Advanced Turbine Systems Program Conceptual Design and Product Development

**Quarterly Report
August - October 1994**

January 1995

Work Performed Under Contract No.: DE-AC21-93MC30246

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
Solar Turbines, Incorporated
San Diego, California

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EXECUTIVE SUMMARY

This Quarterly Technical Progress report covers the period August 1, 1994 through October 31, 1994, for Phase II of the Advanced Turbine Systems (ATS) Program by Solar Turbines Incorporated under DoE Contract No. DE-AC21-93MC30246. The objective of Phase II of the ATS Program is to provide the conceptual design and product development plan for an ultra-high efficiency, environmentally superior and cost competitive industrial gas turbine system to be commercialized by the year 2000. A secondary objective is to begin early development of technologies critical to the success of ATS.

During the period covered by this report, Solar received the DOE's Solicitation for Cooperative Agreement Proposal (SCAP) titled, "Industrial Advanced Turbine Systems (ATS) Development and Demonstration," DE-SC21-94MC31173. During the allotted response period, Solar's ATS Team prepared and submitted a proposal meeting all requirements stated in the SCAP for ATS Phases III and IV.

A majority of Phase II technical activity during this period provided direct input to the proposal and resulted in on-time completion of the following tasks:

- Task 5, Market Study
- Task 6, System Definition and Analysis
- Task 7, Integrated Program Plan

A detailed technical account of work performed in these three tasks will appear in their respective Topical Reports.

During the period covered by this report, revision A003 to the subject contract increased the funding for Task 8 - "Design and Test of Critical Components." This task includes expanded materials and component research covering recuperators, combustion, autothermal fuel reformation, ceramics application and advanced gas turbine system controls. Progress on these items is discussed in this report.

As required by the subject contract, papers have been prepared by Solar's ATS Director, Dr. D.A.Rohy, and by Phase II Program Manager, K.W.Karstensen, for presentation in November at the ATS Annual Review.

Contract labor and cost status as of October 31, 1994:

- Labor: 15,137 hours versus 16,416 hours planned.
- Total Program Cost*: \$1,860K versus \$2,202K planned.

*Including Solar's contractual cost share.

- 7023 labor hours have been charged to an internally funded project directly related to ATS. This represents cost sharing of approximately \$632,000 in addition to that provided for in the contract.

1.0 WORK STATUS

Tasks 1, 2 and 3 have been completed and Topical Reports submitted.

1.1 TASK 4 - CONVERSION TO COAL

Work has begun on this task based on cycle conditions finalized for Solar's "ATS 50" intercooled and recuperated (ICR) gas turbines as well as for interim ATS designs being considered in response to the Phase III-IV SCAP.

With the final selection of a proposed ATS cycle, an evaluation of the applicability of the direct-fired system developed on a previous contract with DOE was started. The initial findings indicate that because the ATS cycle is recuperated, serious material problems with the primary zone and impact separator will be encountered. By richening the primary zone the outlet temperature can be reduced but with a possible deleterious effect on emissions. The conclusion at this point is that the direct-firing is not a viable option. Pressurized Fluidized Bed Combustion (PFBC) and gasification will be examined next.

1.2 TASK 5 - MARKET STUDY

During the period covered by this report, a major portion of the Task 5 effort was completed by Solar's two market study subcontractor/consultants and their results reviewed by Solar's ATS Marketing Team. A third market study, not funded by DOE, was prepared by Science Applications International Corporation (SAIC) for the California Gas Turbine Action Alliance (CGTAA). Selected results from all three studies were incorporated into Solar's ATS Phase III-IV proposal in order to demonstrate the market's capacity for providing ATS economic and environmental benefits via a Solar ATS. Detailed results of the two subcontracted market studies will be presented and interpreted in the Task 5 Topical Report.

1.3 TASK 6 - SYSTEM DEFINITION AND ANALYSIS

During preceding quarters, Task 3, titled "System Selection", defined an ATS uniquely suited to Solar's established marketplace and the company's technology base. This machine, an intercooled and recuperated (ICR) gas turbine, was designated "ATS50," denoting its thermal efficiency--50 percent. ATS 50's overall pressure ratio is 16 to 1, its firing temperature (TRIT) 2500° F (Figure 1). At these conditions, the major determinant in thermal efficiency is cooling air bleed. Due to their reduced cooling air requirements, the use of ceramic turbine airfoils results in a two-point increase in thermal efficiency over that attainable with cooled metal airfoils that could be developed within the ATS time frame (Figure 2).

Figure 1. ICR Thermal Efficiency vs PR at Lines of Constant TRIT One-Spool Configuration. The optimum efficiency is shown to be at Rc of 16:1, with a TRIT of 2500°F.

Figure 2. Thermal Efficiency of an ICR Gas Turbine as a Function of Cooling Air Flow

1.3.1 ATS Size Selection

At such time as the market study enables a choice of the exact size of an ATS to be proposed, the size (or sizes, if more than one is indicated) can be established through application of mechanical laws of scaling. These scaling laws operate as follows on gas turbine aero components:

- For constant rotor linear tip speeds, geometrically similar components will operate with:
 - Identical Pressure Ratios
 - Identical Efficiencies
 - Identical Stresses
 - Comparable Metal Temperatures

- Rotational speeds will scale inversely proportional to linear dimension.
- Air flow and power will scale with the square of linear dimension.

Heat transfer components such as intercoolers, recuperators or cooled airfoils will scale differently because the quantity of heat in place at any given location will vary with the cube of a linear dimension and the size of the heat transfer path scales with the its square. This does not affect the application of the rules for scaling aero components and heat transfer designs will be "thermally" similar but geometrically some-what dissimilar.

Scaling is not applied to standard hardware such as fasteners and tubing. It may also be intentionally set aside where performance advantages are available in the larger scales through relatively reduced airfoil leading and trailing edge thickness, endwall clearances and surface finish.

1.3.2 ATS Power Plant Integration

The concept cross section of Figure 3 shows an ICR gas turbine for a 12 MWe ATS system. This two shaft gas turbine has a variable area power turbine nozzle. The combustion system is a gas fueled, nine can annular ultra-lean premix design retrofittable to catalytic combustion. The approach to structural design follows proven industrial gas turbine practice. Structures are sized to provide the necessary rigidity to preserve optimum alignment of components through the entire range of transient and steady state thermal expansions.

The industrial gas turbine practice of using hydrodynamic mainshaft bearings is continued in Solar's ATS rather than changing over to rolling element bearings. While the latter offer a small reduction in power loss, they lack the damping capability, long life and general robustness of hydrodynamic bearings. Solar's tilting pad bearing designs also have an ability to accept levels of misalignment that would result in severe overloading of rolling element bearings.

Mainshaft sealing in current Solar gas turbines is by air-buffered labyrinth seals. This type of seal is low in cost and rugged under operational conditions. Acceptable alternatives, such as face seals, will be sought during the ATS development program that will eliminate the loss to the cycle resulting from buffering air bleed and will also reduce fugitive emissions from the oil tank.

1.3.3 ATS System Integration (Packaging)

During the period covered by this report, Solar's ATS Team further developed the concept of packaging "ATS50" into an integrated gas turbine generator system. The previous quarterly report showed an outline drawing of a 12 MWe ATS generator set. This concept has now been developed into the 3D definition shown in Figure 4.

Figure 3. Solar's ICR Core Gas Turbine Cross-Section

Efficiency improvement in a fully integrated system such as that shown in Figure 4 goes beyond the boundary of the gas turbine prime mover itself by reducing parasitic losses in the associated systems. Such reductions achieved in the system shown in Figure 4 include:

- Demand-driven variable speed lube and servo pumps, eliminating the loss from dumping excess oil flow over relief valves.
- A less restrictive inlet system.
- Integration of the reduction gear and generator eliminating one entire bearing and its associated power loss.

Careful attention has also been given to product cost in defining the integrated ATS system shown in Figure 4. Typically, in versions of this system in current production, the in-plant cost of the gas turbine prime mover itself amounts to less than half of the total system cost. Thus, cost effective gas turbine design must be supported by cost effective system integration in order to meet ATS lifetime cost goals.

1.4 TASK 7 - INTEGRATED PROGRAM PLAN

During the quarter covered by this report, the majority of effort completing both Task 6 and Task 7, coincided with the preparation of Solar's ATS Phase III-IV proposal. Task 6 undertook to apply the technologies and principles invoked in completing Task 3 toward the definition of a commercially viable predecessor to "ATS50" that would meet or exceed the requirements of the Phase III-IV SCAP. Task 7 activity resulted in a development plan for Solar's ATS that will deliver ATS hardware to field test in the time frame required by the

Figure 4. ICR Gas Turbine Integrated Into an ATS System

SCAP while managing technical risk with a carefully planned array of back-up technical elements. A detailed account of Task 6 and 7 activity and results will be provided in the Topical Reports for these two tasks.

1.5 TASK 8 - DESIGN AND TEST OF CRITICAL COMPONENTS

The major Task 8-related event during the quarter was additional funding by DOE for Task 8. This addition is defined by Revision A003 to Contract No. DE-AC21-93MC30246. This action reflects the DOE's recognition of the value of early validation of technologies which are key to the timely commercial introduction of a new product. The following discussion describes activity during this quarter in the nine subtasks in Task 8.

1.5.1 Subtask 8.1 - Low Pressure Drop Recuperator

During the period covered by this report shakedown and baseline tests were completed at the Caterpillar Technical Center on the recuperator performance and f and j rigs. Additional thin foil creep test were also completed for Type 347 Stainless Steel and Inconel 625 recuperator materials. The large scale folded fin strain test rig has been assembled and calibrated.

The f and j rig is used to obtain Fanning Friction Factor (F) and Colburn modulus (J) data for the primary surface geometry for both air and gas side geometries. This rig has been run using a core surface of known performance. The data from this "standard" surface agreed extremely well with previous tests that used the identical surface. An air inlet mixer, used to minimize minute thermal gradients in the room air, is being added, as recommended by Professor Moffat of Stanford University.

Thin foil creep data are needed to define the operating limits, as far as creep failure is concerned, for various recuperator materials. Several tests have been run while others are in progress.

Table 1 and Table 2 describe the thin foil creep tests that have been completed and those currently in progress. The results from these tests will be used to generate recuperator thin foil design curves for high temperature applications.

The equipment necessary to perform the flattened tube test has been calibrated, set up for the static testing conditions, and the experiment is now underway. Strain data will be collected in the areas of highest stress and will then be used to calibrate and verify the folded profile strain model. This is done by using strain gages on a scaled-up model of the folded profile since the actual size of the recuperator folded sheet is much too small to instrument. Tubes of various thickness (0.0030 to 0.0045-inch) will be employed.

A flattened tube simulates a scaled-up cross-section of the recuperator primary sheet folded profile. The objective is to directly obtain strain data to calibrate and validate an in-house strain model. Scaled tubes are needed to provide a sufficiently large-scale model for the attachment of strain gages.

The room temperature yield portion of this test has been completed and the results are currently being documented. The yield pressure was larger than predicted values. Therefore, a higher pressure -- 100 psi -- was selected for the high temperature portion of the test.

To reduce the effects on electronic equipment of external variables, such as noise and ambient temperature fluctuations, the test was relocated to another site. The instrumentation is being set up again and once it has been verified that it is functioning properly, the high temperature test will be conducted.

Table 1. Thin Foil Creep Test Results

Test No.	Direction	Material	Thickness (inch)	Stress (psi)	Temp (F)	5% creep Calcul. HRS	5% Creep Actual HRS	Stress at Rupture Actual HRS
#4	Long	SS 347	0.003	17000	1300	127	165	194
#7	Trans	SS 347	0.003	17000	1300	127	224	251
#17	Long	SS 347	0.003	17000	1250	560	a	725
#18	Trans	SS 347	0.008	17000	1250	560	960	1025
#19	Unknw	SS 347	0.003	14000	1300	277	b	490
#20	Trans	SS 347	0.003	14000	1300	277	700	1020
#21	Unknw	SS 347	0.0025	11000	1300	649		
#22	Unknw	SS 347	0.0025	11000	1300	649		
#23	Unknw	SS 347	0.0025	9000	1300	1170		
#24	Unknw	SS 347	0.0032	12000	1250	2154		3240
#25	Trans	Inconel 625	0.0037	30000	1330	1344 ^c	111	436
#26	Long	Inconel 625	0.003	11000	1440	3360 ^c	727	d
#27	Trans	Inconel 625	0.003	11000	1440	3360 ^c	639	1055 ^g
#28	Trans	Inconel 625	0.003	8000	1480	4569 ^c	445	698.5 ^g
#29	Long	Inconel 625	0.003	8000	1480	4569 ^c	406	671 ^g
#30	TBD	SS 347	0.0035	7000	1350	2065		
#31	Long	Inconel 625	0.0035	20000	1350	700		
#32	Trans	Inconel 625	0.0035	20000	1350	700		
#33	Long	Inconel 625	0.0035	30000	1330	1344 ^c		

- a - Ruptured at 2.5% Creep. b - Ruptured at 3.5% Creep.
c- The data is for 0.008 inch foil.
d- The test coupon did not fail. The test stopped after 18% creep.
g- This is the 10% creep value. The test coupon did not fail.

Table 2. Thin Foil Creep Test Results

Test No.	Direction	Material	t (in)	Stress(psi)	Temp(F)	5%Creep Calcul. HRS	5%Creep Actual HRS	Rupture Actual HRS
#3	Unkwn	SS 347	0.0032	17000	1300	127	166	195
#4	Long	SS 347	0.0032	17000	1300	127	165	194
#6	Long	SS 347	0.0032	17000	1200	2715	k	1500
#7	Trans	SS 347	0.0032	17000	1300	127	224	251
#8	Unkwn	SS 347	0.0032	17000	1200	2715	2391	2630
#9	Trans	SS 347	0.0032	17000	1200	2715	l	1203
#12	Long	SS 347	0.0032	17000	1250	560	i	842
#13	Trans	SS 347	0.0032	17000	1250	560	j	842
#14	Long	SS 347	0.0032	17000	1250	560	l	460
#16	Trans	SS 347	0.0032	14000	1300	277	h	220
#17	Long	SS 347	0.003	17000	1250	560	a	725
#18	Trans	SS 347	0.003	17000	1250	560	960	1025
#19	Unkwn	SS 347	0.003	14000	1300	277	b	490
#20	Trans	SS 347	0.003	14000	1300	277	700	1020
#21	Unkwn	SS 347	0.0025	11000	1300	649	1331	2080
#22	Unkwn	SS 347	0.0025	11000	1300	649	e	3773
#23	Unkwn	SS 347	0.0025	9000	1300	1170		
#24	Unkwn	SS 347	0.0032	12000	1250	2154	2687	3158
#25	Trans	Inconel 625	0.0037	30000	1330	1344c	109	436
#26	Long	Inconel 625	0.003	11000	1440	3360c	739	d
#27	Trans	Inconel 625	0.003	11000	1440	3360c	639	1055g

Table 2. Thin Foil Creep Test Results (Continued)

Test No.	Direction	Material	t (in)	Stress(psi)	Temp(F)	5%Creep Calcul. HRS	5%Creep Actual HRS	Rupture Actual HRS
#28	Trans	Inconel 625	0.003	8000	1480	4569c	445	699g
#29	Long	Inconel 625	0.003	8000	1480	4569c	406	671g
#30	TBD	SS 347	0.0035	7000	1350	2065		
#31	Long	Inconel 625	0.0035	20000	1350	700		
#32	Trans	Inconel 625	0.0035	20000	1350	700		
#33	Long	Inconel 625	0.0035	30000	1330	1344C		

a-Ruptured at 2.5% creep.

b-Ruptured at 3.5% creep.

c-The data is for 0.008 inch foil.

d-The test coupon did not fail. The test stopped after 18% creep.

e-Ruptured at 4.4% creep.

f-Ruptured at 0.8% creep.

g-This is the 10% creep value. The test coupon did not fail.

h-Ruptured at 3.1% creep.

i-Ruptured at 3.8% creep.

j-Ruptured at 2.5% creep.

k-Ruptured at 1.55% creep.

l-Ruptured at 0.87% creep.

Currently, the finite element model of the flattened tube is being modified for an ANSYS creep analysis to predict the number of hours and the creep rate for the flattened tube test. It will also provide enough data for comparison of the test and theoretical results. The ANSYS creep analysis of the flattened tube will use the experimental constant obtained from the creep test of the material thin foil coupons.

1.5.2 Subtask 8.2 - Low Pattern Factor Combustors

Three additional tests were completed on the subscale catalytic combustor. Results of these test provided information for modifications of the catalyst bed leading to reduction of CO and UHC emissions commensurate with the very low NOx emissions already achieved.

Preparations for testing the subscale catalytic reactor with a longer bed of 9.5 inch (versus 6.5 inch) have been completed. A new catalyst bed has been fabricated and received at

Solar and installation is underway. The fuel profile entering the catalyst bed has been measured again and the fuel tubes have been modified to improve the variation in radial fuel concentration to within $\pm 2.4\%$. Testing will begin shortly.

1.5.3 Subtask 8.3 - Autothermal Fuel Reformer (ATR)

The ATR test rig is being fabricated. Quotes of ceramic monolith catalysts used for the rig testing have been received from suppliers. The active catalytic materials will be deposited on the inner surface of the monolith channels to extend the contact area. The rig tests are designed to investigate the combustion efficiency, emission levels, pressure drop, and flame stability. Hastelloy tubes are inserted through the ceramic refractory lining for inlet air paths. Preparation of the rig testing at the existing test facilities is under way.

Additional tests are being performed with the existing equipment to evaluate sulfur tolerance on the autothermal fuel reforming catalysts. Fuel was mixed with hydrogen sulfide (H_2S) with a concentration of 200 ppm, compared to 1 ppm H_2S containing in the local natural gas. The initial test results indicate over 70 per cent of hydrogen produced with no deactivity on the testing catalyst. Regeneration of spent catalysts by steaming as well as study of the effect of a dual oxide absorbent for controlling sulfur poison are under way.

Additional tests of autothermal fuel reformation were conducted to evaluate the effect of a dual-oxide absorbent on the performance of the reforming catalyst. An absorbent consisting of zinc and calcium oxides was selected for removing acidic species (H_2S , HCl , etc.) in the raw natural gas and serving as a polishing step to ensure a constant quality of gas turbine fuel. The test results showed that fuel reformation produces a high hydrogen content of product gas under the absorbent steady-state operation. Testing is continued to fully investigate the effects of absorbent on the catalyst active life and sulfur-poisoning control.

1.5.4 Subtask 8.4 - Dual Property Turbine Disk

Significant work has been performed over the last 3 months on the Dual-Property Turbine Disk Program using Solar internal funding, plus DOE Task 8.4 funding. The major issue being addressed is the viability of the originally proposed Vacuum Plasma Structural Deposition (Howmet VPSD) process for producing large diameter dual-property turbine disks. It has been concluded that the large diameter disks required by Solar's proposed ATS gas turbine exceed the capability of the VPSD process. Additionally, it was determined that attaching these large size rim and hub components would best be accomplished by a solid-to-solid bonding technique. A revised program is being finalized by Howmet to develop a solid-to-solid bonding process which encompasses both Solar's proposed ATS gas turbine as well as smaller designs applicable for retrofit to existing product. The goal of the original program has not changed, only the fabrication technique to achieve that goal has changed. The up-dated program will fit the same cost and schedule requirements of the original Task 8.4, and will feed directly into the ATS Phase III Program as before.

1.5.5 Subtask 8.5 - Low Emissions Combustor

Design activity for the full-scale catalytic combustor rig has begun and will be the dominant activity over the early portion of the next quarter.

1.5.6 Subtask 8.6 - Total Plant Controls

Work has started on this subtask. Initial efforts entailed configuring Solar's Systems Engineering computers to work with the software required in developing the Man-Machine Interface (MMI). Writing of a design specification for the MMI has also begun.

Next, the development operating system hardware and software was procured and installed. The ATS development Application Server sub-network was installed along with developer workstations for executing the proof-of-concept task. This equipment has been tested and the development of communication protocol between the Allen Bradley PLC and MMI is underway. Specification of software development standards has also begun.

1.5.7 Subtask 8.7 - Recuperator Materials

Survey and test preparation portions of the subtask were started. Foils have been ordered for each of the candidate materials and test samples will be prepared upon their receipt.

The recuperator materials program includes evaluating several potential recuperator materials for higher temperature and higher pressure operation. These tests include tensile, oxidation and creep tests. All of the tensile tests have been completed, the oxidation tests are in progress and short-term creep tests of the materials will begin shortly. The tensile data are currently being evaluated. All of these tests are scheduled to be complete by February '95 at which point a down-selection of materials will occur. A list of the materials under current evaluation are shown in Table 3.

1.5.8 Subtask 8.8 - Low Cost Combustor Materials

This subtask has been retitled from "Reheat Combustor Materials" since there is no reheat combustor included in Solar's ATS. This is a change of nomenclature only; there is no change to the proposed statement of work to the DOE.

Three candidate materials (B-30 from LoTEC, Altra KVS 16 from International Thermoproducts, and System 2.2 from AEA Technology) were identified in the proposal phase. Parts will be ordered at the beginning of November. Requirements for the test rig are also being identified.

The statement of work from one of the three material suppliers AEA Technology requires modification to be in full support of the contract statement of work. SOW 's from the other two, LoTEC and International Thermoproducts, are acceptable. All test articles will be ordered in November. Test rig requirements are currently being identified.

Table 3. Recuperator Alloy Candidates

Material Class	Material
Iron/Chromium/Nickel alloys	347 Stainless steel
	RA 85H
Iron/Cobalt based	N-155
Nickel/Chromium and Nickel/Chromium/Iron alloys	Inconel 600
	Incoloy 800
	Incoloy 825
Nickel/Chromium/Molybdenum	Inconel 625
	Hastelloy-X
Nickel/Chromium/Tungsten/Molybdenum	Haynes 230
	RA-333

1.5.9 Subtask 8.9 - Advanced Ceramic Materials

The statement of work for this subtask has been reviewed and Solar finds that a small modification is indicated as a result of completion of Task 6. There are two subjects included in this project – a combustor duct and a turbine blade. The ATS defined in Task 6 does not include the proposed combustor duct. It does, however, include a turbine interstage duct that is a candidate application for the material to be developed in this subtask. The alternative is a metal duct which would require cooling. Thus, successful application of a ceramic composite will improve ATS performance.

This change does not require any change to the statement of work or to the labor or cost expenditure for subtask 8.9.

2.0 PROGRAM SCHEDULE AND BUDGET

2.1.1 Schedule

As of October 31, 1994, Solar's Phase II ATS program is approximately one month late to plan. Tasks 5, 6 and 7 are approximately on plan. Task 8 work is approximately one month late to plan, "plan" having been set by a fixed start date for the Revision A003 work rather than on an "ARO" (after receipt of order) basis. At this point it appears that ATS Phase II work will be completed on or slightly ahead of schedule (11/30/95).

2.1.2 Budget

As of October 31, 1994, a total of 15,137 labor hours were charged to the contract versus 16,416 hours planned. This is reflected in a total program cost (including Solar's contractual cost share) as of the same date of \$1,860K versus \$2,202K planned. This apparent underrun is temporary and reflects the "late to plan" status cited above. At this point Solar's ATS Phase II work is expected to be completed within the labor hours and cost currently budgeted in the contract as amended by Revision A003.

In addition to the charges to the contract, an additional 7023 labor hours have been charged to an internally funded project directly related to ATS. This represents cost sharing of approximately \$632,000 in addition to that provided for in the contract.

3.0 FUTURE INVESTIGATIONS

During the next quarter, Topical Reports will be submitted for Task 5 (Market Study), Task 6 (System Definition and Analysis) and Task 7 (Integrated Program Plan). Task 4 (Conversion to Coal) will be completed and the required Topical Report submitted. This reduces Phase II to the completion of the nine Task 8 technology subtasks. These will continue per Revision A003 to the contract.

A briefing to DOE representatives is planned for January of 1995 which will summarize the final results of Tasks 5, 6 and 7 and also present the status of the nine Task 8 elements. The major theme of the latter will be to illustrate the firm connection between the results of these efforts and the Phase III ATS design efforts as well as to identify the application of these results to current Solar product.

APPENDIX 1

GLOSSARY

ACE	<u>Advanced Component Efficiency</u> . A Solar-funded multi-disciplinary, advanced technology program. It currently includes programs on compressors, turbines, cooling, and ducting.
ATS	<u>Advanced Turbine System</u> . A gas turbine-based energy conversion system as defined To the U. S. Congress by the U. S. Department of Energy (DOE). An ATS is distinguished from current gas turbines by markedly increased thermal efficiency, reliability, availability and maintainability and by decreased exhaust emissions and cost of power produced.
ATS50	Solar's designation for an ATS designed to meet the contract goal of 50 percent thermal efficiency.
ATS60	Solar's designation for an ATS designed to meet a "stretch" goal of 60 percent thermal efficiency.
BASELOAD	Typically describes a specific number of operating hours the power generation system is operating. In this case it represents (on average) 6500 hours.
BZP	<u>Barium Zirconium Phosphate</u> . A family of materials whose composition can be tailored to result in low, or zero, coefficient of thermal expansion. It is resistant to thermal shock, and is stable to 1200°C.
CFATS	<u>Coal-Fired Advanced Turbine System</u> . An advanced turbine system modified to operate on coal or coal derived fuel.
CFCC	<u>Continuous Fiber-Reinforced Ceramic Composite</u> . A high temperature composite material which consists of a ceramic matrix reinforced with fabric, tape, or rows of a high modulus fiber. CFCC's are typically not as flaw sensitive as monolithic ceramics, and can be fabricated into large parts such as combustion chambers.
CHORD	The axial length of an airfoil measured along a line drawn tangent to the leading- and trailing-edge radii. Chord is the characteristic dimension used in scaling of airfoils.
CSGT	<u>Ceramic Stationary Gas Turbine</u> . A DOE-funded program contracted to Solar Turbines Incorporated. The program goal is to demonstrate improved performance of a production gas turbine by retrofitting key components with ceramic counterparts for a 4000-hour field test.
EDX	<u>Electron Dispersive Xray</u> . A process conducted using a specially equipped Scanning Electron Microscope (SEM) whereby a "semi-quantitative" analysis of the subject alloy by element is obtained.

EFFECTIVENESS	(ϵ_r for recuperator, ϵ , for intercooler). A characteristic of a heat exchanger – the ratio of the amount of heat transferred to the total heat available in the hot fluid between its entry temperature and the entry temperature of the cold fluid.
EFFICIENCY, COMPRESSOR	(η_c). Ratio of the work imparted to the air flow to the total work input. Unless otherwise specified, "adiabatic" efficiency (subscript. - ad) is implied, i.e., flow conditions at both inlet and outlet are in terms of absolute, or total, pressure and temperature. "Polytropic" efficiency (subscript. - p) is the theoretical efficiency of a very large number of identical low pressure-ratio stages and essentially normalizes pressure ratio for comparison of differing compressors.
EFFICIENCY, THERMAL	(η_{th}). Also termed cycle efficiency. The ratio of energy input to energy output from a gas turbine. Unless specifically designated otherwise, thermal efficiency of an ATS will be defined on the basis of net power output from the turbine shaft.
EFFICIENCY, TURBINE	(η_t). Ratio of the work produced by a turbine to the work it extracts from the gas flow. When applied to a GP turbine, total-to-total efficiency is implied, this definition being based on total or absolute inlet and exit conditions. When applied to a power turbine, total-to-static efficiency is implied, thus accounting for static pressure recovery as a result of kinetic energy conversion in the exhaust diffuser.
FGM	Functionally Graded Material. A multi-layer material or coating system with each layer graded to provide different properties at the surface of the component relative to the core or substrate. An illustrative example would be a turbine tip-shroud with a top coating tailored for abrasability, an intermediate layer designed for oxidation resistance, and a substrate tailored for high strength.
GAS PRODUCER	(Abbr. GP) An element, or module, of a gas turbine which is required to provide a hot gas stream capable of propelling a power output turbine or other energy conversion device. As a minimum it consists of a compressor, a combustor, a turbine and associated shafting. Each of these components, in turn, may be of any of several types and may consist of one or more stages.
GPT	Gas Producer Turbine. May include HP and LP turbines.
GFATS	Gas-Fired Advanced Turbine System. An advanced turbine system which uses natural gas for fuel.
GP	See GAS PRODUCER.
HCF	High Cycle Fatigue. High cycle fatigue is characterized as the fatigue mechanism where vibratory loads are superimposed onto a steady state loading condition. The typical example is turbine blade under aero excitation. The turbine blade exhibits a significant steady state stress level due to the centrifugal load, where vibratory stresses are induced by high frequency pressure perturbations in the gas stream. Vibratory stress levels are typically

within the elastic range of the materials. Failures typically occur due to excitation at the component's natural frequency, setting up a resonant condition. This failure mode is associated with large numbers (10^5 - 10^7) of low stress amplitude cycles.

HIP	Hot Isostatic Pressing. A process for simultaneously heating a component, or powder metallurgy compact while subjecting it to isostatic pressure using an inert gas atmosphere. The temperature and pressure area are high enough to produce densification of the materials.
HP	High Pressure. This prefix is used to designate an individual section of a series pair of aerodynamic components operating in the high pressure regime of the two. HPC designates the high pressure compressor and HPT designates the high pressure turbine of an HP, or high pressure, spool.
INTERCOOLER	A heat exchanger placed between stages of compression in a gas turbine in order to remove heat from the compression air thereby reducing the temperature of air going to and through the succeeding stage(s).
I.O.U.	Investor Owned Utility. There are approximately 280 investor owned utilities in the United States. They are differentiated by the fact that they are owned through a stock ownership plan and are usually traded on the open market. they are more tightly regulated in their service area by regulatory bodies like public utility commissions than the Municipal utilities or the cooperative utilities.
IPP	Independent Power Producer. A non-regulated producer of electric energy. Currently the majority of these IPPs are larger power generation stations much like the Central Power Station that is owned by the Investor Owned Utilities.
LAC	Levelized Annual Cost. The name of the financial model used by the utilities to determine the cost of the capital equipment of the usable life of the equipment. Takes into consideration present worth arithmetic. Sometimes interchanged with book value analysis/life cycle analysis.
LCF	Low Cycle Fatigue. The fatigue mechanism typically associated with large thermal or mechanical loading. The cycles are typically a transient loading condition, such as start-up and shut-down of an engine. Low cycle fatigue is characterized by allowable pseudo elastic strain range for a material whereby a fatigue crack will develop after a specified number of cycles. typically LCF is considered cyclic loading of the base load leading to plastic deformation. Cycles are on the order of less than 10,000 to 15,000 cycles.
LP	Low Pressure. This prefix is used to designate the individual of a series pair of aerodynamic components operating in the lower pressure regime of the two. LPC designates the low pressure compressor and LPT designates the low pressure turbine of an LP, or low pressure, spool.

MCrAlY	A designation for an overlay coating applied to superalloy turbine components for increased oxidation and corrosion resistance. "McCrAlY" is derived from the elemental constituents of the coating i.e., Cr = Chromium, Al = Aluminum, Y = Yttrium M = Ni Fe or Co (depending on substrate).
NEPA	National Environmental Policy Act.
PATTERN FACTOR	(Abbr. PF). A parameter defining the range of temperatures extant in the exit gas flow from a gas turbine combustor. $PF = \frac{T_{MAX\ EX} - T_{AVG\ EX}}{T_{AVG\ EX} - T_{AVG\ INLET}}$ <p>All temperatures are absolute.</p>
PF	See PATTERN FACTOR.
PITCH	The circumferential distance between two adjacent airfoils in an axial turbomachinery annulus. It is equal to 2 times pi times the radius from the annulus centerline to the subject airfoil divided by the number of airfoils in the annulus.
POWER TURBINE	(Abbr. PT). A turbine stage in a gas turbine whose work output is used solely to drive the load with none being used by the compressor. In a 2-shaft gas turbine, the power turbine is fixed to a separate shaft from that of the GP turbine. It is normally -- but not required to be -- the last, or lowest pressure, turbine stage.
PR	Pressure Ratio. For a compressor or compressor stage, the ratio of outlet to inlet total pressure. For a turbine or turbine stage, the ratio of inlet to outlet total pressure.
PRIS	Particle Rejection Impact Separator. A device located between the primary and secondary zones of a rich-lean coal fired combustor which removes particulates from the gas stream.
PROFILE	The distribution of gas temperature within a single radial plane of a gas turbine combustor exit or other downstream annulus. The temperature profile represents the environment experienced by a turbine blade as it rotates through a temperature pattern thus averaging out circumferential variations. A "Profile Factor" can be defined using the Pattern Factor equation but confining the temperature data to a single radial plane.
PSR	Primary Surface Recuperator. Solar's proprietary design in which all heat exchange surfaces are "primary," i.e., transferring heat in their transverse direction. (A "secondary" surface, such as a fin, transfers heat in a lateral direction).
PT	See POWER TURBINE.

RECUPERATOR	A heat exchanger placed in the exhaust gas stream of a gas turbine in order to extract heat from the exhaust gases and return it to the cycle by heating the combustor inlet air. The term "recuperator" designates a static device as opposed to a "regenerator" which is a periodic device.
SHROUDED	A type of turbine blade design. A "shrouded" turbine features a short circumferential shroud segment attached to each blade tip. Together, these segments make up a full circular, rotating shroud. The outside surface of this shroud normally carries one or more circumferential seal elements. Conversely, a "non-shrouded" turbine is characterized by open blade tips rotating in close proximity to a stationary shroud.
SPOOL	The compression and expansion element of a gas producer, consisting of a compressor, a turbine and associated shafting. The turbine is designed so as to provide the amount of work required for the compression process plus any mechanical losses. A gas producer includes one or more spools and will be designated as 1-spool, 2-spool, etc.
SR	<u>Stress Rupture</u> . Stress rupture is the failure mechanism where gross rupture occurs due to time dependent deformation caused by steady stress at elevated temperatures. The mechanism at intermediate stages of deformation is called creep and is measured in terms of plastic strain. Stress rupture is usually associated with the Larson-Miller Parameter (LMP) which correlates the relationship between service life in hours and service temperature at a constant stress level. For a given material, Larson-Miller Parameter curves are developed which depict the LMP as a function of steady stress level.
STAGE WORK FACTOR	The ratio of work actually performed by a flow of cooling air within a turbine stage, to that possible if the flow were added to the hot gas stream.
STALL	A condition arising in one or more stages of an axial compressor in which the design pressure-velocity-rotational speed relationship is disrupted such that separation of the air flow from the blade contour occurs.
STANDBY	Use as a descriptor of a power generation station or unit that is only drawn upon when there is a demand. It currently is thought of as an emergency back-up unit in case the primary system fails, or when the primary unit cannot meet the load demand. Sometimes called an "on-demand" system.
SURGE	The condition occurring when a compressor is operated below its minimum stable air flow rate for a given rotational speed. Surge is characterized by cyclic backflow of air in the flowpath accompanied by violent pressure fluctuations. During surge all stages of the compressor will be in a stall condition.
TBC	<u>Thermal Barrier Coating</u> . A thermally insulating ceramic coating (ZrO_2) applied to superalloy combustor and airfoil components. The insulative properties of the coating allow increased turbine inlet temperatures while maintaining acceptable metal substrate temperatures.

T&D	Transmission and Distribution. The system used to get the power (or fuel) from the point of origin to the consumer.
TRIT	Turbine Rotor Inlet Temperature. The average gas temperature entering the rotor annulus of the first turbine stage in a gas turbine. It is less than the average combustor exit temperature due to the mixing of spent cooling air flow from upstream sources, primarily the first stage nozzle vanes.
TSSC	Two-Stage Slagging Combustor.
ZWEIFEL COEFFICIENT	A measure of turbine blade loading based on pitch/chord ratio and gas turning angle as independent variables.