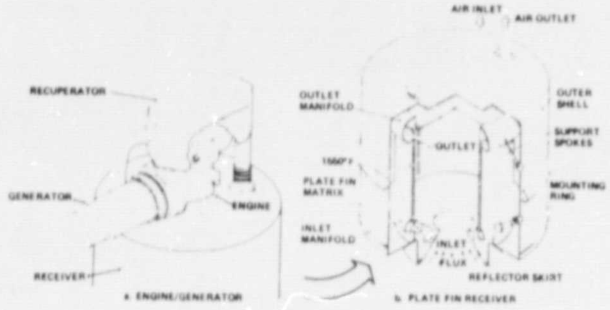

Figure 6. First-Generation Brayton Engine/ Generator and Receiver

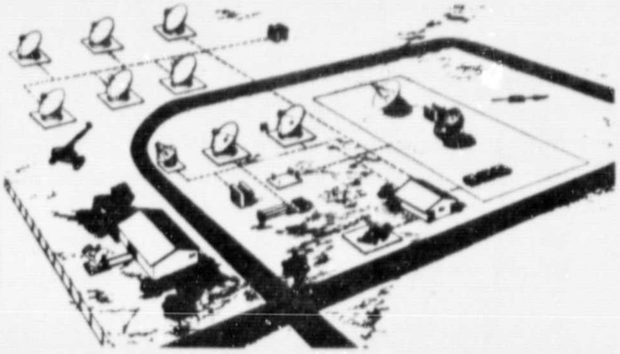

Figure 7. JPL Desert Test Site (PFSTS)

commercially from the Omnium-G Company of Anaheim, California has been under evaluation at the test site since early 1979. By September 1979, an 11-meter dish designed and constructed by E-Systems of Garland, Texas will be under test and evaluation at JPL. It is called a test bed concentrator (TBC) and will be used to test and evaluate receiver and engine units prior to installation on either first or second generation concentrators for full power tests.

Advanced Development

The work of this project element is directed to the development of materials and dish subsystems which meet the cost and performance goals of second and subsequent generation dish power plants. Example components are cellular glass monolithic gores for concentrators; both heat pipe and non-heat pipe hybrid high-temperature receivers for both power conversion and high temperature thermal applications; thermal transport and buffer storage; and under LeRC technical management, both free piston and kinematic Stirling engines for power conversion. This advanced work is in direct support of the Technology Development effort described previously.

An important part of the Advanced Development effort is the development of second-generation point focusing components (Ref. 2). The main thrust regarding engine concept is the Stirling engine although consideration is also being given to high temperature Brayton engines ($\sim 2000^0$F), and/or combined-cycle engines (which combine Brayton and Rankine technologies). Work for JPL on a Stirling engine and receiver is underway in a joint effort between Fairchild Stratos and United Stirling of Sweden based on the USS model P-40 engine.

Applications Development

The third project element is concerned with market applications of dish systems (Ref.3). Implementation of engineering experiments in various user environments is the major activity of the Applications work. It has the goal of demonstrating technical, operational, and economic readiness of dish systems in both electric power and process heat applications. The experiments are identified in terms of market sector in Figure 8. Three series of experiments have been defined, each related to a different market sector. These three series of experiments are described below.

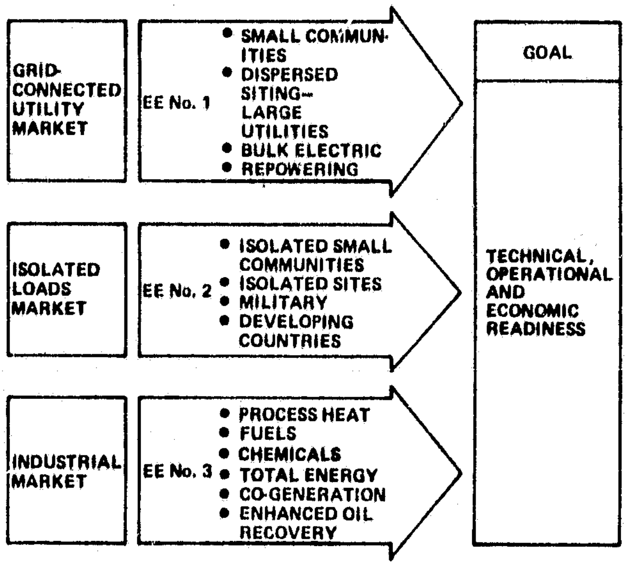

Figure 8. Engineering Experiments

EE No. 1 is known as the "Small Community Solar Thermal Power Experiment," and is one megawatt in size. As noted in Figure 8, it looks toward the grid-connected market of the continental United States. Because this market is as important as it is difficult, work is under way through EE No. 1 to gain early experience in that highly competitive market. It is scheduled to be on-line in early CY 1983. The systems contractor will select the power converter but the collector will be first-generation technology as developed by the Project.

EE No. 2 is known formally as the "Isolated Application Experiment Series," and addresses island sites, rural electricification in foreign countries, and other applications remote from the grid. Plant sizes will be about 100 kilowatts (electrical). A joint effort is now under way with the Navy Civil Engineering Laboratory on a co-funded basis. The EE No. 2a power plant will use receivers of hybrid design, and Brayton power converters. EE No. 2a is the first of the series, and is scheduled to be operational in late CY 1982.

The EE No. 3 series, addressing the industrial market, will initially be implemented through a series of very small experiments (less than 20 KWe) for thermal, electric and combined (cogeneration) applications. These small experiments known as the dish module experiments will be conducted using available hardware to the maximum extent possible. Because they are small they can be constructed and installed in a very short time. Although not a direct product of the JPL program, an example of such an experiment is the ongoing effort co-funded by DOE and the Southern New England Telephone Company for an industrial cogeneration application, using the Omnium-G power module. The primary function of this power unit is to produce electricity for a switching center, but excess power will be used for space heating and for absorption cooling. The unit is to be operational early in CY 1980. A number of other units of this class are scheduled by JPL for operation in CY 1981.

Experiments in all three series will follow an improved technology path with each new experiment utilizing the then current state-of-the art dish-engine technology.

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