5240-3
Photovoltaics Program
Technology Development and Applications
Lead Center

DOE/ET-20356-1
Distribution Category UC-63b

Systems Test Facilities Existing Capabilities Compilation

Robert Weaver

August 1, 1981

Prepared for
U.S. Department of Energy
Through an agreement with
National Aeronautics and Space Administration
by
Jet Propulsion Laboratory
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Pasadena, California

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ABSTRACT

Systems Test Facilities (STFs) are used to test total photovoltaic systems and their interfaces. STF Planning is contained in the Systems Development (SD) Plan. This report supports the SD Plan, being a compilation of existing and planned STFs, as well as subsystem and certain key component testing facilities, which are available to support the development of photovoltaic systems. The scope of this compilation includes photovoltaic systems in all application sectors, and government and private testing facilities. The sources that were investigated and summarized in the report are categorized as: Photovoltaics Program Field Centers, government agencies and centers, government-sponsored contract efforts, and private testing labs. Because photovoltaic system development is at an early stage but advancing rapidly, it is recommended that the existing capabilities compilation be annually updated to provide an assessment of the STF activity and to disseminate STF capabilities, status and availability to the Photovoltaics Program.

ACKNOWLEDGMENT

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Inquiries regarding material contained herein should be addressed to Kent Volkmer at JPL.

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EXECUTIVE SUMMARY

A. INTRODUCTION

To meet the goals of the National Photovoltaics Multi-Year Program Plan (MYPP) a number of evaluation, environmental and performance tests of systems, subsystems and components must be conducted during the next few years. An insufficiency in either the number or the capabilities of test facilities could result in delays in the program. This report is a compilation of existing test facilities and their respective capabilities.*

B. DISCUSSION

Thirteen test installations were contacted by mail or phone and were asked to respond to a series of questions relating to their test capabilities. Of the thirteen queried, five were program Field Centers, two were state operated agencies and six were private testing laboratories, one of which declared no photovoltaic capabilities. Tables 1 and 2 present an overview of the existing facilities.

The two state agencies, Florida Solar Energy Center and Southwest Research Institute, did not have photovoltaics test capabilities but were oriented towards solar thermal testing. Their services and experience may be of use for possible PV/T testing.

Four of the five Program Field Centers indicated a total system test capability. This means that the arrays, power processing units, controls and distribution equipment for a particular system design can be installed and operated for the purpose of obtaining the data required for performance evaluation. In addition to total system testing, each of the four indicated that subsystems could be tested independently. This allows performance evaluations of either arrays, power processing units or controls to be made independently of each other. This type of testing is required to determine the effects of one subsystem on the performance of another and leads to the establishing of interface requirements. The application sector testing capabilities of each center are as indicated in Table 1. It should be noted that the Jet Propulsion Laboratory has only module test capabilities.

The five private laboratories surveyed indicated extensive experience in environmental and accelerated life testing of components and small subsystems. Whereas this experience has not been directly related

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*The Residential Experiment Stations (RES) within the Massachusetts Institute of Technology (MIT) effort are not included in this compilation because they are designed for the purpose of conducting an operational experiment for a specific system. This differs from a System Test Facility (STF) in that an STF is designed to accept and test different systems and subsystems. This is not to say that the data from RESs will not be used in the overall systems development effort.

to photovoltaics, it indicates a capability applicable to the testing needs of the Program. These private laboratories represent a resource to the Program in that they have designed and conducted tests and experiments in areas related to the needs of the Program.

C. CONCLUSIONS

The following is a list of the conclusions:

(1) The limited number of facilities capable of total system testing may impact the MYPP schedule because several prototype systems will be tested simultaneously.

(2) Alternative means for total systems testing should be explored.

(3) There are sufficient facilities available to perform the component and subsystem evaluation tests for evaluation of environmental and accelerated life performance effects.

(4) It is recommended that this STF Existing Capabilities compilation be updated annually to reflect the on-going effort and be a service to industry.

Table 1. Facility Information: Field Centers and State Agencies

Managing Agency or Company	Location	Application* Sector(s)	Maximum Power kW
NASA/Lewis Research Center	Cleveland, Ohio 44135	RS - U	30
MIT/Lincoln Laboratory	Lexington, Massachusetts 02173	RS, R, I - U	10
MIT/Lincoln Laboratory	Concord, Massachusetts 02173	RS, R, I - U	(Included above)
Sandia National Laboratories	Albuquerque, New Mexico 87185	RS, R, I, CS - U	150
Jet Propulsion Laboratory	Pasadena, California 91003	Modules	1
Brookhaven National Laboratory	Upton, New York 11973	R, RS	10
Florida Solar Energy Center	Cape Canaveral, Florida 32920	Solar Thermal Only	
Southwest Research Institute	San Antonio, Texas	Solar Thermal Only	

*RS - Remote - Stand Alone
R - Residential
I - Intermediate
CS - Central Station
U - Utility Interface Capability

Table 2. Facility Information: Private Laboratories

Company	Location(s)	Comments
AETL	Encino, California 91436	A general purpose environmental test laboratory - sand, dust, vibration, shock, etc. AETL is a division of National Technical Services Co. Capabilities vary from site to site. AETL has five sites in Southern California with varying capabilities and size.
Acton Energy Laboratory	Acton, Massachusetts 01720	Test procedures are generated using customer provided test plans. Some solar thermal experience. No current plans for photovoltaics. Facility Size 3200 m^2.
Franklin Research Center	Philadelphia, Pennsylvania 19103	Non-Profit. Facility Size: 19,000 m^2. Experience relative to tracking and control of electrical output and utility interface. Some research relative to development of thermal collectors.
Structural Dynamics Research Corp.	Milford, Ohio 45515	Facility Size: 800 m^2. Mechanical and structural engineering consulting company - primarily failure and fatigue through analysis and testing.
Wyle Laboratories	Huntsville, Alabama 35807	Environmental testing capabilities include accelerated; power conditioner testing to 27 kW DC; load capability to 100 kW.

SECTION I

INTRODUCTION

A. BACKGROUND

Concerted efforts toward the application of photovoltaics technology to terrestrial power generation began in the early 1970s. Initial emphasis was placed on reducing the cost of the photovoltaic cell, the major cost driver. As efforts proceeded in finding and implementing low cost photovoltaic cell manufacturing and packaging processes, additional emphasis was then placed on the use of photovoltaic cells in power generating systems. It was soon determined that existing tools developed for space applications were inadequate for estimating system performance and that testing was required to evaluate system designs. To address this issue, the Photovoltaic Program participants began planning and implementing systems test facilities (STFs)*.

In the summer of 1978, the major participants in photovoltaic testing -- NASA Lewis Research Center (LeRC); NASA Jet Propulsion Laboratory (JPL), Low-Cost Solar Array (LSA) Project; MIT Lincoln Laboratory (MIT/LL); and Sandia Laboratories - formed a working committee to plan and coordinate future system testing and activities. A major conclusion of the committee was that a comprehensive plan for system testing could not be developed because of the absence of an overall photovoltaic program plan.

Subsequently, the Multi-Year Program Plan (MYPP), a plan for the overall direction of the Photovoltaics Program, was drafted and JPL was assigned the role of Technology Development and Application (TD&A) Lead Center. As the TD&A Lead Center, JPL was given the responsibility for the planning and coordination of STFs for the Photovoltaics Program.

To meet the goals of the MYPP, the Photovoltaics TD&A Program require the use of additional STFs over the next few years. To provide program coordination for adequate and timely planning and utilization of STFs, the TD&A Lead Center has developed the approach of compiling the existing capabilities for STFs and developing multi-year STF planning. This STF Existing Capabilities Compilation summarizes the current and planned STF capabilities of the Photovoltaics Program, the government, and private industry. Multi-year STF planning is contained in the Systems Development (SD) Plan as a task supportive of achieving the MYPP system and delivered energy price goals.

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*Acronyms and abbreviations used in this document are defined in Appendix A.

B. OBJECTIVE

The objective of this Systems Test Facilities Existing Capabilities Compilation is to survey* and catalog present and planned capabilities of STFs as well as subsystem and major component testing facilities. This objective is part of the overall STF program objectives described in Section III.

C. PURPOSE/USERS

The purpose of this compilation is to disseminate information to the Photovoltaics Program and industry regarding photovoltaic system, subsystem and component testing capabilities, and their status and availability. The capabilities of these testing facilities and their availability will be needed by the Program and industry alike to support the development of photovoltaic systems.

Test facilities are required by the Photovoltaics Program to determine if technological goals and objectives are being met on a timely basis. Facilities must be available and capable of performing the required tests of systems, subsystems and components that are being developed for the program. This document will assist the planning of facility scheduling, and, if necessary, construction.

D. SCOPE

The information in this compilation was obtained through surveys sent to the Photovoltaics Program Field Centers, state-sponsored facilities and private testing laboratories. The results of those surveys, presented herein, encompass the following areas of concern:

(1) All application sectors--residential, intermediate, central station, and remote.

(2) Grid connected and stand-alone systems.

(3) Test level--total system, subsystem or component.

(4) Facility ratings--maximum power handling capability, thermal capacity, storage, etc.

(5) Measurement capability as to type and accuracy, when applicable.

This compilation also includes subsystem and component (environmental, product approval, and accelerated-life) testing facilities.

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*A list of the facilities surveyed is in Appendix B.

Although not a part of system testing, these facilities are important elements of system development and are therefore included. Currently, most testing of established products is performed at the subsystem and product approval levels. As more is learned about the system-subsystem interactions and how to better model and simulate those interactions, less emphasis will be placed on system-level testing and more placed on subsystem and product approval testing.

E. DEFINITIONS

Terms used in this compilation are defined below:

(1) Systems Test Facility (STF). A facility that tests and evaluates the performance of total photovoltaic systems and their interfaces.

(2) Subsystem Test Facility. A facility that tests and evaluates the performance of photovoltaic subsystems. Currently there are three subsystems: array, power processing, and energy storage.

(3) Component Test Facility. A facility that tests and evaluates the performance of photovoltaic system components, which are elements of subsystems. Component testing includes environmental, product approval, and accelerated-life testing.

(4) Environmental Testing. Testing which attempts to simulate failure mechanisms caused by extremes of loads induced by environmental forces, either acting alone or in combination.

(5) Product Approval Testing. Testing which is performed in fulfillment of the requirements of regulatory agencies. These tests are performed under industry consensus test standards. Where regulatory agencies have not established codes or requirements, temporary standards will be developed. The successful passage of these tests indicates a product which can be marketed subject to the approval of local regulatory bodies.

(6) Accelerated-Life Testing. Testing which attempts to accelerate long-term degradation effects and, in so doing, correlates that degradation with time.

(7) Programmatic Facilities. Test facilities that are directly owned or sponsored by the federal government and are a part of the National Photovoltaics Program.

(8) Non-Programmatic Facilities. Test facilities that are either owned and operated by a state or agency thereof or are privately owned. These facilities are available to the program on a contract basis as required.

SECTION II

SYSTEMS TESTING FACILITY DESCRIPTION

A. PURPOSE AND FUNCTION

The purpose of an STF is to test and evaluate total photovoltaic systems and their interfaces.

The direct function of an STF is to evaluate photovoltaic system performance, concepts, and interfaces and system/subsystem interactions.

The indirect functions of an STF are to verify photovoltaic system and subsystem performance requirements, modeling and simulation, and to identify areas for further technology development.

STFs are testing and evaluation facilities. By testing total photovoltaic systems and their interfaces, an evaluation can be made of the performance of the systems. By having repeatable and standardized procedures, different photovoltaic system concepts can be evaluated for later comparison. Interfaces and system/subsystem interactions can be monitored and evaluated for later comparison with modeling results. These are "direct functions" of an STF because they are performed at a test facility.

The "indirect functions" come as a result of the testing performed at an STF. This is the verification of the design of the photovoltaic system and/or subsystems through testing results. Based on these results, performance requirements included in the design are evaluated against test results, with any deviations factored back into the design, either through redesign or upgrading of the current design. Additionally, modeling and simulation results are checked to see if they accurately predict performance. Refinement of models to meet test data will eventually enable full-scale system testing to be reduced. As a result of this verification process, new areas for technology development will be identified for that equipment which does not meet the expectations or desired results of the Photovoltaics Program or the industry.

B. RATIONALE

In the development of photovoltaics as a new energy source for the United States, the design of terrestrial systems is quite new. Modeling and simulation have been used to help design these systems prior to their deployment. However, when deployed, these systems did not always perform to the expectations of the analysis; sometimes new problems were discovered, such as interactions between the system and the operational environment and between subsystems. To address these issues, some form of testing and evaluation of real systems under actual conditions is mandatory to evaluate photovoltaic systems before they enter the market place. This need is fulfilled by STF.

STFs need two traits to operate in the manner decribed above. The first trait is to be "behind-the-fence," that is, to be in a facility with limited public access. The "behind-the-fence" categorization is consistent with the normal industry practice of proprietary test results. Once the system or subsystems are developed, they are placed or tested in "outside-the-fence," publicly-visible experiments or experiment stations.

The second trait is that the facility must be adaptable to many different configurations of photovoltaic systems and, in turn, must be capable of being readily changed to facilitate on-the-spot system changes and reconfiguring. To be effective, an STF must be able to test many combinations of photovoltaic modules and arrays, including photovoltaic and thermal systems (whether side-by-side or combined), concentrators, photovoltaic systems with storage, and combinations of these. Additionally, since system evaluation is a function of an STF, the STF must be capable of accepting rapid changes in system design and configuration to permit retesting and evaluation. This latter characteristic is termed "bread-boarding".

With these characteristics, the Systems Test Facility becomes a powerful tool for quickly evaluating prototype photovoltaic system and subsystem designs for the Photovoltaics Program and industry which, in turn, supports the overall system development goals contained in the MYPP.

C. IMPLEMENTATION

The following discusses key elements involved in the programmatic implementation of STFs.

(1) Configuration. In its most general form, a photovoltaic system could be configured as shown in Figure 3-1. Both electrical and thermal systems are involved. This requires an STF to be highly adaptable, able to reconfigure its test bed quickly to accommodate and test a completely different system once the testing of the previous system is complete. Additionally, STFs must be able to simulate different forms of mounting to test and evaluate installation concepts. All of these must be considered when selecting an STF for use or, from the programmatic viewpoint, a new STF.

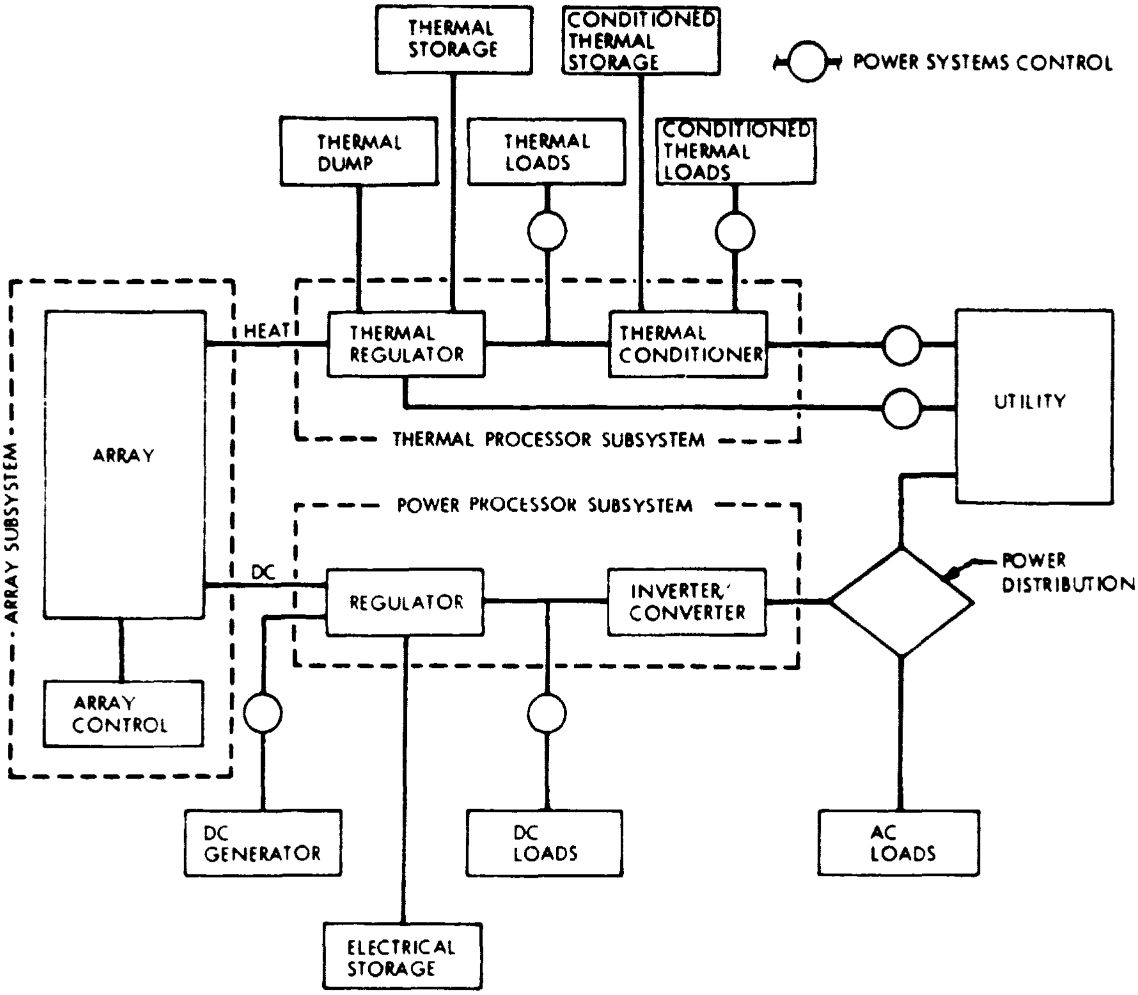

Figure 3-1. Generalized Photovoltaic System

(2) Test Procedure and Equipment. Commonality of test equipment and procedures is not only desirable, it is mandatory. With STFs in many climates testing photovoltaic systems, there must be commonality in the test and evaluation methods to ensure uniformity of results. It is not adequate to have systems evaluated using different test procedures with equipment of different capability and accuracy. Accordingly, programmatic STFs will be using the test procedures being developed through the Solar Energy Research Institute (SERI) managed Performance Criteria and Test Standards (PC&TS) activity. When the Interim Performance Criteria document (IPC) is published, the existing STFs, as well as private testing laboratories, will be able to use these procedures for evaluation of photovoltaic systems. Through this process, iteration and improvements of the PC&TS are anticipated.

(3) Data Acquisition and Processing. Typical types of information provided by an STF include overall efficiency for various modes of operation, initial reliability estimates, transient response characteristics, assessment of system modeling and simulation, assessment of control strategies, and stability assessments. The programmatic analysis and distribution of those data will be assisted through use of the Data Acquisition and Dissemination Activity being developed through the Tests and Applications (T&A) Subprogram of the TD&A Lead Center. Dissemination of programmatic systems testing and evaluation performed in STFs will enhance the worth of the data because of its timely release. Existing and planned programmatic STFs will use this avenue for rapid dissemination to all elements of the program.

SECTION III

PHOTOVOLTAICS PROGRAM TEST FACILITIES ACTIVITIES DEVELOPMENT

The objective of STF activity planning is to ensure that sufficient system test facilities are available in order to meet Program objectives.

In order to achieve this objective, three steps will be taken:

(1) Compile information on existing and planned facilities, including programmatic and non-programmatic, delineating their characteristics and capabilities.

(2) Determine from the MYPP the requirements for facilities in terms of capability and date required.

(3) Determine the optimum combination of programmatic and non-programmatic facilities, including construction of new facilities, if necessary.

The STF planning activity will assist the Photovoltaics Program to meet the MYPP milestones and will help the photovoltaics industry to determine the testing programs required for evaluation and qualification of systems, subsystems and components.

SECTION IV

SYSTEMS TEST FACILITIES EXISTING CAPABILITIES--1979

The following provides a compilation of the photovoltaic system, subsystem and component testing facilities, status, and availability. These are contained in five sections: Summary Tables, Systems Test Capabilities, Photovoltaics Program Field Centers, Private Laboratories, and State Agencies.

A. SUMMARY TABLES

Table 4-1 summarizes the information obtained for Field Centers and state agencies. Location, contacts, application sector capabilities, maximum power handling capability and, where available, initial and annual costs are shown.

Table 4-2 summarizes the capabilities of private laboratories.

B. SYSTEMS TEST CAPABILITIES

Table 4-3 delineates the capabilities of those facilities that have total system testing capacity. These capabilities are broken down by major subsystem; i.e., array, power conditioner, and storage.

C. PHOTOVOLTAICS PROGRAM FIELD CENTERS

Tables 4-4 through 4-6 give detailed descriptions of the test capabilities of the Program Field Centers.

D. PRIVATE LABORATORIES

Tables 4-7 through 4-9 give a detail description of the test capabilities of the surveyed private laboratories.

E. STATE AGENCIES

The state agencies surveyed indicated that they have only solar thermal test capabilities.

Table 4-1. General Facility Information: Field Centers and State Agencies

Managing Agency or Company	Location	Phone No. Contact	Application* Sector(s)	Maximum Power kW	Initial $Cost_K$(Year)	Annual Cost K
NASA/Lewis Research Center	Cleveland, Ohio 44135	(216) 433-6732 (FTS) 294-6732 Dr. H. Brandhorst, Jr.	RS	30	NASA Facility	
MIT/Lincoln Laboratory	Lexington, Massachusetts 02173	(617) 862-5500, ext 7973 S. E. Forman	RS, R, I	10	$250 (1978)	$50-65
MIT/Lincoln Laboratory	Concord, Massachusetts 02173	(617) 862-5500, ext 7973 S. E. Forman	RS, R, I	(Included above)		
Sandia National Laboratories	Albuquerque, New Mexico 87185	FTS 844-0112 H. J. Gerwin	RS, R, I, CS	150	$500 (1976)	$600K
Jet Propulsion Laboratory	Pasadena, California 91103	(213) 577-9440 R. Baisley	Modules	1		
Brookhaven National Laboratory	Upton, New York 11973	(516) 345-3567 (FTS) 666-3567 Dr. E. Kush	R, RS	10		
Florida Solar Energy Center	Canaveral, Florida 32920	(305) 783-0300	Solar Thermal Only		(State Agency)	
Southwest Research Institute	San Antonio, Texas 78284	(512) 684-5111, ext 2384 Dr. D. Deffenbaugh	Solar Thermal Only		(State Agency)	

* RS - Remote - Stand Alone
R - Residential
I - Intermediate
CS - Central Station

Table 4-2. Facility Information: Private Laboratories

Company	Location(s)	Phone/Contact	Comments
AETL	Corporate Offices 15720 Ventura Blvd. Encino, CA 9143o	213/783-5985 Mr. A. Edelstein	A general purpose environmental test laboratory - sand, dust, vibration, shock, etc. AETL is a division of National Technical Services Co. Capabilities vary from site to site. AETL has five sites in Southern California with varying capabilities and size.
Acton Energy Laboratory	533 Main St. Acton, MA 01720	617/263-2933 Mr. R. Levin	Test procedures are generated using customer provided test plans. Some solar thermal experience. No current plans for photovoltaics. Facility Size 3200 m^2.
Franklin Research Center	20th and Parkway Philadelphia, PA 19103	214/448-1591 Dr. H. Lorach	Non-Profit. Facility Size: 19,000 m^2. Experience relative to tracking and control of electrical output and utility interface. Some research relative to development of thermal collectors.
Structural Dynamics Research Corp.	200 Eastman Drive Milford, OH 45515	513/576-2400 Mr. F. Base	Facility Size: 800 m^2. Mechanical and structural engineering consulting company - primarily failure and fatigue through analysis and testing.
Wyle Laboratories	7800 Governors Dr West Huntsville, AL 35807	205/837-4411 Mr. Bob Losey	Environmental testing capabilities include accelerated testing, power conditioner testing to 27 kW DC; load capability to 100 kW.

Table 4-3. Systems Test Capabilities Summary

Facility	Array					Power Conditioner		Utility Connection kVA	Storage		Load	
	Size	Flat Plate	Concentrator	Tracking	Thermal	DC Rating kW	AC Rating kVA		Type	Rating kWh	Static kW	Reactive kVA
NASA/Lewis Research Center	12,000 m^2 (RS)	Yes	Yes - 100 Suns	No	No	30	30 + 0.8 PF	30	Batteries Redox	48 10	50	2
MIT Lincoln Laboratory	750 m^2 (RS,R,T)	Yes	Yes - 3 Suns	No	Yes (ASHRAE)	2.5	10	10	Batteries Flywheel	750 Experimental	10	3
Sandia National Laboratories	930 m^2 (RS,R,T, CS)	Yes	Yes - 1500 Suns	Yes +.08 deg	Yes 60 kBtu/h Cooling	10	180 ± 0.8 PF, 3Ø	180	Batteries	24	150	228
Brookhaven National Laboratory	0.5 Acres (RS,R)	Yes	Yes - 10 Suns	Yes +0.1 deg	Yes - 10 Tons Cooling, 2×10^6 Btu Storage ASHRAE	10	-	No (easily acquired)	Batteries	100 amp h	10	Yes

Table 4-4. Collector Test Capabilities: Field Centers

	NASA-Lewis	MIT-LL	Sandia	JPL	Brookhaven
I. Qualification (Environmental) A. Controlled	(RS)	(RS,R,I)	(RS,R,I,CS)	(Modules)	(RS,R)
1. Rain	No	Yes	No	Yes	Yes
2. Humidity	No	No	Yes	Yes	Yes
3. Salt Fog	No	No	Yes	Yes	Yes
4. Hail	No	No	Yes	Yes	Yes
5. Fire (UL790/723)	No	ASTM D635	Yes	No	No
6. Shipping/Handling	No	No	Yes	No	Yes
7. Wind/Vibration (UL997)	No	No	Yes	Yes	Yes
8. Temperature Cycling	No	$-70^{\circ}C$ to $200^{\circ}C$	$-65^{\circ}C$ to $120^{\circ}C$	$-65^{\circ}C$ to $150^{\circ}C$	Yes
9. Size Limits	UNK	Temp - 3 x 3 x 3 ft other 4 x 8 ft	4 x 10 ft	4 x 4 ft	UNK
B. Natural (NE,SE,MW, etc.)	Midwest	NE	SW, High Desert	See Appendix C	NE - Coastal

Table 4-4. Collector Test Capabilities: Field Centers (cont'd)

	NASA-Lewis	MIT/LL	Sandia	JPL	Brookhaven
II. Performance					
A. Capability	(RS)	(RS,R,I)	(RS,R,I,CS)	(Modules)	(RS,R)
1. Flat Plate	Yes	Yes	Yes	Yes	Yes
2. Concentrator (Suns)	100	3	1500	No	10
3. Tracking Accuracy	No	No	±0.08 deg	No	±1.0 deg
4. Simulator (size)	4 x 8 ft	5 x 5 ft	No	4 x 8 ft	No
5. Thermal					
a. Cooling	No	Yes	60k Btu/h	No	10 tons
b. Storage	No	40 gal	No	No	2×10^6 Btu
c. Fluid Loop	No	100°C, 1 gpm	90°C, 12 gpm	No	205°F, 20 gpm
d. ASHRAE	No			No	
i. Storage	-	No	No	-	No
ii. Collector	-	Yes	Yes	-	Yes

Table 4-4. Collector Test Capabilities: Field Centers (cont'd)

	NASA-Lewis	MIT/LL	Sandia	JPL	Brookhaven
B. Measurement					
1. Simulator					
a. Temperature (Module)	Yes	Yes	Yes	Yes	Yes
b. Hot Box	No	4 x 4 ft, 150°C	No	4 x 4 ft, -65°C to 150°C	7.5 x 3.75 ft
c. Irradiance	Pulsed 10^4 MW/cm^2 Steady 150 MW/cm^2	85-110 MW/cm^2	105 MW/cm^2	150 MW/cm^2	1 to 6 Suns
2. Insolation					
a. Direct	Yes	Yes	Yes	Yes	Yes
b. Diffuse	Yes	No	No	Yes	Yes
c. Total	Yes	Yes	Yes	Yes	Yes
d. UV	No	Yes	No	No	No
3. IV Curves					
a. Manual	Yes	Yes	No	Yes	Yes
b. Automatic	Yes	Yes	Yes	Yes	Planned
4. Load					
a. Dynamic Sweep	Manual	Auto & Manual	Auto & Manual	Auto & Manual	Manual
b. Static	Yes	Yes	Yes	No	Yes

Table 4-5. Power Conditioner Test Capabilities: Field Centers

	NASA-Lewis	MIT/LL	Sandia	JPL	Brookhaven
I. Environmental					
A. Temperature					
1. Min-Max	No	3 x 3 x 3 ft -70°C to 200°C	-65°C to 120°C	No Power Conditioner Capabilities	-18°C to 230°C
2. Cycling	No	Yes	Yes	-	Yes
3. Dwell	No	Yes	Yes	-	No
B. Humidity	No	No	Yes	-	Yes
C. Vibration	No	Yes	Yes	-	No
D. Noise					
1. Acoustic	-	No	Yes	-	No
2. External EMI	-	-	Yes	-	No
3. Internal EMI	Yes	-	Yes	-	No

Table 4-5. Power Conditioner Test Capabilities: Field Centers (cont'd)

	NASA-Lewis	MIT/LL	Sandia	JPL	Brookhaven
II. Performance					
A. DC					
1. Rating	30 kW, 600 V	2.5 kW, 400 V	10 kW, 375 V	-	10 kW, 440 V
2. Switch Rating	240 V, 125 amp	-	600 V, 100 amp	-	1000 V, 100 amp
B. AC					
1. Rating (kVA,V,PF)	30, 240, ±0.8	10, 240, 1	(3Ø) 180, 440, 0.8	-	-
2. Commutation	Line & Self	Line & Self	Line & Self	-	-
C. Load Variation	Yes	Yes	Yes	-	Yes
D. Input Variation	Yes	Yes	Yes	-	Yes
E. Functional Tests					
1. Short-Circuit	Yes	Yes	Yes	-	No
2. Lightning	No	No	Yes	-	No
3. Internal Switching	Yes	Yes	Yes	-	Yes
4. External Switching	Yes	Yes	Yes	-	Yes
5. Controls	Yes	Yes	Yes	-	Yes
6. Temperature	Yes	Yes	Yes	-	Yes

Table 4-5. Power Conditioner Test Capabilities: Field Centers (cont'd)

	NASA-Lewis	MIT/LL	Sandia	JPL	Brookhaven
III. Measurement A. Array Simulation	No	No	10 kW and 75 kW	-	No
B. Load Simulation 1. Static	50 kW, 250 V	10 kW, 240 V	(3Ø) 150 kW, 240 V	-	10 kW, 240 V
2. Reactive	2 kVA, 240 V ± 0.8 PF	-	228 kVA, 240 V, ± 0.05 PF	-	10 kVA, 240 V, ± 0.7
3. Overload	-	-	-	-	-
4. Incremental Load	Continuous kW	Continuous kW	3.3 amp, 1kW	-	Continuous
5. Wattmeters	Yes	Yes	Yes	-	Yes
6. Auto Data Rate	5 kHz	12 channels/ sec	14/sec	-	0.1 sec

Table 4-6. Storage Test Capabilities: Field Centers

	NASA-Lewis	MIT/LL	Sandia	JPL	Brookhaven
I. Environmental					
A. Temperature				No Storage Test Capability	
1. Min-Max	No	No	$-65^{o}C$ to $200^{o}C$	-	$0^{o}C$ to $100^{o}C$
2. Cycling	-	-	Yes	-	Yes
3. Dwell	-	-	Yes	-	Yes
B. Water Loss	No	Yes	Yes	-	Yes
C. Hydrogen Accuml.	No	No	No	-	Yes
II. Performance					
A. Batteries	48 kWh	750 kWh	24 kWh	-	
1. Constant Discharge	No	2.5 kW, 20 amp	24 kW, 100 amp	-	
2. Constant Charge	130	130 V, 150 amp	320 V, 10 amp	-	120 V, 20 amp

Table 4-6. Storage Test Capabilities (cont'd)

	NASA-Lewis	MIT/LL	Sandia	JPL	Brookhaven
B. Flywheel	No	36 in. dia	No	-	-
C. Pumped Hydro	No	No	No	-	-
D. Other	Redox, 10 kWh	-	-	-	-
III. Measurement (Volts, amps, shunts)	Yes	Yes	Yes	-	Yes

Table 4-7. Collector Test Capabilities: Private Labs

	AETL	ACTON E. L.	SDRC	FRC	WYLE
I. Qualification (Environmental) A. Controlled	(Modules and Panels)	Small Components			
1. Rain	Yes	-	-	-	Yes
2. Humidity	Yes	-	-	-	Yes
3. Salt Fog	Yes	Small chamber	-	-	Yes
4. Hail	Yes	-	-	-	Yes
5. Fire (UL790/723)	Yes	-	-	-	Yes
6. Shipping/Handling	Yes	-	Yes	-	Yes
7. Wind/Vibration (UL997)	Yes	Seismic Vibration	Seismic Vibration	-	Yes
8. Temperature Cycling	$-470^{o}F$ to $2000^{o}F$	Small chamber	-	-	Yes
9. Size Limits	25 x 40 x 12 ft	-	-	-	12 x 24 ft
B. Natural (NE, SE, MW, etc.)	SW - So. CA 10 x 14 ft	-	-	-	SE

Table 4-7. Collector Test Capabilities: Private Labs (cont'd)

	AETL	ACTON E.L.	SDRC	FRC	WYLE
II. Performance					
A. Capability		None			
1. Flat Plate	Yes	-	-	-	Yes
2. Concentrator (Suns)	No	-	-	-	60
3. Tracking Accuracy	No	-	-	-	+1.25 deg
4. Simulator (size)	No	-	-	-	4 x 8 ft
5. Thermal	No	-	-		
a. Cooling	-	-	-	No	20 kW
b. Storage	-	-	-	80 gal	300 gal
c. Fluid Loop	-	-	-	200°F	40°F to 600°F, 10 gpm
d. ASHRAE	-	-	-		
i. Storage	-	-	-		Yes
ii. Collector	-	-	-		Yes

Table 4-7. Collector Test Capabilities: Private Labs (cont'd)

	AETL	ACTON E.L.	SDRC	FRC	WYLE
B. Measurement					
1. Simulator	No	No	No	No	
a. Temperature (Module)	-	-	-	-	Yes
b. Hot Box	-	-	-	-	4 x 8 x 2 ft
c. Irradiance	-	-	-	-	100 W/cm^2
2. Insolation	No	No	No	No	
a. Direct	-	-	-	-	Yes
b. Diffuse	-	-	-	-	Yes
c. Total	-	-	-	-	Yes
d. UV	-	-	-	-	Yes
3. IV Curves	No	No	No	No	
a. Manual	-	-	-	-	No
b. Automatic	-	-	-	-	Yes
4. Load	No	No	No	No	
a. Dynamic Sweep	-	-	-	-	Yes
b. Static	-	-	-	-	Yes

Table 4-8. Power Conditioner Test Capabilities: Private Labs

	AETL	ACTON E.L..	SDRC	FRC	WYLE
I. Environmental					
A. Temperature		Small Walk-in Chamber			
1. Min-Max	$-70^{o}C$ to $175^{o}C$		-	Yes	$-85^{o}C$ to $150^{o}C$
2. Cycling	Yes	-	-	Yes	Yes
3. Dwell	Yes	-	-	Yes	Yes
B. Humidity	Yes	-	-	Yes	Yes
C. Vibration	Yes	-	-	Yes	Yes
D. Noise					
1. Acoustic	Yes	Yes	-	Yes	Yes
2. External EMI	Yes	Yes	-	Yes	No
3. Internal EMI	Yes	Yes	-	-	No

Table 4-8. Power Conditioner Test Capabilities: Private Labs (cont'd)

	AETL	ACTON E.L.	SDRC	FRC	WYLE
II. Performance					
A. DC					
1. Rating	-	-	-	-	27 kW, 90 V
2. Switch Rating	Yes	-	-	Yes	90 V, 300 amp
B. AC					
1. Rating	-	-	-	-	90 kVA, 480 V, ± 0.8 PF
2. Commutation	Line and Self	-	-	-	Line and Self
C. Load Variation	Yes	-	-	-	Yes
D. Input Variation	Yes	-	-	-	Yes
E. Functional Tests					
1. Short-Circuit	Yes	-	-	-	Yes
2. Lightning	Yes	-	-	-	Yes
3. Internal Switching	Yes	-	-	-	Yes
4. External Switching	Yes	-	-	-	Yes
5. Controls	Yes	-	-	-	Yes
6. Temperature	Yes	Small Chamber	-	-	Yes

Table 4-8. Power Conditioner Test Capabilities: Private Labs (cont'd)

	AETL	ACTON E.L.	SDRC	FRC	WYLE L.
III. Measurement					
A. Array Simulation	No	-	-	-	Yes
B. Load Simulation					
1. Static	100 kW	-	-	-	Yes, Variable V
2. Reactive	480 V, 3∅	-	-	-	90 kVA, 480 V ± 0.8 PF
3. Overload	Yes	-	-	-	Yes
4. Incremental Load	Yes	-	-	-	No
5. Wattmeters	Yes	-	-	-	Yes
6. Auto Data Rate	1 kHz	-	-	-	Yes

Table 4-9. Storage Test Capabilities: Private Labs

	AETL	ACTON	SDRC	FRC	WYLE
I. Environmental					
A. Temperature		Small Walk-in Chamber			
1. Min-Max	-70°C to 170°C	-	-	-	-85°C to 150°C
2. Cycling	Yes	-	-	-	Yes
3. Dwell	Yes	-	-	-	Yes
B. Water Loss	Yes	-	-	-	Yes
C. Hydrogen Accuml.	Yes	-	-	-	Yes
II. Performance					
A. Batteries	Yes	-	-	No	9 x 1 kW
1. Constant Discharge	-	-	-	-	30 kW, 200 amp
2. Constant Charge	-	-	-	-	60 V, 100 amp
B. Flywheel	4 ft dia	-	Yes	No	No
C. Pumped Hydro	200 psig 20 ft dia x 11 ft	-	-	No	No
D. Other	-	-	-	Compressed Air	-
III. Measurement (Volts, amps, shunts)	-	-	-	-	Yes

SECTION V

SUMMARY AND CONCLUSIONS

A. TOTAL SYSTEM TESTING

The survey indicates that there are four test facilities that can perform total system tests. These are NASA/Lewis, MIT, Sandia and Brookhaven. Of these, only Sandia has the capability to test a central station class system of up to 150 kW. Two of the facilities indicated that they have intermediate class test capabilities: Sandia (up to 150 kW) and MIT (up to 10 kW). In addition to Sandia and MIT, Brookhaven indicated that they have a residential test capability of 10 kW. NASA Lewis Research Center has a remote-stand alone test capability of up to 30 kW.

There is very limited test capability in the total systems regime of solar photovoltaic applications testing.

B. SUBSYSTEM AND COMPONENT TESTING

All of the Field Centers and the private testing laboratories have a subsystem or component testing capability to some degree. The private labs have considerable experience and testing facilities to do environmental testing of components and small subsystems. These private labs also indicated that they can design tests to customer specifications. There is no apparent shortage of testing facilities for subsystems and components.

C. CONCLUSIONS

With the limited capability to conduct total system testing, the number of tests that can be performed simultaneously is limited. This means that if several Initial System Evaluation Experiments and/or System Readiness Experiments are scheduled for the same period of time there will be a shortage of facilities in which to conduct these experiments. Alternative testing plans should be explored to alleviate this possible problem. In addition to the small number of facilities available, there is the possible problem of maximum power handling limits. Of the five Program STFs, two can perform testing to 10 kW, another to 30 kW, and only one can test to 150 kW.

There appears to be a sufficient number of facilities available to conduct component environmental testing. Accelerated-life testing facilities are claimed to be available. However, insufficient evidence exists to determine if the test methods are pertinent to photovoltaic system components.

It is recommended that this STF capabilities compilation be updated annually as a service to industry.

APPENDIX A

ACRONYMS AND ABBREVIATIONS

BOS	Balance of System
DOE	Department of Energy
ISEE	Initial System Evaluation Experiment
JPL	Jet Propulsion Laboratory
LeRC	Lewis Research Center
LSA	Low-Cost Solar Array (Project)
MIT/LL	Massachusetts Institute of Technology, Lincoln Laboratory
MYPP	Multi-Year Program Plan
PV	Photovoltaics
PV/T	Combined Photovoltaic/Thermal (System or Collector)
RES	Residential Experimental Station
SD	Systems Development Subprogram
SERI	Solar Energy Research Institute
STF	Systems Test Facility
T&A	Test and Applications Subprogram

APPENDIX B

FACILITIES SURVEYED

A. PROGRAM FIELD CENTERS

Brookhaven National Laboratory

Jet Propulsion Laboratory

MIT Lincoln Laboratory

NASA Lewis Research Center

Sandia National Laboratories

B. STATE AGENCIES

Florida Solar Energy Center

Southwest Research Institute

C. PRIVATE LABORATORIES

Acton Energy Laboratory

Approved Energy Testing Laboratories (AETL)

Franklin Research Center

Structural Dynamics Research Corp.

Wyle Laboratories

United Technology Laboratory*

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*Facilities were not compatible with photovoltaic systems testing.

APPENDIX C

JPL REMOTE SITES

Table C-1 summarizes the various environments for the JPL remote tests sites. Figure C-1 indicates the location of the sites.

Table C-1. Summary of Continental Remote Sites

Category	Location	Latitude (degrees)	Altitude (feet)	Key Features
Extreme Weather	Canal Zone (Ft. Clayton	9	~0	Typical tropic: hot and humid; 100 inch-per-year rainfall
	Alaska (Ft. Greely)	64	1,270	Subarctic environment;-30°F winters
Marine	Key West, Florida	25	0	Hot and humid: corrosive salt spray
	San Nicholas Island, California	34	0	Somewhat milder than Key West
Mountain	Mines Peak, Colorado	40	13,000	Clear and cold; high-velocity winds; maximum UV
High Desert	Albuquerque, New Mexico	35	5,200	Dry with clear skies; an abundance of UV
	Dugway, Utah	40	4,300	Cold winters, hot summers; alkaline soil
Midwest	Crane, Indiana	39	~0	Typical midwest: hot humid summer, cold snowy winters
Northwest	Seattle (Ft. Lewis)	47	~0	Typical northwest: mild temperatures and an abundance of rain
Upper Great Lakes	Houghton, Michigan	47	750	Mild summers, severe winters
Urban	New London, Connecticut	41	0	Typical New England Coastal
	New Orleans, Louisiana	30	~0	Hot and very humid; high pollution environment

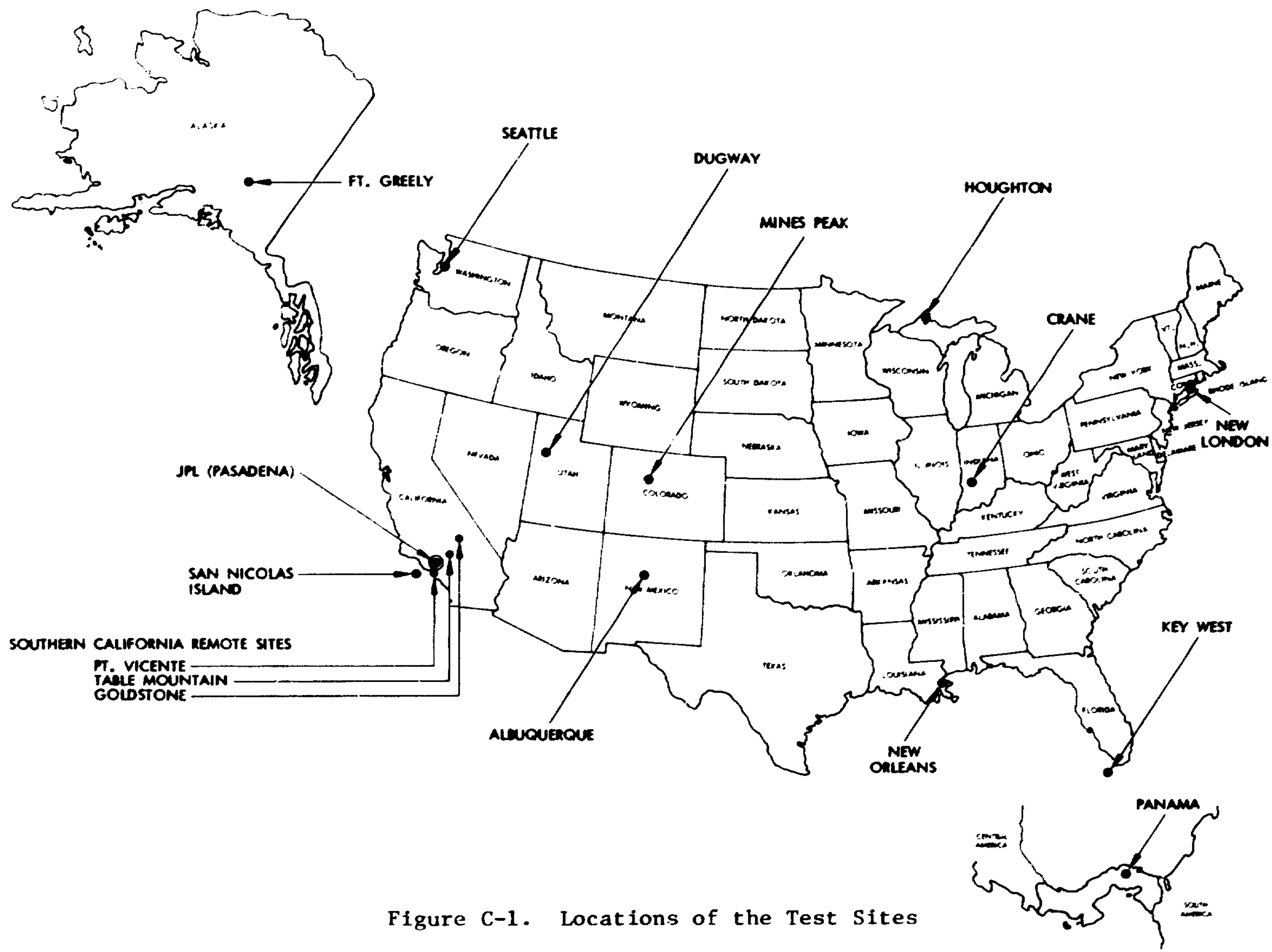

Figure C-1. Locations of the Test Sites