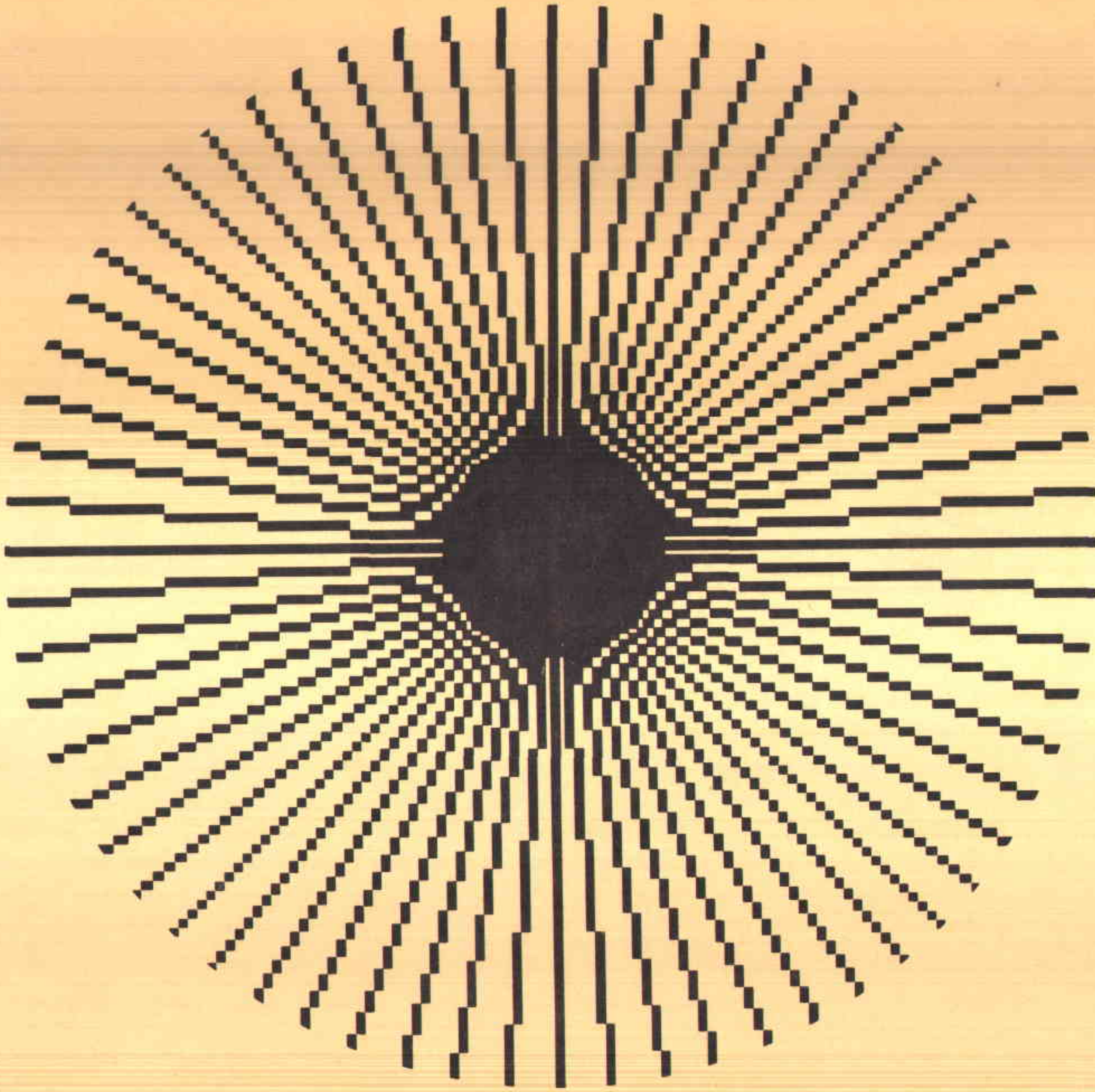
1392

Central Receiver Development Plan 1985-1986
Sandia National Laboratories / Livermore



**National
Solar Thermal Technology
Program**

CENTRAL RECEIVER DEVELOPMENT PLAN 1985-1986

FY85 ANNUAL OPERATING PLAN
SANDIA NATIONAL LABORATORIES, LIVERMORE

Central Receiver Research and Development

Solar Thermal Technology Planning & Assessment

November 15, 1984

Solar Central Receiver Department
Sandia National Laboratories
Livermore, California 94550

Approved: James B Wright

J. B. Wright, Manager
Solar Central Receiver Department

REPRINTED JANUARY 1985

CONTENTS

INTRODUCTION

This document describes activities for fiscal years 1985 and 1986 in the National Solar Thermal Technology Program to be performed by Sandia National Laboratories Livermore. These activities include the development of central receiver technology and Solar Thermal Program planning and assessment.

Central receivers employ a field of individually controlled mirrors, termed heliostats, to reflect the sun's energy onto a receiver which is mounted on a tower. At the receiver, the redirected, highly concentrated flux is utilized to heat a circulating heat transfer media. The collected energy may power a conventional steam or gas turbine or provide thermal energy to an industrial process or be used in the direct production of transportable fuels or energy-rich chemicals. The collected energy may also be stored for later use.

The objective of the Central Receiver Program is to establish reasonable evidence of the technical and economic feasibility of the central receiver concept. Through the performance of applied research and engineering development, the federally-funded efforts are intended to achieve the goals of central receiver-supplied electricity in 1995 at a cost of 5 cents/kWhe and industrial process heat at $9/MBtu.

The objective of the Planning and Assessment program element is to provide support to the Solar Thermal Program in the areas of analysis, planning, and evaluation. Both short-term and long-range planning are performed together with analysis of critical technical and economic issues. In addition, program evaluation and documentation are conducted to insure a balanced and properly prioritized program.

This plan is the Annual Operating Plan for Sandia National Laboratories Livermore (SNLL). It references other operating plans (specifically, the plan for activities at the San Francisco Office of the Department of Energy) which include work related to central receivers in order to provide an overview of all central receiver technology development activities.

Solar thermal research and technology development are carried out under the direction of the Division of Solar Thermal Technology at the Department of Energy. Other organizations involved with implementing the Solar Thermal Technology Program and their specific responsibilities are shown in Figure 1.

This Central Receiver Development Plan has been prepared to accompany the Distributed Receiver Development Plan prepared by Sandia National Laboratories Albuquerque (SNLA) and the Research Plan prepared by the Solar Energy Research Institute (SERI). The three program plans describe the specific activities to be carried out in FY85 and FY86 to

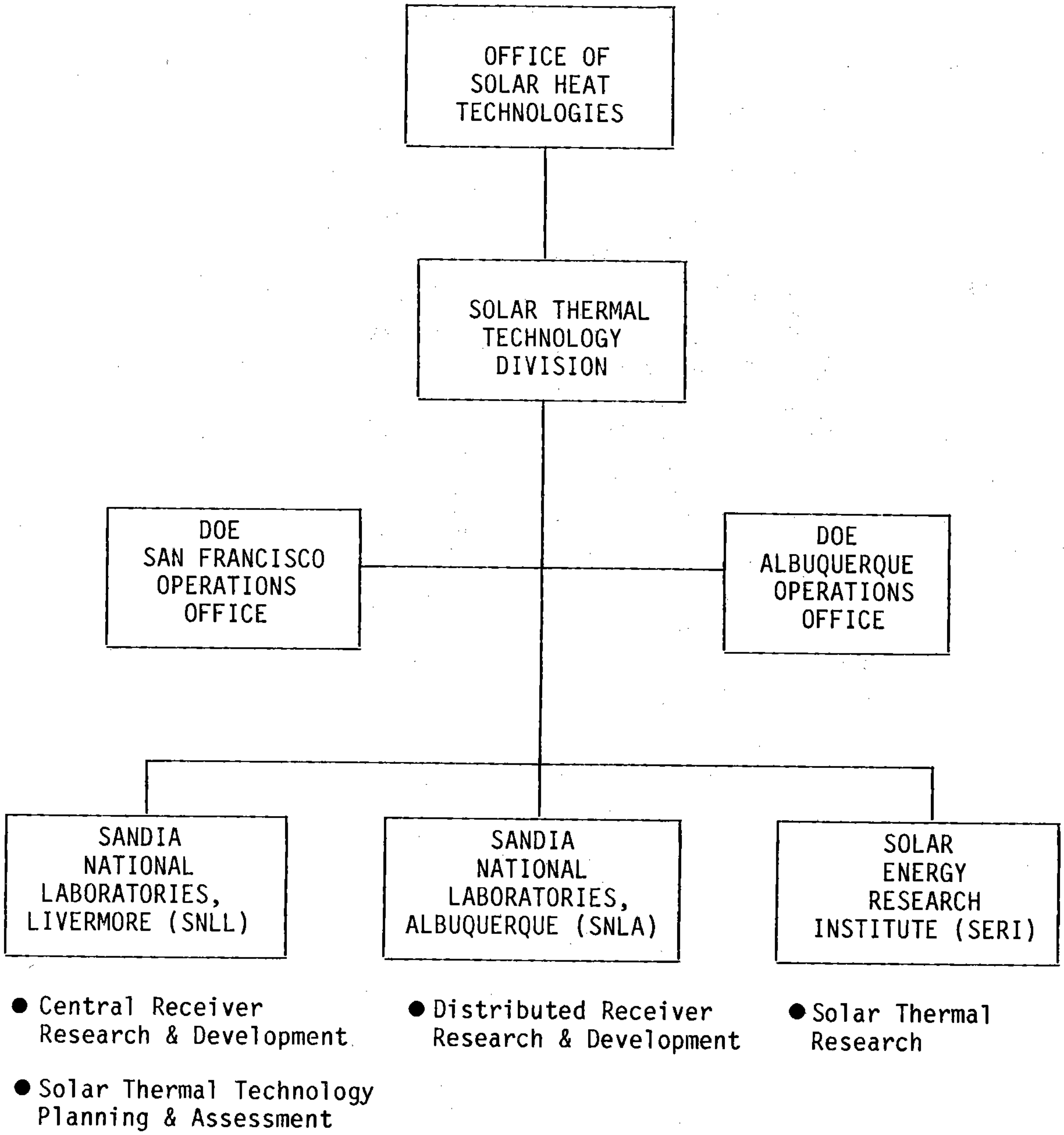


Figure 1. Solar Thermal Technology Organizational Structure and Responsibilities

meet the objectives of the National Solar Thermal Technology Program as stated in its Five Year Research and Development Plan. Although this document serves as the FY85 Annual Operating Plan, it also describes activities for FY86. This approach provides continuity since actual research and development activities are planned at least a year in advance and then revised before being carried out.

The focus and strategy of the Solar Thermal Technology Program are described in its Five Year Research and Development Plan. Program activities are oriented toward the widespread use of solar thermal technologies through the achievement of specific market-based, cost-performance goals for the production of electricity or process heat. Solar thermal technologies being developed to meet the goals include distributed receivers such as parabolic dishes and line-focus troughs, and central receivers which this report considers.

A summary of elements of the Five Year Plan is included in the following chapter to show the Annual Operating Plan's specific activities in the context of its broader program goals. The Five Year Plan organizes the research and development activities into eleven tasks, each specifically directed toward achieving the component goals. The status of central receiver technology and lessons learned from completed work are reviewed in the third chapter. Central receiver research and development activities described in this plan fall into six of the eleven tasks. These task descriptions and specific sub-task activities, together with budget and procurement requirements, are detailed in the fourth chapter. The fifth chapter considers implementation of the planned activities and gives the management organization at SNLL, the major milestones for the next two years, and resource and procurement summaries.

SOLAR THERMAL FIVE YEAR RESEARCH AND DEVELOPMENT PLAN

The controlling document for long-term planning in the Solar Thermal Technology Program is its Five Year Research and Development Plan. That plan summarizes national solar thermal policy, structures the program, and provides long-term (mid to late 1990's) and five-year quantified component goals, milestone charts for progress, and task descriptions of activities which will lead to success. The Sandia Development Plans provide more detail on the tasks and milestones related to central receiver and distributed receiver development, plus a description of planning and assessment activities. SERI has prepared a Research Plan describing solar thermal research carried on in conjunction with the solar central receiver and distributed receiver programs, these three plans provide planning information to support the overall Five Year Research and Development Plan goals.

To be successful in contributing to an adequate national energy supply at reasonable prices, solar thermal energy must eventually be economically competitive with a variety of other energy sources. System-level planning targets expressed in terms of solar thermal capital cost, efficiency, and energy cost have been developed to meet the need for quantitative program goals. These targets are used to plan research and development activities, to measure progress, to assess alternative technology options, and to make optimal component research and development decisions.

Table 1 summarizes system-level targets for solar thermal technologies in the mid-to-late 1990's for plants producing electricity and plants producing heat. The respective target energy costs of 5 cents/kWhe and \$9/MBtu are determined by the competition to solar thermal. (These costs are levelized in 1984 dollars to factor out the effects of inflation.) The ranges of system capital costs and efficiencies arise from inherent differences in the way the solar thermal technologies can meet the system targets. Separate targets are required for electricity and heat because these applications represent different end markets (bulk utility and general industrial) with significantly different economic requirements and energy costs. These differences result in a higher allowable energy cost in the heat market than electricity markets after accounting for energy conversion. The Five Year Plan contains additional information on the levelization procedures, bases, and assumptions involved in the targets.

The long-range levelized cost targets of 5 cents/kWhe (for electricity) and \$9/MBtu (for heat) in the Five Year Plan are used to develop long-range cost and efficiency targets for the individual components of a solar thermal plant. These component goals for central receiver technology are detailed in Table 2. The component targets then provide a path for reaching the system energy cost target -- a solar electric plant consisting of components that meet the component goals would have a levelized energy cost of 5 cents/kWhe.

TABLE 1. SOLAR THERMAL LONG-TERM TARGETS[a]

	Electricity	Heat
System Annual Efficiency	22-28%	56-68%
System Capital Cost (1984$)[b]	$1300-1600/kWe	$400-490/kWt
Capacity Factor	0.25-0.50	0.25-0.30
System Energy Cost (1984$)[c]	5¢/kWhe	$9/MBtu

[a]Mid to late 1990's.

[b]Normalized to turbine or process capable of handling peak field thermal output; includes indirect costs.

[c]Energy costs levelized in real dollars; economic assumptions differ between electric & heat systems.

TABLE 2. CURRENT CENTRAL RECEIVER CAPABILITIES AND LONG-TERM TARGETS

	Current Capabilities				Long-Term Targets[f]			
	Electricity		Heat		Electricity		Heat[c]	
Research Tasks	Annual Effic.	Cost (84$)	Annual Effic.	Cost (84$)	Annual Effic.	Cost (84$)	Annual Effic.	Cost (84$)
2. Concentrators[a] ($/m^2)	55%	210	55%	210	64%	100	64%	100
3. Receivers[a] ($/m^2)	90%	80	90%	80	90%	45	90%	45
6. Transport[a] ($/m^2)	99%	75	99%	75	99%	25	99%	25
Storage ($/kWht)	98%	95	98%	95	98%	20	98%	20
8. Balance of Plant[a] ($/m^2)	n.a.	70	n.a.	120	n.a.	50	n.a.	50
9. Central Receiver Systems ($/kWe or kWt peak)[d]	16%	4600	48%	1300	22%	1600[e]	56%	470[e]
11. System Experiments (¢/kWhe or $/MBtu)	16%	16¢	48%	29	22%	5¢[b]	56%	9[b]

[a] Dollars per square meter of concentrator aperture
[b] System goals levelized in real dollars; values levelized in nominal dollars (assuming 7% inflation) are 11¢/kWhe, $14/MBtu. The $9/MBtu (84$) industrial process heat target is the levelized cost of delivered energy in the 1990's; it is derived from current fossil fuel costs of $5/MBtu (84$). See Five Year Plan.
[c] Includes production of fuels and chemicals.
[d] Normalized to turbine or process capable of handling peak field thermal output; includes indirect costs.
[e] Capacity factors are 0.5 central receiver electric and 0.29 central receiver thermal.
[f] Mid to late 1990's.
n.a. - not applicable

Research and development activities are structured as tasks specifically directed toward achieving the component targets. These tasks fall into the general areas of collection technology, energy conversion technology, and systems and applications technology. The tasks are defined in Table 3. The objective of each activity is to achieve the long-term cost/efficiency target of the component, and thereby contribute toward achieving the overall energy cost target.

Goals to be achieved within five years for each research task are described in Table 4. A five-year goal is needed to supply a focused orientation for each research activity. These five-year goals and the program milestones in the Five Year Plan provide near-term targets for each task that can be used to measure progress. The five-year goals provide a logical progression for moving from the current capabilities to the long-term targets and represent expectations of attainable progress in each area, assuming continued funding at present levels.

TABLE 3. THE MAJOR TASKS OF THE SOLAR THERMAL TECHNOLOGY PROGRAM

Collection Technology

1. Optical Materials
   Development of materials for the reflective surface of concentrators or the transmissive and absorptive components of receivers

2. Concentrators
   Development of heliostats, dishes, and troughs (not including receivers)

3. Receivers
   Development of components which convert solar radiation into thermal or chemical energy

Energy Conversion Technology

4. Heat Engines
   Development of components which convert thermal energy into electricity or shaft power via thermodynamic processes

5. Direct Conversion Technology
   Development of components that convert solar radiation into electricity or chemical energy without the use of a heat engine

6. Transport and Storage
   Development of components which convey energy to the eventual consumption point or allow delay of its usage

Systems & Applications Technology

7. Innovative Concepts and Applications
   Entry point activities for promising component and system concepts which constitute major departures from conventional solar thermal technology

8. Balance of Plant
   Development, characterization and optimization of other components necessary to construct and operate a complete solar thermal facility

9. Central Receiver Systems
   Activities related to the analysis and development of central receiver applications from a system perspective

10. Distributed Receiver Systems
    Activities related to the analysis and development of dish and trough applications from a system perspective

11. System Experiments
    Activities related to the design construction, startup, operation, and testing of solar thermal installations.

TABLE 4. RESEARCH AND DEVELOPMENT TASK FIVE YEAR GOALS

Research Phase/Task	Five Year Goal*
Collection Technology	
1. Optical Materials	Develop polymer reflective materials with 93% lifetime averaged reflectivity, costing $15/m^2$, lasting 5 years.
2. Concentrators	Improve annual efficiency by 5 percentage points and reduce cost to 120, 300, and 150 $/m^2$ for heliostats, dishes, and troughs, respectively.
3. Receivers	Design receivers for higher temperature applications while maintaining efficiencies. Reduce costs by 30% from the current capabilities.
Energy Conversion Technology	
4. Heat Engines	Reduce dish-mounted engine costs to $1000/kWe(peak). Obtain 35% efficient (annually averaged) dish mounted engines.
5. Direct Conversion Devices	Conduct exploratory research on promising high flux/high-heat rate/photon-specific processes.
6. Transport and Storage	Obtain a 25 $/kWht cost for storage while maintaining high efficiency. Reduce transport costs to 40, 75, 30 $/m^2$ for central receivers, dishes, and troughs, respectively.
Systems and Applications Technology	
7. Innovative Concepts and Applications	Conduct research on novel concepts and applications. Select the most promising for further study.
8. Balance of Plant	Characterize balance of plant requirements. Strive for automated control.
9. Central Receiver Systems	Study system integration issues through detailed designs. Achieve at least a 40% capital cost reduction while maintaining or improving efficiencies.
10. Distributed Receiver Systems	Study system integration issues through detailed designs. Obtain 5 percentage point efficiency improvements with at least a 40% capital cost reduction.
11. System Experiments	Obtain the necessary information to verify full system operating characteristics and identify technical requirements for further collection, conversion, and systems research. A 40% energy cost reduction will be sought.

*Annual Efficiencies; $/m^2$ of concentrator aperture area

CENTRAL RECEIVER INTERNAL PLANNING PLAN TASKS	FY-86 BUDGET	TOTAL REQ'D	DELTA
TASK 2 COLLECT. TECH	1.39	1.895	.505
SURFACE CONTAMINAT	.475	.475	0
STRESSED MEMBRANE	.36	.4	.04
LG AREA H'STATS	.185	.2	.015
SMALL SYS. OPT.	.175	.175	0
CODE DEVELOPMENT	.15	.15	0
LOW COST DRIVES	.045	.045	0
WINDSPOILERS	0	.2	.2 } SERI
1 ST. SURF MIRRORS	0	.2	.2 } SERI
H. C. S.	0	.05	.05
TASK 3 RECEIVERS	2.005	3.97	1.965
CATEGORY B	.65	1.8	1.15
Na/SALT HT. EXCR	.485	.485	0
OPTIMAL R. S.	.435	1.25	.815
SYS IMPROVEMENTS	.3	.3	0
R. S. EVALUATION	.135	.135	0
TASK 6 TRANS + STOR	~~.115~~	~~.115~~	0 } OUT
TASK 8 B.O.P. CONTROLS	.575	1	.425
TASK 9 C. R. SYSTEMS	2.325	2.325	0
UTILITY SYSTEMS	.7	.7	0
SYSTEM IMPROVEMENT	.5	.5	0
SMALL SYSTEMS	.5	.5	0
FUELS & CHEMICALS	.375	.375	0
INTERNATIONAL	.25	.25	0
TASK 9A CRTF	1.3	1.3	0
TASK 11 SYS EXPER. BARSTOW	.7	.7	0
CAPITAL EQUIP.	.15	.15	0
TOTAL	8.56	11.455	2.895
UTILITY STUDIES			2.1
GRAND TOTAL			4.995
RESOURCES:			
1370.00			3.3
1582.00			.4
FALLING PART.			.75
BARSTOW			.25
TOTAL			4.7

62485INTERNAL.BUD

CEN L RECEIVER PLAN TASKS	85/ AOP DEV PLAN	GRONICH/ BARTEL 5/9 BUDGET	CUR NT BNL LABOR FTE	BASELINE BNL LABOR $	BUD BNL PURCH $	PLAN BNL TOTAL $
TASK 2 COLLECT. TECH	1	1.7	3.5	.525	.875	1.4
SURFACE CONTAMINAT		.5	.5		.4	
STRESSED MEMBRANE		.5	.9		.225	
LG AREA H'STATS		.5	.3		.15	
SMALL SYS. OPT.			.5		.1	
CODE DEVELOPMENT			1			
LOW COST DRIVES		.2	.3			
TASK 3 RECEIVERS	3.4	2.5	4.9	.725	~~2~~ 1.25	~~1.035~~ 1.985
CATEGORY B		1	1		.5	
Na/SALT HT. EXCR		.5	.1		.45	
OPTIMAL R. S.		.5	.9		.3	
SYS IMPROVEMENTS		0	2			
R. S. EVALUATION		.5	.9			
TASK 6 TRANS + STOR	.5	0	.1	.015	.1	.115
TASK 8 B.O.P.	1.1	.5	.5	.075	.5	.575
CONTROLS		.5	.5		.5	
TASK 9 C. R. SYSTEMS	3.3	2	9	1.35	.975	2.325
UTILITY SYSTEMS		1	3		.25	
SYSTEM IMPROVEMENT		.6	2		.2	
SMALL SYSTEMS		.2	2		.2	
FUELS & CHEMICALS		.2	1		.225	
INTERNATIONAL		0	1		.1	
TASK 9A CRTF	1.3	1.3	10	1.3	0	1.3
TASK 11 SYS EXPER. BARSTOW	1.3	.4	2	.3	.4	.7
CAPITAL EQUIP.	.15				.1	.1
TOTAL	12.05	8.4	30	4.3	3.25	~~7.85~~ 8.50

6/24/84
JJBARTEL

10/4/84

• CONSISTENT SET OF BUDGET NUMBERS TO 12 M$ BY JBW

		FY85				FY86			
	EXT	INT	TOT		EXT	INT	TOT		
2. CONCENTRATORS	.6	.7	1.3	1.3	.3	.7	1.0	1.0
Glass/Metal Improvements	.3	.2	.5		–	.25	.25	
Drives	.25	.05	.30			.05	.05	
Windspoilers ?	(.05)	–	.05					
Rotating Fields	–	–	–			.1	.1	
Codes	–	.15	.15			.1	.1	
New Concepts	.3	.5	.8		.3	.45	.75	
Stretched membrane	–	.25	.25		.15	.2	.35	
Large (150 m²) Sacred	(.25)	.05	.3			.05	.05	
NCS	.05	.2	.25		.15	.2	.35	
3. RECEIVERS	1.3	1.4	2.7	2.7	2.0	1.4	3.4	3.4
Receiver Development	1.0	.8	1.8		1.6	.8	2.4	
Cat B	.3	.3	.6		.1	.3	.4	
Characterization	.2	.1	.3		.1	.1	.2	
Optimized	(.5)	.4	.9		1.4	.4	1.8	
High T Receivers	.3	.6	.9		.4	.6	1.0	
Solid Particle	.2	.5	.7		.2	.5	.7	
Terminal Concn.	–	.05	.05		.1	.05	.15	
FOC Components ?	(.1)	.05	.15		.1	.05	.15	
6. TRANSPORT AND STORAGE	.3	.4	.7	.7	.4	.1	.5	.5
Cat B	.15	.05	.2		.05	.05	.1	
Reduced Cost →	(.15)	.35	.5		.35	.05	.4	
8. BALANCE OF PLANT	1.2	.2	1.4	1.4	.8	.3	1.1	1.1
Heliostat Washing (+.5 from FY84)	.1	.1	.2		.2	.1	.3	
Controls →	(1.1)	.1	1.2		.6	.2	.8	

10/4/84

PAGE 2 - CONSISTENT BUDGET NO's

	FY85 EXT	FY85 INT	FY85 TOT		FY86 EXT	FY86 INT	FY86 TOT	
9. CENTRAL RECEIVER SYSTEMS	1.1	3.0	4.1	4.1	2.0	2.6	4.6	4.6
Systems Application Studies	.5	1.8	2.3		1.5	1.4	2.9	
Optimization	–	.9	.9		–	.4	.4	
Project Development	.35	.35	.7		.5	.6	1.1	
Fuels and Chemicals	–	.5	.5		.7	.3	1.0	
Brayton Cycle →	(.15)	.05	.2		.3	.1	.4	
CRTF	.3	1.0	1.3		.3	1.0	1.3	
INTL	.3	.2	.5		.2	.2	.4	
11. SYSTEMS EXPERIMENTS	.9	.9	1.8	1.8	.8	.6	1.4	1.4
Barstow	.6	.9	1.5		.8	.6	1.4	
MSEE	.3	–	.3		–	–	–	
TOTALS	5.4	6.6	12.0		6.3	5.7	12.0	
TECHNOLOGY PROGRAM INTEGRATOR	.7	.6	1.3	1.3	.7	.6	1.3	1.3
Planning	.2	.3	.5					
Analysis	.5	.3	.8					
TOTAL	6.1	7.2	13.3		7.0	6.3	13.3	13.3

CENTRAL RECEIVER STATUS AND LESSONS LEARNED

A review of the current status of solar central receiver technology is included in this chapter to help provide understanding of the future direction, tasks, and goals of the central receiver program.

The 10 MWe Solar Thermal Central Receiver Pilot Plant shown in Figure 2 near Barstow, California, is the world's largest electric power generating solar central receiver facility. It was designed and constructed between 1977 and 1981, and in 1982 delivered its first net power to the utility grid. Under the technical management of Sandia National Laboratories Livermore, a two-year experimental testing and evaluation phase was completed in August, 1984, and the pilot plant entered its current three-year power production phase.

The power plant with its 1818 computer-controlled, sun-tracking heliostats, its 45 foot high superheated steam generating receiver atop a 235 foot tower, and its 7 MWe for 4 hours thermal storage capability, has firmly established the technical feasibility of a solar central receiver electrical power generating plant. Considering its small size relative to envisioned future plants, and considering that the 10MWe plant is the first of its kind, it was not expected to be a cost effective plant. The value of this experiment is to generate technical and economic knowledge which will allow cost competitive plants to be built.

In September 1984, a second major experimental solar central receiver system, the Molten Salt Electric Experiment, was dedicated at the Central Receiver Test Facility in Albuquerque, New Mexico. Electricity generated by this 750 kWe plant, which uses molten nitrate salt as its heat transfer fluid, flows into the local electric utility distribution grid. The MSEE can also be operated during low insolation and night times with its 7 MWt-hr thermal storage capability.

The lessons learned from the operation of these two pioneering solar central receiver system experiments, as well as studies of other potentially effective uses of this technology, have provided a wealth of technical and economic insight which has been utilized to determine the future direction of the promising solar central receiver industry.

The key lessons learned have led the solar central receiver program to look for ways of reducing plant cost and improving efficiency with larger, lighter-weight, more accurately controlled heliostats, smaller, higher temperature receivers utilizing more effective heat transfer fluids, more sophisticated transport and storage materials and designs, and more reliable, less costly overall plant control systems.

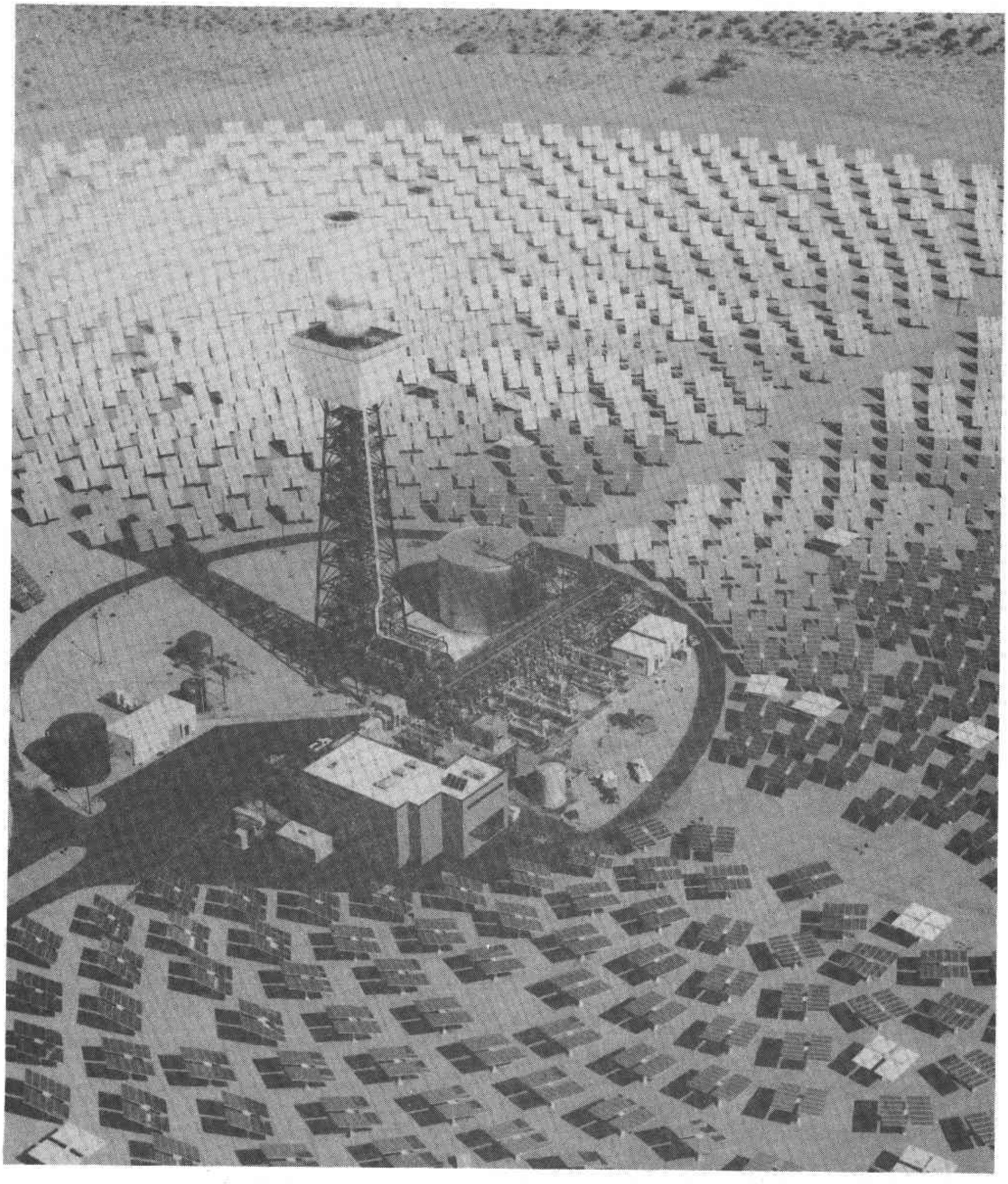


Figure 2. 10 MWe Solar Thermal Central Receiver Pilot Plant

The technology development strategy of the central receiver program (as shown in Figure 3) is laid out to provide a logical step-by-step sequence for developing a central receiver system concept from the study of its market potential through all of the major steps required to reach the actual construction and commercialization stages. The solar central receiver development program tasks described in detail in the following chapter are shown in Figure 3 at their appropriate stage of development. Work on all of these tasks will lead to more efficient, reliable, cost-effective components and systems and/or will explore new potentially valuable applications of solar central receiver system technology.

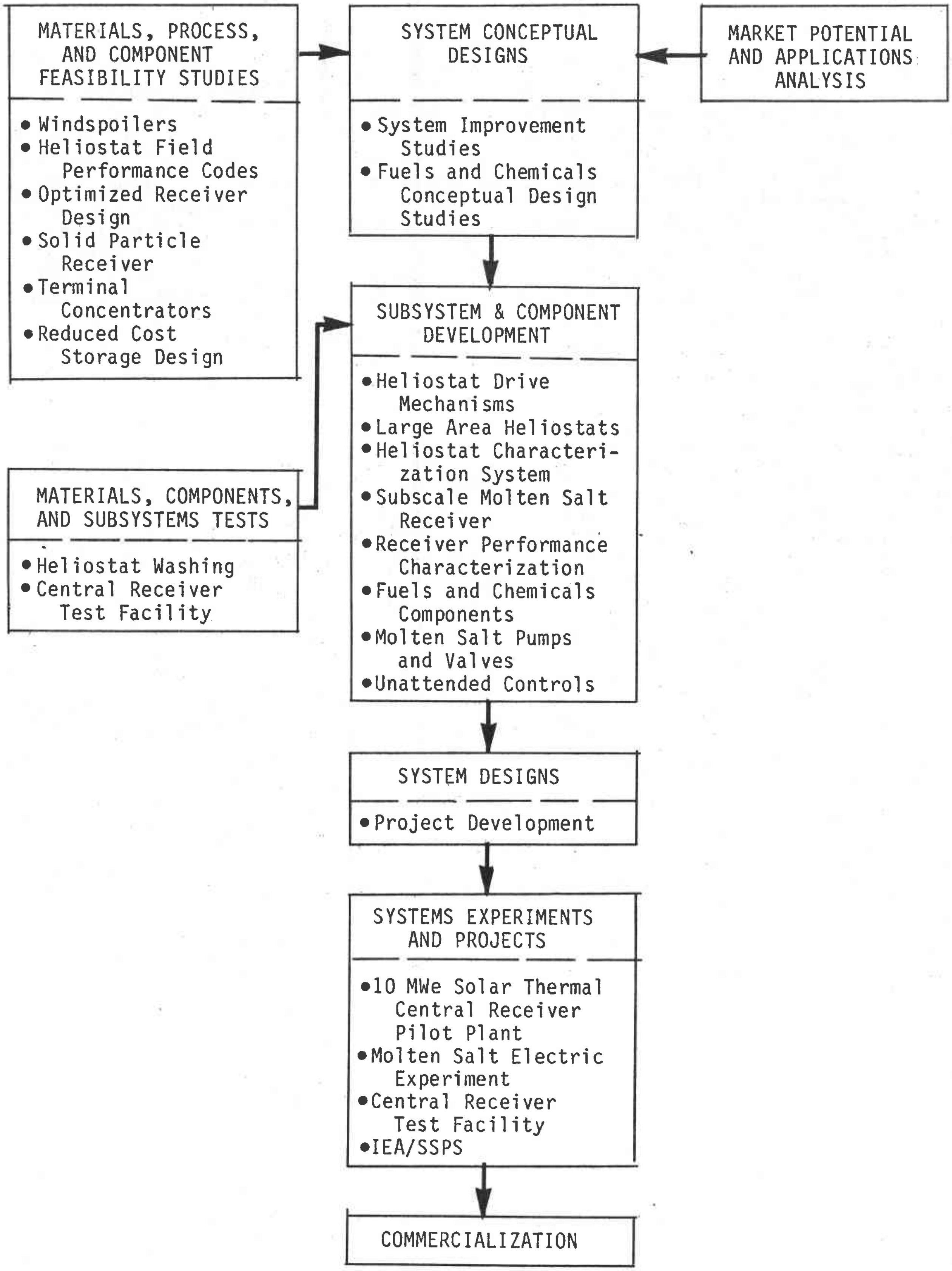


Figure 3. Technology Development Strategy

TASK DESCRIPTIONS

Central receiver development activities rely on the breadth of research and development efforts in all eleven research tasks in the Solar Thermal Program. All activities are oriented toward the achievement of the goals delineated in the Five Year Research and Development Plan. Central receiver research and development activities to be carried out in fiscal years 1985 and 1986 fall into six of the eleven solar thermal research task categories.

The six central receiver research and development activities are Concentrators, Receivers, Transport and Storage, Balance of Plant, Central Receiver Systems and System Experiments. These tasks for the central receiver program are illustrated in Figure 4. Specific activities in each of these areas together with their respective resource requirements are described by task in this chapter. The task and sub-task structure used to organize these descriptions is listed in Table 5. In addition, activities and resources for the Planning and Assessment effort are also described.

A portion of the work carried out in support of central receiver development is directed research oriented toward program goals which uses unique Sandia National Laboratories capabilities. These activities are described as part of the task which they support.

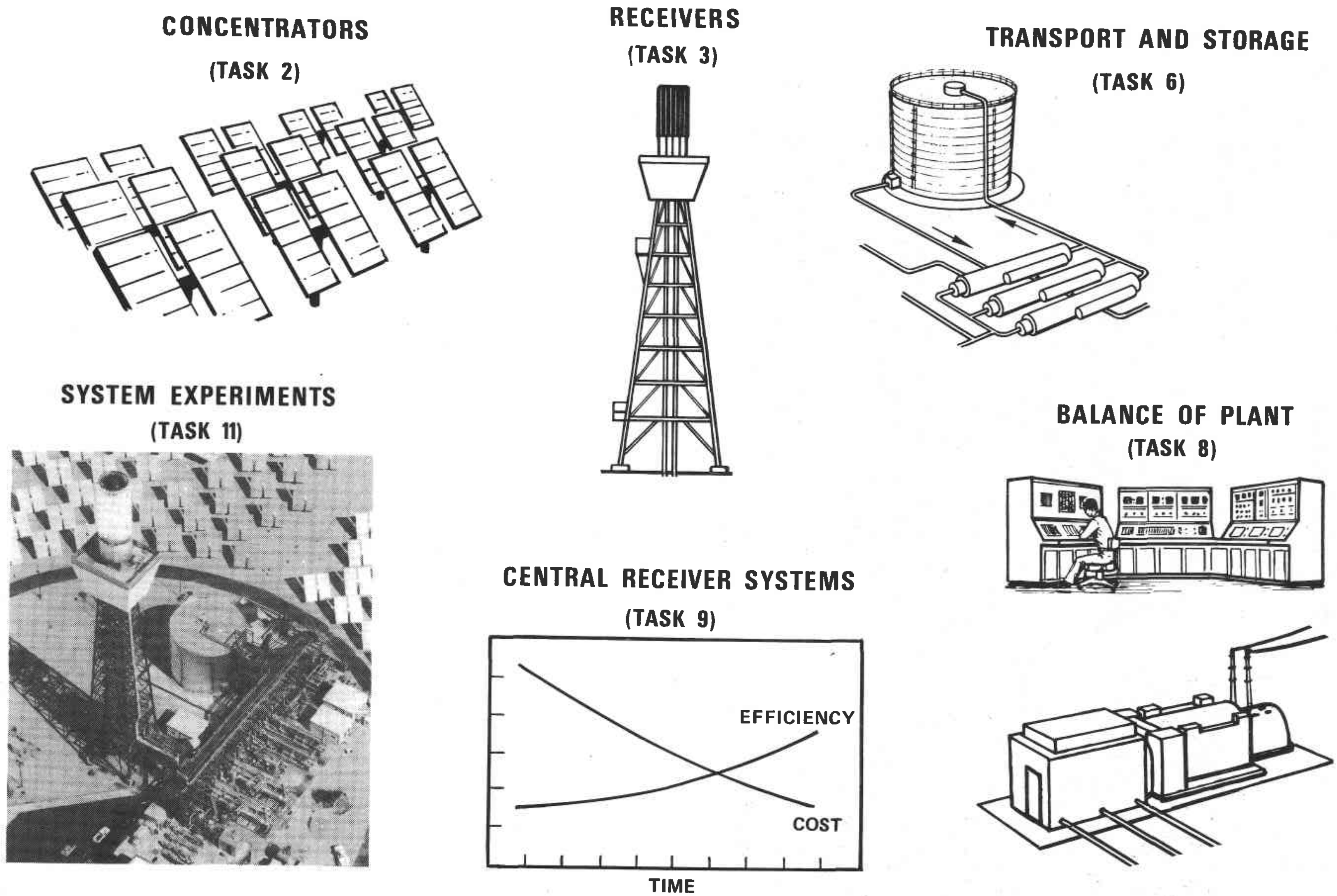


Figure 4. Central Receiver Research and Development Activities

TABLE 5. TASK AND SUBTASK STRUCTURE

Collection Technology	Energy Conversion Technology	Systems and Applications Technology

2. CONCENTRATORS
 	
Drives
Windspoilers
Codes
Stressed Membrane
Large Area
Heliostat Characterization System
 	
3. RECEIVERS
 	
Receiver Development
  Molten Salt Receiver
  Receiver Performance Characterization
  Optimized Receiver Design
 	
High Temperature Receivers
  Solid Particle
  Terminal Concentrator
  Fuels & Chemicals Components
	6. TRANSPORT AND STORAGE
	
	Molten Salt Pumps & Valves
	Reduced Cost Storage Design
		8. BALANCE OF PLANT
		
		Controls
		Heliostat Washing
		
		9. CENTRAL RECEIVER SYSTEMS
		
		Systems Application Studies
		  System Improvements
		  Project Development
		  Fuels & Chemicals
		
		Central Receiver Test Facility (CRTF)
		
		International
		
		11. SYSTEM EXPERIMENTS
		
		10 MWe Solar Thermal Central Receiver Pilot Plant
		
		Molten Salt Electric Experiment (MSEE)

TASK 2 - CONCENTRATORS

The concentrators in central receiver systems are the heliostats. Heliostats comprise the largest cost element of a central receiver system and their performance has a direct effect on overall system efficiency. Research and development activities are intended to achieve cost reductions with little or no performance degradation. As reviewed in the Five Year Research and Development Plan, current capabilities of heliostats are an annual efficiency of 55% at a cost of $210/m^2$ at low production rates. The long term objective is to reduce the cost at low production rates to $100/m^2$ and to improve the annual efficiency to 64%. Mass production costs are now estimated at $80/m^2$ and the long term objective is $40/m^2$. In the nearer term (5 years), annual efficiency improvements of 5 percentage points will be investigated and at least a 25% cost reduction will be sought.

The strategy for achieving these goals has been described in the Concentrator Research and Development Plan. Activities described in this AOP are those in the Concentrator Plan for the central receiver development program for Fiscal Years 85 and 86. The strategy is to pursue step-wise improvements in glass/metal technology to trim their costs while also pursuing alternate concepts which have the potential for dramatic cost reductions. A competitive evaluation of the various cost reduction schemes will be performed in a Third Generation Heliostat design and fabrication effort planned to begin in FY87.

Glass/metal heliostats have been under development since the inception of the central receiver program. It is encouraging that, recently, privately funded prototype heliostats have been built which improve and extend DOE developed technology. Thus, work in the FY85 and FY86 Central Receiver Program will be directed at specific improvements not being explored in industry and at evaluation of state-of-the-art industrial technology. In addition, new approaches to heliostat design such as the use of stressed membrane mirror modules will be examined to assess their potential for dramatic cost reductions.

Specific activities include the development of alternative low-cost drive mechanisms, the application of heliostat-mounted windload avoidance schemes, and the evaluation of large area heliostats. To support high temperature receiver development as well as the heliostat development and evaluation efforts, existing computer codes will be updated and modified. An innovative heliostat which employs a stressed membrane covered with a silvered polymer will be examined. The performance of heliostat prototypes, both stressed membrane and large area, will be examined using a quantitative heliostat characterization system which is being developed.

Heliostat Drive Mechanism -- Heliostat manufacturers have identified drive mechanisms as an important area for federal research and development. For example, the cost of the drive unit in the

McDonnell Douglas Second Generation Heliostat was $\$27/m^2$. However, drive manufacturers are reluctant to undertake research and development with their own funds because of the lack of a near term market for heliostats. The potential for cost reductions and the applicability of this work to both glass/metal and stressed membrane heliostats makes it an appropriate area for government supported research and development.

To support drive mechanism development, a study will be initiated in early FY85. First, previous and current ideas on cost reductions will be reviewed. This review will be used to prepare an RFQ for design and fabrication over the next eighteen months of new or improved drive mechanisms. Parallel in-house and contract studies will be carried out to optimize and make innovative improvements to conventional drive mechanisms. The drives will be designed for glass metal heliostats but should also be compatible with stressed membrane designs.

This work should result in long term drive costs of $\$11/m^2$, which translates to a long term heliostat cost reduction of \$15 to $\$20/m^2$. It will be completed in the third quarter of FY87.

Windspoilers -- Survival windloads control the requirements for mirror module, drive mechanism, and mirror support structure strengths. The survival requirements could be reduced together with structural costs if the windloads on a horizontally stowed heliostat could be significantly reduced. One possible approach is the use of windspoilers located on the periphery of the heliostat's reflective surface. In FY85, an in-house feasibility study will be performed. If the study results are promising, a design study will be performed under contract. Potential cost savings will be identified as a part of the contract work. Follow-up prototype fabrication and wind tunnel testing are anticipated in FY86 depending the results of the design study.

Another windload avoidance scheme uses field shielding systems in which the heliostat wind loads are reduced for the entire field. This approach is currently under investigation as part of the research program at SERI. Interaction between the two studies is ongoing and will be maintained.

Heliostat Field Performance Codes -- Central receiver conceptual designs and system studies utilize a family of computer codes which have been developed to lay out the heliostat field and to estimate its performance. These codes include the calculation of the receiver flux from the individual heliostats by the codes MIRVAL and HELIOS and the system performance code DELSOL2, each written over five years ago. An internal effort will begin in the second quarter of FY85 to update, clarify, and make more user-friendly several of these computer codes.

Later in FY85, the capability will be added to optimize fields with sloped and rolling terrain. This is an important modification. At Barstow for example, there is a ten foot change in elevation from the front of the field to the back. Most prospective plant locations do have sloped or rolling terrain. This elevation change affects the blocking and shadowing of the heliostats.

Next, to support the evaluation of high temperature receiver concepts, the models will be expanded to handle conical terminal concentrators and to predict receiver flux levels with much less computer connect time than is currently required.

Large Area Heliostats -- An approach to cost reductions for heliostats which has been developed in the private sector is the design of heliostats significantly larger than those evaluated in the second generation heliostat study. The heliostat area is $150m^2$, three times larger than the second generation heliostats. Estimates indicate that the cost/efficiency ratio of both small build and mass-produced large heliostats could be reduced by 50% over that of today's smaller heliostats. The current small heliostats cost $\$300/m^2$ at low production rates and $\$100/m^2$ in mass production.

To validate the performance and potential cost savings, two to four large area glass/metal heliostats will be purchased through an competitive industrial procurement. The heliostats will be installed at the CRTF and their performance will be evaluated using the heliostat chacterization system. The impact of these heliostats on receiver design, total system design, and cost will also be studied.

Stressed Membrane Heliostat -- Two development contracts will be awarded to industry to pursue design, manufacturing, and cost studies as well as full size prototype fabrication and testing of a stressed membrane heliostat assembly. This work was initiated in FY84 and will be continued through the next two years.

The stressed membrane heliostat consists of a silvered polymer film mirror supported by a thin steel membrane stretched over a eight meter diameter ring, with a second steel membrane stretched over the backside of the ring. Internal pressure controls the heliostat's focal length as well as defocuses the beam upon command. Due to weight reduction and design simplification, a \$24 to $\$36/m^2$ cost reduction in the long term in mirror module and structure cost is expected. This represents a reduction of 50 to 75% in the cost of the mirror and support structure for the second Generation heliostats.

Preliminary feasibility studies and tests of different joining techniques, fabrication methods, and control methods will be performed at SNLL to provide guidance to the contractors.

Heliostat Characterization System -- The performance of these new heliostat concepts must be carefully evaluated. A quantitative heliostat characterization system will be developed in FY85 and used for the evaluations. A current qualitative system which has been used for previous investigations will be upgraded to provide quantitative information on heliostat curvature and canting. Utilizing advanced video technology, this system will be used to characterize fully the surface contour of an operating heliostat. The work will principally involve software development to integrate the specialized video techniques and will be carried out internally.

The system will be used first to evaluate the stressed membrane prototypes and then will be used to examine the performance of the large area heliostats.

FY85 Resource Allocations - Concentrators

Internal ($K)		700
External ($K)		600
	TOTAL	1300

TASK 3 - RECEIVERS

Receivers transform the heliostat-concentrated solar radiation into thermal energy. Receivers have been designed, built, and tested using water/steam, molten nitrate salt, liquid sodium, and air as heat transfer fluids. As summarized in the Five Year Research and Development Plan, present liquid receivers operate at temperatures near 550°C with efficiencies between 75 and 90% and with costs of $80/m^2 -- expressed in dollars per square meter of concentrator aperture area. Consistent with the five year goals, receiver research and development activities are focused in two principal areas: Receiver Development and High Temperature Receivers.

Receiver Development activities are directed at improvements in receivers operating below 600°C. This work has been and will continue to be the principal focus of receiver research in the Central Receiver Program since the 600°C receivers enable electricity production through coupling with Rankine-cycle steam turbines and intermediate temperature industrial process heat generation. The development path outlined should result in the achievement of the program goals. The long term goal is to reduce the cost of these receivers to $45/m^2. In the nearer term, the five year goal is to reduce receiver costs by 30% while maintaining current performance.

The second area of receiver research and development is High Temperature Receivers, in which the activities have the goal of extending the capability of central receivers to 800 - 1000°C with a long term goal of 90% efficiency. Receiver Development activities provide a relatively straightforward path to the achievement of the solar thermal program goals while the High Temperature Receiver Development activities represent a higher risk alternate path to the achievement of similar goals. In addition, the High Temperature Receivers are directed at extending the potential applicability of central receivers to new applications.

Receiver Development

Receiver Development activities include the testing of a molten salt receiver subsystem, the continued development of receiver performance measurement tools, and the initiation of an optimized design of a 600°C receiver.

Subscale Molten Salt Receiver -- This molten salt subsystem/component test is directed at the resolution of technical uncertainties currently associated with molten salt subsystems and components. In addition, this work provides a sound technological base for development of molten salt central receiver systems and supports the design and construction plans for advanced central receiver plants. This work is a joint, cost-shared effort among industry, utilities, and the DOE.

In April 1984, a two year contract was initiated for the design, construction, and testing at the Central Receiver Test Facility (CRTF) of a 5 MWt molten salt receiver. Design of the receiver will be complete in January of 1985 with procurement and fabrication of the hardware complete in June 1985. Installation of the receiver at the CRTF and checkout will be completed at the start of FY86. Testing of the receiver is planned to begin in early FY86 and will be completed in mid FY86.

The receiver to be tested will consist of panels designed and fabricated by two different manufacturers; the panels will be arranged in a cavity configuration with wing panels. The receiver will be mounted on top of the CRTF tower for solar tests and will include such major components as heat absorption panels, piping, surge tanks, control valves, and support structure. It will be installed as a part of the existing Molten Salt Electric Experiment in place of the previously tested Martin Marietta receiver, thus enabling a direct comparison of the performance of the two receivers.

SNLL will provide technical management and support for the receiver design and testing, as well as evaluation of the test results.

A related experiment dealing with molten salt pumps and valves is described in Task 6 - Transport and Storage.

<u>Receiver Performance Characterization Techniques</u> -- Characterization of receiver performance is an integral part of understanding and evaluating receivers. Tools to characterize the performance of receivers require development or improvement. Quantities of interest include flux levels, receiver temperatures, fluid temperatures, and surface optical properties.

In FY85, improvements in a flux measurement system will be made to make possible two-dimensional mapping of flux profiles. Current capabilities of the system now being checked out at Barstow only allow one-dimensional vertical scans. Faster response flux sensors will also be investigated.

Infrared thermography will continue to be developed as a technique for remote temperature measurements for both state-of-the-art receivers and for advanced, high-temperature systems. This is a near term approach to satisfy central receiver program needs and has been coordinated with the longer term thermography development at the Georgia Institute of Technology. Measurements of surface optical properties are also required, and emissivity and reflectivity will be examined. Observed changes in receiver surface optical characteristics at Solar One due to an unknown degradation mechanism will be investigated.

A unique opportunity exists to resolve the continuing question of performance comparisons between cavity and external receivers. The

Martin Marietta receiver which is currently part of the Molten Salt Electric Experiment will be tested in FY85 both with and without its enclosing shroud to determine relative convective losses. An overall performance evaluation will be made for each configuration.

In FY86, measurements of the flow field about a receiver will be performed to enable better understanding of receiver convective losses. If schedules permit, this work will be performed for both cavity and external configurations.

Optimized Receiver Design -- Receivers tested to date in the Central Receiver program have performed well, but their cost has been high because they were designed to develop the technology rather than to optimize cost or performance. This activity will initiate the design of a receiver for Rankine-cycle bulk electric applications that is optimized with respect to cost and performance.

Two approaches to this objective will be pursued: (a) near- term FY85 activities will support the selection of baseline configurations for proposed projects for converting the 10 MWe Solar Thermal Central Receiver Pilot Plant or for construction of a Western States Utilities project (see Task 11); and (b) longer-term activities are aimed at the definition and conceptual design of a receiver that is optimized in terms of cost and performance, and can benefit from the utilization of advanced, non-traditional receiver technologies. Receiver design optimization activities will complement and support the systems-level optimization studies that are described under Task 9. Their common objective is the definition of an optimum central receiver systems technology for Rankine-cycle bulk electric power applications.

Initially, an analysis of the principal cost elements of a receiver subsystem will be performed, identifying those elements with the greatest potential for cost reduction and possible methods for achieving receiver cost goals. Design options to be evaluated include the type of receiver fluid (nitrate salt or sodium) and the effects of cavity receiver vs. external receiver (and north field vs. surround field) on receiver performance, startup time, receiver structural weight and cost, and tower height and cost. Related issues specific to the cavity configuration include the cost and performance effects of cavity doors and nighttime draining of the receiver fluid. Preliminary results from these studies will provide guidance for selection of a configuration for the Western States Utilities Project. More detailed results will be used in the definition of a receiver configuration for conversion of the 10 MWe Solar Thermal Central Receiver Pilot Plant.

The major output of these receiver design activities will be integrated with the systems studies of Task 9 to define an optimum central receiver system for Rankine-cycle conversion. Longer-term projects that may affect concept selection include the incorporation of new models of materials behavior now being developed at SNLL to facilitate the design of lower-cost, less-conservative receivers and utilization of technology being developed for high-temperature direct absorption receivers to permit a reexamination of this concept for lower temperature fluids (e.g., nitrate salts). The initial phases of conceptual design for the selected receiver configuration will be performed internally; detailed design definition of the concept will most likely be performed by industry under contract.

FY85 Resource Allocations - Receiver Development

Internal ($K)		800
External ($K)		1000
	TOTAL	1800

High Temperature Receivers

Research and development will continue on receivers which operate between 600°C and 1000°C. Work will continue on the solid particle receiver and on other high temperature receiver components. Terminal concentrators for high temperature receivers will also be examined.

Solid Particle Receiver -- Work on the solid particle receiver in FY85 and FY86 will have the objective of completing the technical feasibility study, a milestone in the Five Year Research and Development Plan, through the acquisition of detailed cost and performance information. This concept employs solids as a high density, high temperature working media in a compact, efficient receiver. A recommendation as to further work will be made as a part of the technical feasibility determination. This determination will be made using the results of the ongoing research and development efforts together with cost and performance information.

Cost and performance information will be obtained through completion of competitive industrial system design studies, the RFQ for which will be issued in the first quarter of FY85. These design studies will build upon the applied research carried out in this program in the past two years, particularly the successful feasibility experiment completed in FY84. This experiment demonstrated that particles falling a vertical distance of ten meters could be heated to temperatures exceeding 1000°C with incident fluxes of 0.25 to 0.50 MW/m^2. Heating of solids in this configuration had not been previously demonstrated.

Supporting analytical work on the thermal and aerodynamic phenomena in a particle receiver will continue. A model of the fluid mechanics in the heated cavity will be coupled with models for the fluid mechanics of the falling particles and the radiative transport in the particle curtain. Initial results from these coupled models will be complete in mid FY85. Characterization of leading candidate materials with respect to their fracture and agglomeration behavior and their optical properties will be completed in FY85. The examination of the Norton Master Beads will be completed in the first quarter of FY85.

Terminal Concentrators -- An in-house effort will be initiated in FY85 to study terminal concentrators for cavity receivers. A terminal concentrator is essentially a secondary reflector placed around the cavity aperture which redirects some spillage energy into the aperture; analytical studies indicate an approximate doubling of the average aperture flux using terminal concentration. There are two possible benefits of using terminal concentrators: 1) higher aperture fluxes can be achieved which would be beneficial for high temperature applications such as the production of fuels and chemicals and 2) possible relaxation of tracking and optical requirements of the heliostats for intermediate temperature cavity applications, thereby reducing the cost of the collector field. This study will include an assessment of the materials of construction, particularly for the reflective surface, and an analysis of thermal protection and preliminary structural design for commercial-sized cavity receivers.

Fuels and Chemicals Component Development -- A solar catalytic reactor is being developed at GA Technologies. This reactor performs the critical step of acid decomposition at high temperature in the sulfuric acid/iodine thermochemical hydrogen production process. Design and fabrication were nearly complete at the end of FY84, and testing will be performed in the first half of FY85 to characterize the performance and assess the structural design margin of the component.

A ceramic heat exchanger is being developed by Garrett AiResearch to serve as vaporizor of concentrated acid in the sulfuric acid/iodine hydrogen production process. A test rig was built around a single-tube silicon carbide heat exchanger in FY84. Critical glass-to-metal seals were also developed. Testing will be performed in the first quarter of FY85 to characterize the performance of the component.

Following the completion of the fuels and chemicals system studies described in Task 9 in late FY85, component development activities will be initiated as recommended by those studies. These may include receiver-reactor concepts and molten carbonate salt receivers. Research on the latter concept at SERI will be incorporated into the development program as warranted.

FY85 Resource Allocations - High Temperature Receivers

Internal ($K)		600
External ($K)		300
	TOTAL	900

TASK 6 - TRANSPORT AND STORAGE

The objective of the transport and storage task is the development of high-efficiency, low-cost systems which can provide an effective match between the fluctuating solar energy resource and the thermal or electrical load demand. Development of efficient, high-temperature storage allows economical increases in electrical generation capacity factor and allows solar systems to provide energy when it is needed most.

Central receiver activities aimed at the improvement of these subsystems include testing of molten salt valve and piping components and examination of an optimized storage system for grid connected electric power plants.

Molten Salt Pumps and Valves -- Pumps, valves and piping for molten salt central receiver systems will be tested in FY85 and FY86 as a part of the molten salt subsystem/component test experiment. The cooperative, cost-shared industry/utilities/DOE contract effort will translate the need for reduced risk and cost of these critical components into an engineering test program.

This work was initiated in FY84, will continue through FY85, and will conclude in mid FY86. One part of the work consists of laboratory valve stem seal compatibility experiments being performed at SNLL. These tests will screen potential valve stem seal materials and determine their compatibility with molten salt at elevated temperatures. This will be followed by a bench test at the CRTF to evaluate several stem seals under the required conditions of temperature and pressure. The results of both the laboratory and bench tests will be used to identify suitable stem seals for valves in the Pump and Valve Loop Test.

As a separate task, a molten salt freeze-seal valve will be developed to use in the event that a suitable packing material is not identified. Freeze-seal valves have been used for liquid sodium applications for many years.

Two large-scale pump and valve loop experiments will be performed at the CRTF in FY85 and FY86. Components representative of those specified for recent central receiver plant designs will be tested at their required temperatures, pressures, and molten salt flow rates. Performance of the components will be evaluated in both a cold salt loop and a hot salt loop.

As a part of the subscale receiver and the pump and valve loop test, design specifications and installation procedures for trace heating will be developed. Trace heating is required to preheat pipes, valves, and other components which contain molten salt. The need for additional development was identified in the Molten Salt Electric Experiment. Trace heating technology which has been developed for liquid sodium in the nuclear power industry will be investigated for design and installation procedures which could result in higher reliability of molten salt solar systems.

Optimized Storage Design -- Commencing in late FY85, optimal storage systems viewed from a design-to-cost basis will be examined. Important storage system issues include externally versus internally insulated tanks, single tank versus multiple tanks, above-the-ground versus on-the-ground (or in-the-ground). The optimum trade between the amount of storage versus fossil-fuel hybridization is also significant.

Storage research activities to address these issues include the continued study of storage materials, containment techniques, heat transfer techniques, and heat exchanger technology required for the interface between storage and the heat transport system. A synthesis of the optimum storage features will be derived and used in a conceptual design of a storage system for the intermediate term central receiver project. These items will be examined from an operational as well as a first cost basis. Initial work will be internal; industrial design expertise will be sought in later phases of the effort.

Also, solid particle and molten carbonate salt storage media, externally and internally insulated tank designs, raft thermoclines, and direct contact heat exchangers will be investigated for high-temperature sensible heat storage systems. In addition, thermochemical transport using reversing endothermic and exothermic chemical reactions at the receiver and point of use, respectively, will be examined from a systems point of view. These transport systems currently under development as a part of the Distributed Receiver Program, may have potential for use in very large central receiver systems.

FY85 Resource Allocations - Transport and Storage

Internal ($K)		400
External ($K)		300
	TOTAL	700

TASK 8 - BALANCE OF PLANT

Task 8 addresses research on the non-solar components necessary to construct, maintain, and operate a complete central receiver plant. Conventional balance-of-plant equipment constitutes a significant portion of central receiver costs. The research activities include characterization and optimization of site construction, plant service facilities, power conditioning equipment and spare parts inventory, and the design and development of plant controls. The primary goals are the reduction of balance-of-plant capital costs, minimization of parasitic and auxiliary power requirements, and characterization and reduction of operation and maintenance costs for central receiver installations.

In FY85 and FY86, the main development activities in this area will be development and testing of automated controls and continued development of heliostat washing technology. The goal of both efforts is to reduce maintenance and operating costs and to improve the overall performance of central receiver plants.

Controls -- An automated central receiver plant which can operate with minimal personnel or even unattended has been identified as a desirable goal. Benefits of automation include an estimated reduction in plant operating costs of 2-5% and a reduction in capital costs for heliostats of 2-5% (because the required number is reduced). Additional benefits include an increase in plant efficiency on clear days, a decrease in equipment failures (because operator errors are minimized and operation outside design limits is eliminated) and prolonged component lifetimes. Improvements in plant performance will result from decreased start-up time, increased maximum output power level, extension of the daily operating time, reduction of parasitic loads, and more effective management of the available energy from the receiver, thermal storage and auxiliary systems. These benefits however must be weighed against possible penalties: an increased capital cost for the controls hardware and software of 1-5%, a decrease in the plant availability while trouble shooting and on cloudy days, an increase in controls failures, and an increased number of potentially obsolescent computers.

In this task, the limits imposed by current solar technology on an unattended solar central receiver plant will be examined. Guidelines for the instrumentation, computer hardware and software, and operational constraints required to achieve unattended operation of a central receiver plant will be identified. This information will be available to the central receiver industry to allow them to estimate the cost tradeoff of manpower versus unattended controls for future plants.

To accomplish these goals, the Molten Salt Electric Experiment will be automated to permit unattended operation. The specific objectives are to verify design methods and hardware and software performance by field measurements and to determine to what extent automation can improve system efficiencies and affect equipment failures and component lifetimes. The effect of plant automation on system availability will be assessed and operation and maintenence cost data will be obtained. All of the operating experience gained will be used to develop one possible set of automation requirements and specifications.

Automation will be developed under contract. An RFQ including a statement of work will be issued in the first quarter of FY85. The contract is planned to begin in June 85 for an 18 month effort which includes design, installation, and checkout.

Heliostat Washing Technology -- Thorough and effective heliostat washing will improve the performance of a heliostat field by 5 to 10% or more depending on soiling conditions. Improvements in heliostat washing technology are a relatively inexpensive way to make significant improvements in overall plant performance. This was dramatically demonstrated in the recent summer solstice performance experiment performed at the 10MWe Solar Thermal Central Receiver Pilot Plant. Heliostat reflectivity was only 78%, significantly below design conditions of 91%, and the output power levels achieved were reduced accordingly.

Several approaches to this important area are being pursued in the solar thermal program. The physics of mirror soiling is a research task, while investigation of engineering approaches to cleaning are part of the development programs. In the central receiver program, an outside contract will be awarded to define a more effective method of washing heliostats than presently exists. The RFQ for this effort will be prepared and issued in mid-FY85.

The intention of this work is to explore all potential techniques, including those which have not been previously studied. It is envisioned that the study will include both analytical and bench-scale experimental work. Alternatives to the current techniques, which employ a water spray or soft fiber brushes in contact with the mirror, include the use of a recycling, water-jet system with entrained soft fibers or particles. This concept has the attraction of potential universal applicability (i.e., to trough and dishes, as well as to heliostats).

FY85 Resource Allocations - Balance of Plant

Internal ($K)	200
External ($K)	1200
TOTAL	1400

TASK 9 - CENTRAL RECEIVER SYSTEMS

Central receiver systems development includes the development of designs and the analysis of system parameters for complete solar central receiver systems. The integration of components and subsystems into a complete system is necessary to understand the interactions which occur among elements of the system and to define cost and performance tradeoffs. This makes it possible to identify critical technology development requirements.

The goal of central receiver systems research and development is to establish the potential for technical and economic feasibility of solar systems which produce electricity or industrial process heat. Targets for the capital cost and system efficiency are the equivalent of a component goal for this research task. Current central receiver systems for electricity generation have an annual efficiency of 16% and a capital cost of $4600/peak kWe. Current systems for industrial process heat production have an annual efficiency of 48% and a capital cost of $1300/peak kWt. Long term objectives for electricity generation are an efficiency of 22% and a cost of $1600/peak kWe, while for heat production the objectives are an efficiency of 56% and a capital cost of $470/peak kWt. Achievement of these goals is necessary to meet the overall program cost targets listed in Table 1.

Central receiver systems tasks include Systems Application Studies, the Central Receiver Test Facility (CRTF) and International support.

Systems Application Studies

Several studies are under way or planned for FY85 and FY86 which involve applications of the solar central receiver concept. These include performance of several system improvement studies, development of new central receiver projects, and examining some conceptual designs of fuels and chemicals plants.

System Improvement Studies -- Systems studies are an important aspect of central receiver development; they enable proper prioritizing of development activities and place ongoing work in an appropriate context. Studies to be carried out in FY85 are directed at understanding various design and cost tradeoffs in the context of actual data from the operating central receiver systems. These studies will indicate optimum techniques for reducing the delivered energy cost for central receiver systems while improving reliability and decreasing risk.

Several studies are planned to examine system characteristics such as receiver geometry (external versus cavity), heliostat field configuration (north versus surround field), heat transport and storage fluids (sensible and thermochemical systems), economics of scale, storage capacity and hybridization. Brayton cycle electricity generation will be compared to Rankine cycle generation. Using measured performance data from Solar One, MSEE, IEA/SSPS and other international projects, these studies will identify the best combinations of key system and component characteristics for various applications.

Economic and cost analyses of central receiver systems will also be performed. The cost data available from Solar One and the Carrisa Plain and Solar 100 studies will be used.

A new "Solar Power Tower Design Guide" will be prepared which will incorporate recent central receiver design and operating experience. The original document, published by Sandia in 1981, has been an important and widely used summary document for the program. The new guide to be published by the end of FY86 will provide one avenue for discussion of the state-of-the-art central receiver technology.

Project Development -- One solar central receiver project development activity is a study begun in FY84 on the potential of converting the 10 MWe Solar Thermal Central Receiver Pilot Plant at Barstow to a test facility for advanced concepts. Six options were considered for the system conversion of the pilot plant. Five of the options are solar stand-alone plants that add combinations of the following equipment: molten salt or liquid sodium receiver, thermal storage, and steam generator and upgrading of the existing heliostats or the addition of advanced heliostats. The sixth option combines a molten salt receiver, molten salt storage, and steam generator with a fossil-fueled energy source to provide data for hybrid (solar/fossil) operation. The 10 MWe Solar Thermal Central Receiver Pilot Plant conversion study will be completed in early FY85.

A group of western utilities is studying the appropriate path to eventual commercialization of solar thermal central receiver technology. At the request of the utilities, SNLL coordinated a workshop held early in FY85 to discuss the number of scale-up steps required to proceed with confidence to a 100 MWe prototype commercial plant. SNLL will continue to support this utility initiative as appropriate.

Fuels and Chemicals Production -- While electric power generation continues to be the main focus of the solar central receiver development program, an alternative application to electricity generation is the production of fuels and chemicals using a solar central receiver. System conceptual designs are planned to examine this potential application. These studies will increase the data base of process descriptions, design data, operating strategies, and economic predictions to guide future long range research and development in the solar central receiver program.

Two conceptual design tasks are planned. A RFQ has been issued and industrial firms have been selected to perform the initial three conceptual design studies. The processes to be studied should be technically feasible in the 1995 timeframe and address the unique features of a central receiver as a high temperature (up to 1100 ^{o}C) heat source to produce a fuel or chemical which is valuable as an intermediate or end product. These studies will examine processes in which consumption of prime fossil fuel is reduced or a renewable feedstock is used.

The results of these initial studies will provide valuable data to the overall assessment of solar fuels and chemicals production. The second and similar system development task, to be funded in FY86, will focus on a more advanced or alternate solar fuels and chemicals process. The advanced/alternate studies will not be constrained by a technical feasibility timeframe; thus, both near term and longer term applications will be candidates. Results from these and the earlier studies will be used to define appropriate component development activities and tests and further design studies.

FY85 Resource Allocations - Systems Application Studies

Internal ($K)	1800
External ($K)	500
TOTAL	2300

Central Receiver Test Facility

The Central Receiver Test Facility (CRTF) provides the capability and operational support required for testing and evaluation of central receiver systems, subsystems, and components. Equipment at the CRTF includes a 5 MWt heliostat field and 200 foot test tower, data acquisition and control hardware, a heliostat test facility with beam characterization systems, and a solar furnace.

FY85 and FY86 activities at the CRTF will focus on continued MSEE system operation as a utility followed by tear-down and post test inspection (Phase II and Phase III). The molten salt pumps and valves experiment will begin in the first quarter of FY85, and the subscale molten salt receiver test in mid FY85. The CRTF will also provide equipment and operational support for installation and testing of an advanced, unattended control system using the MSEE as a test bed. These activities following MSEE Phase III are discussed under Tasks 3, 6, and 8 of this plan.

The solar furnace will continue to be used for flux gage calibration and materials research and development.

CRTF funding identified under this subtask is that required to keep the facility manned and maintained in a state of readiness to test. Additional funds required to support specific experiments are provided by allocations for those experiments.

FY85 Resource Allocations - CRTF

Internal ($K)		1000
External ($K)		300
	TOTAL	1300

International

Sandia maintains contact and exchange of information with various international central receiver projects. A major portion of this work is participation in the International Energy Agency/Small Solar Power Systems Project (IEA/SSPS) located in Almeria, Spain.

Present work at the IEA/SSPS includes the evaluation of liquid sodium technology, plant scale-up capability, and minimization of plant costs. Completion of the construction, test, and evaluation phase of the project is planned for December, 1984. The plant hardware will then be maintained in an inactive status ready for reactivation as a test facility as needed by project participants. The IEA/SSPS project which also includes a solar distributed receiver system, will then change its orientation to one which will coordinate research and development activities in areas of mutual interest to various combinations of participating countries. Plans for this program are in the formative stage.

Representation on behalf of the DOE at the IEA/SSPS Executive Committee meetings held in Europe will continue to be provided by SNLL. SNLL also supplies in-house technical evaluation, modeling of the central receiver systems, and comparative evaluation of the IEA/SSPS and other central receiver systems; SNLL will also provide for participation in the new cooperative activities as appropriate. This activity serves to develop a world-wide data base on central receiver technology. External funding requests will cover cooperative international evaluations of central receiver systems as well as the U.S. share of costs to maintain the IEA/SSPS project facility in an inactive status. Also included is a small amount set aside to cover other cooperative activities.

International activities include evaluating data from central receiver projects in other countries, especially the Themis project in France. Under consideration is a jointly funded program for international project evaluation. The possibility of having a SNLL solar expert in residence at Themis for three months during this evaluation is being explored.

FY85 Resource Allocations - International

Internal ($K)		200
External ($K)		300*
	TOTAL	500

*A portion of this external funding ($150K) is for funding of the IEA/SSPS Project through DOE/HQ and should be retained at DOE/HQ until the total FY85 costs are identified.

TASK 11 -- SYSTEM EXPERIMENTS

System experiments provide valuable data on capital cost, performance, and operations and maintenance of complete solar thermal systems. The system experiments are conducted with major participation from solar equipment manufacturers and potential users. These experiments lead to the establishment of technical feasibility, to the development of a valuable cost and performance data base, to technology transfer which can be used in private sector decisions, and to the identification of future research and development needs.

Current system experiments in the Central Receiver Development Program consist of the 10 MWe Solar Thermal Central Receiver Pilot Plant in Barstow, California, and the Molten Salt Electric Experiment at the CRTF in Albuquerque, New Mexico.

10 MWe Solar Thermal Central Receiver Pilot Plant (Solar One)

SNLL provides technical support for the 10 MWe Solar Thermal Central Receiver Pilot Plant on behalf of DOE/SAN. The objective of this experimental pilot plant is to test the various subsystems and analyze the performance of the components. Evaluation of data provides information to industry to support decisions regarding designs and economics of central receiver systems. The work also identifies areas where future central receiver research and development could lead to significant performance improvements and increased capabilities.

The two-year Experimental Test and Evaluation Phase for the Pilot Plant ended in August 1984. During this period, operating experience was achieved with all the plant's operating modes, plant displays were upgraded, automatic controls were installed, and the pilot plant's system and component performance was evaluated.

A three-year Power Production Phase will now demonstrate the operational capability of the plant to supply electrical power reliably to the utility grid. During this phase, Southern California Edison (SCE) will operate the plant and record the data, and SNLL will analyze and evaluate the data from the plant operations. Of particular importance while operating the plant in a utility environment will be the determination of operating strategies to maximize the energy output of the plant. The annual capacity factor will be determined; it is an important quantity necessary to assess the technical feasibility of solar central receiver technology for utility and industrial use. Also important is assessing and possibly reducing the operations and maintenance costs. A series of SNLL reports will be published to disseminate the information to industry.

In addition to evaluating the Power Production Phase plant performance, SNLL planned activities include:

a. Completing the evaluation of plant performance during the previous Test and Evaluation Phase and publishing the (approximately 12) scheduled reports;

b. Studying and understanding the receiver tube cracking problem through laboratory tests and analysis;

c. Completing the receiver convective loss experiment and documenting the results; and

d. Supporting the operation of the plant and diagnosing and solving non-routine problems.

The budget figures that follow reflect only SNLL 10 MWe Solar Thermal Central Receiver Pilot Plant expenditures. DOE/SAN will also be providing $3000K to cover Barstow operations and maintenance, spare parts, and one-time activities at the pilot plant. This allocation is described in more detail in DOE/SAN's operating plan.

FY85 Resource Allocations - Pilot Plant

Internal (K$)	900
External (K$)	600
TOTAL	1500

Molten Salt Electric Experiment

The Molten Salt Electric Experiment (MSEE) presently underway at the CRTF is a 5 MWt system experiment funded jointly by industry, utilities, and DOE. The goals of the project are to verify the molten salt central receiver concept, to provide performance information and operating experience for molten salt systems, and to establish a test bed for component and advanced controls development. The information and experience gained from the MSEE will be invaluable in the design of future intermediate and large solar plants using molten salt as the heat transfer medium.

Design, construction and checkout were carried out under Phase I of the MSEE in FY84. All MSEE subsystems are operating, and synchronization to the grid was accomplished in May 1984. Phase II is currently in progress and entails system performance evaluation as well as the training of utility personnel in the operation of the MSEE. The main thrust of Phase III will be a one-month power production campaign during which the system will be operated sun up to sun down, seven days a week, and optimized procedures will be developed to maximize the power output.

The MSEE will then be used as a test bed for the subscale molten salt receiver and pumps and valves subsystem testing as well as for unattended controls development.

FY85 Resource Allocations - MSEE

Internal (K$)	0
External (K$)	300
TOTAL	300

PLANNING AND ASSESSMENT

The objective of this activity is to provide support to the Solar Thermal Program in the areas of overall program planning and assessment. Short-term and long-range planning, analysis, and assessment of technical and economic issues are conducted to ensure a balanced and properly prioritized and directed program.

Results of the special studies and analyses conducted in such areas as the economic competitiveness of solar thermal systems, understanding of market impacts, industrial involvement, and the relative merits of competing technologies for particular applications provide data needed to establish program priorities, future directions, and program justification. Ongoing annual efforts of the TPI office include tasks such as development and implementation of the Five Year Research and Development Plan.

Planning

Planning is an ongoing task. The Five Year Plan developed during FY84 has established a new framework and philosophy for the Solar Thermal Program. The Program structure is simplified into eleven tasks, and the Program philosophy is oriented around specific, quantified, long-term and five year goals.

During FY85, the Five Year Plan will be updated in consulation with the research and development centers. Particular emphasis will be placed on further refinement of the cost/performance goals and on the further definition of program activities required to accomplish these goals. The schedule for the Five Year Plan update is dependent on the publication date of the present version. A specific schedule will be developed as more data is available.

FY85 Resource Allocations - Planning

Internal ($K)		300
External ($K)		200
	TOTAL	500

Analysis

The analysis activities focus on two areas: analysis of economic competitiveness and characterization of potential markets.

Economic competitiveness must be considered within the Solar Thermal Program (among the technologies) and with respect to fossil alternatives. Knowledge of these comparisons aids in program planning and prioritizing. One study will estimate electric energy costs from central receivers, dishes and troughs based upon projections of component efficiency and cost which can be reasonably achieved by the middle to late 1990's. Levelized energy costs will be developed for a wide range of system sizes and capacity factors. The study will provide a stronger analytical base for the Solar Thermal Five Year Research and Development Plan. The levelized energy cost methodology, in particular, will be standardized and documented in a readily usable form.

Market characterization will be studied on two fronts. For electricity applications, a utility perspective of solar thermal electric plants will be sought and the capacity growth patterns better defined. For industrial process heat applications, the market will be characterized as fully as possible by temperature, size of application, fuel choice, etc. Another study will determine the value of heat supplied at a range of conditions from $100^{o}C$ to above $1400^{o}C$. An external activity will investigate and characterize business development of photovoltaic and wind technologies as applicable to solar thermal futures.

System tradeoffs and potential economic advantages of hybrid solar electric plants will be evaluated. This study will complement related work on fossil hybridization conducted in Tasks 6 and 9.

Figure 5 shows major milestones for the activities described above. More milestones for FY86 will be developed as firm schedules are established.

FY85 Resource Allocations - Analysis

Internal ($K)	300
External ($K)	500
TOTAL	800

CAPITAL EQUIPMENT

In FY85, $150K is required for capital equipment in the central receiver program. These funds will be used for upgrading the technical capability of the Central Receiver Test Facility as well as for dedicated equipment for central receiver program experiments.

RESOURCES AND IMPLEMENTATION

A strategy for performing the work described in the previous chapter, together with the required resources, is described in this chapter. In addition to the resources, major milestones for the two year period covered by this plan, significant reports, the SNLL organizational structure, a procurement plan and summary, and the relation of FY84 and FY85 activities are included here.

RESOURCE SUMMARY

Resources required in FY85 to carry out the work described in this document are summarized in Table 6. Summaries of FY85 and FY86 resources are shown in Table 7.

MILESTONES AND REPORTS

Major milestones for the Central Receiver Program and the Planning and Assessment Effort are shown in Figure 5. Significant reports in the central receiver development program to be issued in FY85 are listed in Table 8.

TABLE 6. FY85 RESOURCES

	External ($K)	Internal ($K)	Internal (FTE*)	Total ($K)
Collector Technology				
1. Optical Materials	-	-	-	-
2. Concentrators	600	700	4.8	1300
3. Receivers	1300	1400	10	2700
Energy Conversion Technology				
4. Heat Engines	-	-	-	-
5. Direct Conversion	-	-	-	-
6. Transport and Storage	300	400	2.7	700
Systems and Applications				
7. Innovative Concepts	-	-	-	-
8. Balance of Plant	1200	200	1.5	1400
9. Central Receiver Systems	1100	3000	20	4100
10. Distributed Receiver System	-	-	-	-
11. System Experiments	900	900	6	1800
TOTAL	5400	6600	45	12000
Planning and Assessment	700	600	4.5	1300
TOTAL				13300
Capital Equipment				150

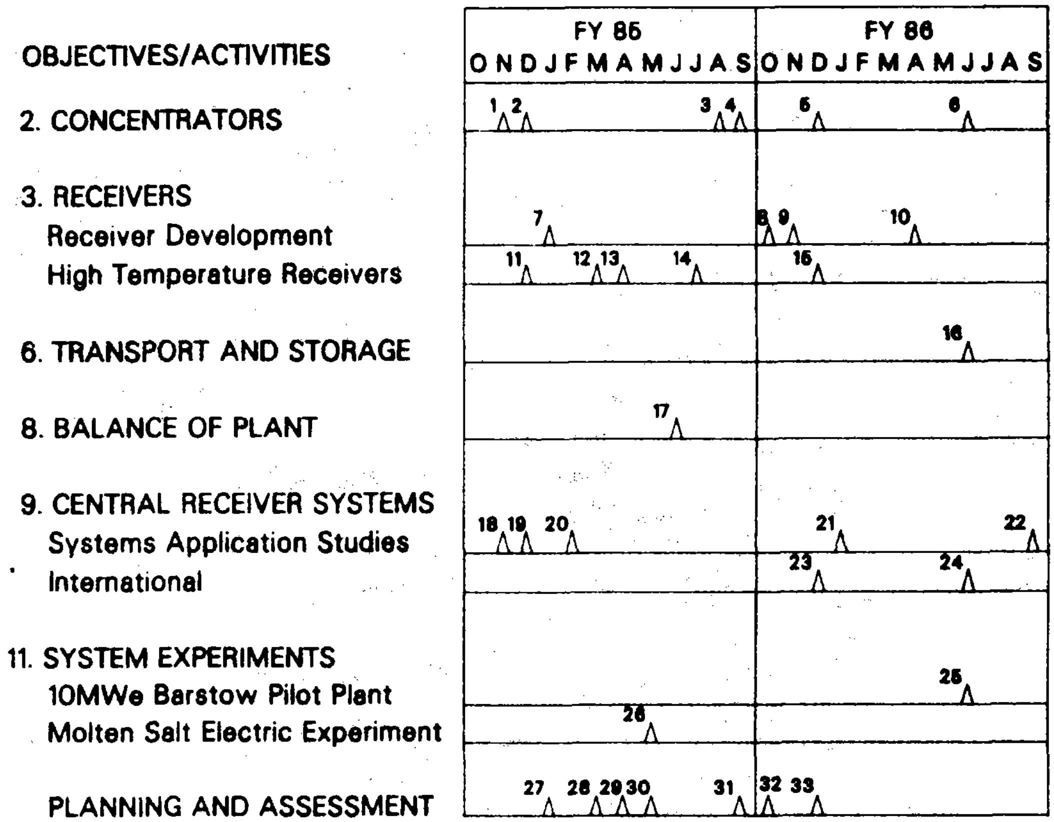
* Staffing levels as Full Time Equivalents.

TABLE 7. FY85 AND FY86 RESOURCE SUMMARY

	FY85 ($K)	FY86* ($K)
Collector Technology		
1. Optical Materials	-	-
2. Concentrators	1300	1000
3. Receivers	2700	3400
Energy Conversion Technology		
4. Heat Engines	-	-
5. Direct Conversion Devices	-	-
6. Transport and Storage	700	500
Systems and Applications Technology		
7. Innovative Concepts & Applications	-	-
8. Balance of Plant	1400	1100
9. Central Receiver Systems	4100	4600
10. Distributed Receiver Systems	-	-
11. System Experiments	1800	1400
Total	12000	12000*
Planning and Assessment	1300	1300
Total	13300	13300
Capital Equipment	150	150

* In accordance with DOE/HQ guidance that level funding should be assumed, proposed FY86 funding was reduced to $12000K.

CENTRAL RECEIVER DEVELOPMENT PROGRAM MILESTONES



2. CONCENTRATORS

1. Begin stretched membrane prototype cost/performance study.
2. Begin development of quantitative heliostat characterization system.
3. Procure large heliostats and initiate performance testing and evaluation.
4. Complete wind load reduction study.
5. Quantitative heliostat characterization system operational.
6. Complete assessment of stretched membrane heliostats.

3. RECEIVERS

Receiver Development

7. Begin optimized receiver conceptual design.
8. Complete subscale molten salt receiver construction and begin testing.
9. Complete testing of fiber optics flux measurements method.
10. Complete subscale molten salt receiver testing.

High Temperature Receivers

11. Complete test of ceramic heat exchanger.
12. Begin solid particle receiver system conceptual designs.
13. Complete test of sulphuric acid decomposer.
14. Complete assessment of receiver-mounted terminal concentrator.
15. Complete solid particle receiver technical feasibility study.

Figure 5. Major Milestones

MILESTONES (cont.)

6. TRANSPORT AND STORAGE

16. Complete molten salt pumps and valves experiment.

8. BALANCE OF PLANT

17. Begin unattended controls development study.

9. CENTRAL RECEIVER SYSTEMS

Systems Applications Studies

18. Begin systems improvement studies.
19. Complete Barstow system conversion study.
20. Initiate fuels and chemicals conceptual design studies.
21. Complete fuels and chemicals conceptual design studies.
22. Issue new Solar Power Tower Design Guide.

International

23. Complete IEA/SSPS project test and evaluation phase.
24. Conduct third international workshop on solar central receiver systems.

11. SYSTEM EXPERIMENTS

10 MWe Solar Thermal Central Receiver Pilot Plant

25. Conduct 1986 summer solstice measurement campaign.

Molten Salt Electric Experiment (MSEE)

26. Complete Phase III testing of Molten Salt Electric Experiment.

PLANNING AND ASSESSMENT

27. Conduct energy cost methodology workshop.
28. Begin study of industrial process heat value versus temperature.
29. Complete baseline solar electric system characterization.
30. Complete first draft of utility market characterization study.
31. Complete first draft of electricity hybridization study.
32. Complete study of business development of photovoltaics and wind.
33. Complete solar thermal electric characterization study.

Figure 5. Major Milestones (continued)

TABLE 8. SIGNIFICANT REPORTS TO BE ISSUED IN FY85

Title	Author(s)	Issue Date
Solid Particle Receiver Experiments: Velocity Measurements	J. M. Hruby V. P. Burolla	Oct 1984
Solid Particle Receiver Experiments: Radiant Heat Test	J. M. Hruby B. R. Steele V. P. Burolla	Nov 1984
Assessment of Solid Particle Receiver for a High Temperature Solar Central Receiver System	P. K. Falcone J. E. Noring J. M. Hruby	Dec 1984
10 MWe Solar Thermal Central Receiver Pilot Plant: Convective Loss Experiment	M. C. Stoddard	Jan 1985
10 MWe Solar Thermal Central Receiver Pilot Plant: Thermal Storage Subsystem Evaluation - 1983 Operations	S. E. Faas	Feb 1985
10 MWe Solar Thermal Central Receiver Pilot Plant: 1984 Summer Solstice Power Production Test	E. H. Carrell	Feb 1985
10 MWe Solar Thermal Central Receiver Pilot Plant: Total Capital Cost	H. F. Norris	Feb 1985
Receiver Temperature Measurement Using Infrared Thermography	M. C. Stoddard N. F. Bergan	Mar 1985
Molten Salt Electric Experiment Status Report	W. R. Delameter	Apr 1985
10 MWe Solar Thermal Central Receiver Pilot Plant: Heliostat Evaluation Report	C. L. Mavis	Apr 1985
10 MWe Solar Thermal Central Receiver Pilot Plant: Receiver Evaluation Report	A. F. Baker	May 1985
10 MWe Solar Thermal Central Receiver Pilot Plant: Experimental Test and Evaluation Phase Final Report	L. G. Radosevich	May 1985

MANAGEMENT PLAN

Management Structure

The Solar Central Receiver Program and Solar Thermal Technology Planning and Assessment are the responsibility of the Solar Central Receiver Department, reporting to the Director of Component and Systems Research at SNLL. The Central Receiver Test Facility (CRTF) is managed by SNLA but the funding administration and program direction comes from SNLL.

The management structure of the Solar Central Receiver Department is shown in Figure 6, along with the distribution of responsibilities for the program elements. The Solar Thermal Programs Division is functionally independent of the other divisions in the department which have responsibility for technology development.

Reporting and Control

Management control over the program is maintained through a schedule of periodic reporting and reviews in order to ensure that the program is proceeding as described in the AOP submitted at the start of the Fiscal Year. Reports to DOE/HQ make up a pyramid of scheduled reports designed to keep program managers informed of development and work progress in an appropriately timely manner. These reports include:

- weekly newsnotes
- a bi-monthly technical and financial report
- a quarterly oral presentation to branch chiefs
- an annual technology transfer meeting for the public.

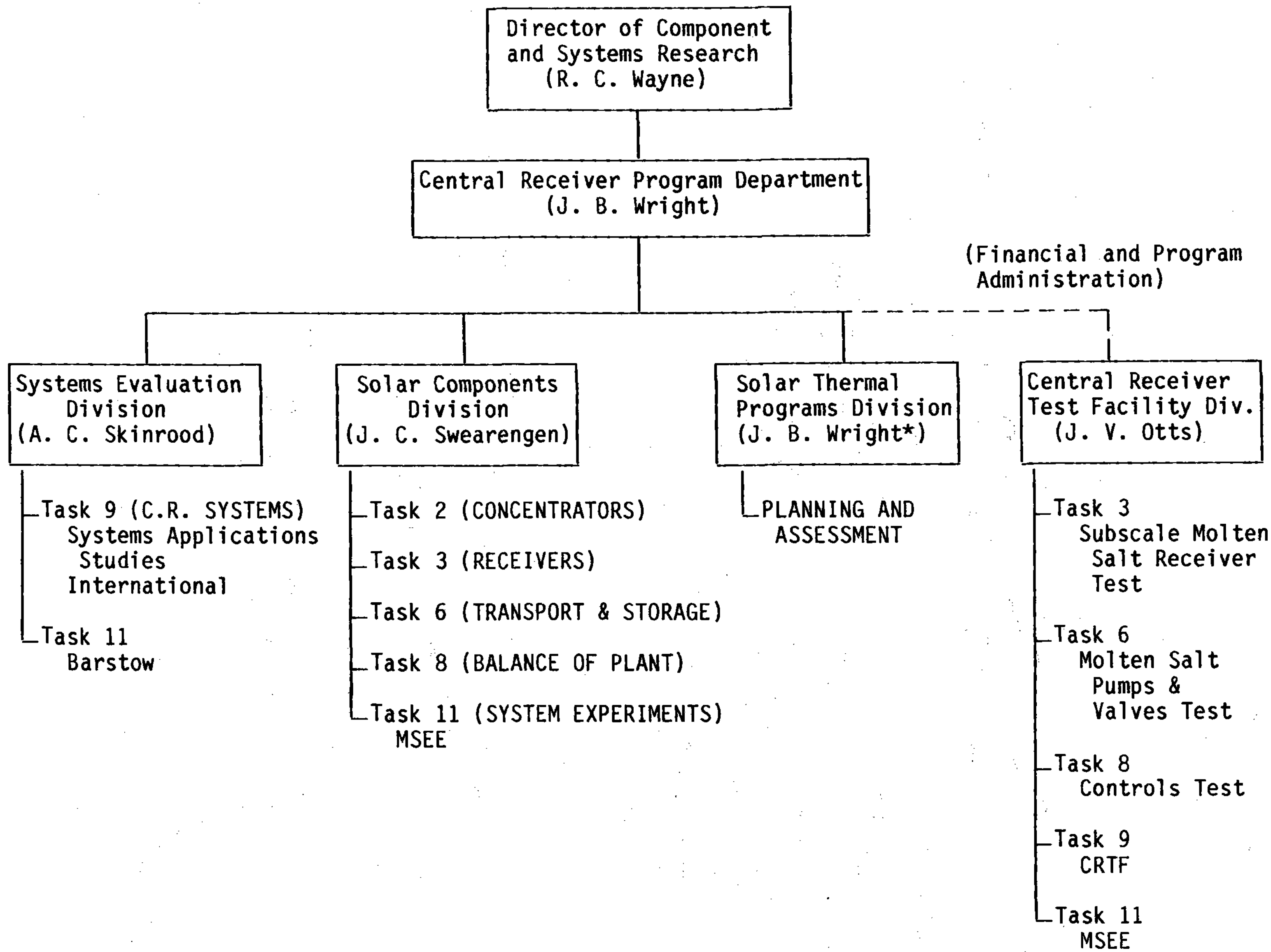


Figure 6. Management Structure for SNLL Solar Central Receiver Program and STT Planning and Assessment

*Acting

PROCUREMENT PLAN

Procurement Strategy

Procurements for the central receiver development program are initiated by Sandia, upon approval of the Annual Operating Plan by DOE/HQ. The procurement summary listed in Table 9 provides a list of the major new procurements which are anticipated in FY85 and FY86. Many of these requests for quotation will be released early in the fiscal years. However, a deliberate attempt will be made to reserve some funds for award in the last half of the fiscal year. The dates for these major procurements are indicated in the procurement summary.

Procurement Policy and Practices

Sandia's procurement rules are similar to the DOE regulations; however, they are not identical. In the substantive cases where they are not, but which have impact on the program, measures are taken to assure that the programmatic requirements are met. An example of this is the policy of advertising competitive procurements in Commerce Business Daily and any other appropriate publication. (This is not generally done on Sandia procurements.) With very few exceptions, all R&D procurements in this program are competitive, with the sole source option being used only in instances where it is very clear that the contractor is the only one who can fulfill the function.

Unsolicited Proposal Funding -- Sandia, through its prime contract held by AT&T Technologies with the U.S. Department of Energy, is excluded from funding unsolicited proposals which have been submitted to the Laboratory. These proposals are to be returned unopened with instructions regarding the proper route of submittal to DOE Headquarters. Once such a proposal is submitted through the proper channels, reviewed, and accepted for funding by the appropriate Division Director (DOE Headquarters), SNLL can hold the contract as a result of a written request from that Director. The strategy then is to expect to hold the contracts for any approved unsolicited proposals on heliostats, receivers, or general central receiver system activities. These will be funded by SNLL either on existing funds or, if such funds are not available, on funds to be forwarded to SNLL through ALO's financial plan accompanying the request to place the contract. In implementing this strategy, Headquarters and SNLL will reach an agreement regarding the source of funding prior to a formal request being sent to SNLL to place a contract. It is expected that most approved unsolicited proposals will be of sufficient value to fit within the scope described in this AOP and will not require additional funding. Exceptions will occur where the proposals are approved using additional criteria and where funds have been reserved at Headquarters for funding such proposals.

Small and Minority Business Policy -- It is both DOE policy and Sandia policy to maximize the use of small and minority businesses in carrying out the programs under their management. While goals are established and careful efforts are made to meet them, meeting the goals is to be done in a manner consistent with meeting the technical programmatic objectives and thus the former is not the primary objective. Every effort will be made by Sandia to meet the goals set by the Solar Thermal Technology Division for small and minority businesses. Sandia policy for procurements does not permit the use of set-asides in the manner that the FPR's suggest for a federal agency. It does, however, permit accomplishment of the objectives by the use of a limited bidders' list. As a result, we believe it is possible to meet the STT goals for procurement from small and minority businesses. It is our preference to incorporate as much of this small and minority business activity in the major or mainstream procurements as possible.

TABLE 9. FY85 AND FY86 MAJOR PROCUREMENTS

Contract Title	Period of Performance	Funding ($K) Prior	FY85	FY86
2. CONCENTRATORS				
Low Cost Heliostat Drives	5/85 - 12/86		200	
Stretched Membrane Heliostat	10/84 - 3/86	1200		
Large Area Heliostats	6/85 - 12/85		250	
3. RECEIVERS				
Category B Substation	12/84 - 6/85		370	
Optimized Receiver Design	3/86 - 3/87			1200
Solid Particle Receiver System Design	5/85 - 12/85	800		
8. BALANCE OF PLANT				
Unattended Controls	4/85 - 4/87		1100	600
9. CENTRAL RECEIVER SYSTEMS				
Solar Fuels & Chemicals System Design Studies	11/84 - 7/85	1200		
Analysis of CR Systems	11/84 - 5/85	140		
11. SYSTEM EXPERIMENTS				
Barstow Technical Support (McDonnell-Douglas)	10/84 - 9/86		400	400
PLANNING AND ASSESSMENT				
Documentation of Five Year Plan	6/83 - 4/85	100		
Solar Thermal Systems Analysis	10/84 - 1/86		370	
Central Receiver Cost Studies			100	

RELATION OF FY84 AND FY85 ACTIVITIES

All activities in the Solar Thermal Technology Program are now organized consistently according to the structure set up in the Five Year Research and Development Plan. This structure of eleven research tasks differs from the organization used to describe central receiver development activities in the FY84 AOP. Figure 7 illustrates the relationship of the FY84 and FY85 organization of program activities.

FY 85	FY 84: CRTF and MSEE	Controls	High Temp Receivers	High Temp Storage	Barstow	Repowering	Advanced Systems	Fuels and Chemicals	International	TPI
1 – Optical Materials										
2 – Concentrators										
3 – Receivers			X			X				
4 – Heat Engines										
5 – Direct Conversion Devices										
6 – Transport and Storage				X		X				
7 – Innovative Concepts										
8 – Balance of Plant		X								
9 – Central Receiver Systems	X					X	X	X	X	
10 – Distributed Receiver Systems									X	
11 – System Experiments	X				X				X	
Planning and Assessment										X

Figure 7. Relationship of FY84 and FY85 Activities