Solar Controlled Environment Agriculture Project

FINAL REPORT

Volume 7 Science Applications, Incorporated Field Test Facility Preliminary Design

Published for the
United States - Saudi Arabian Joint Program
for Cooperation in the Field of Solar Energy
SOLERAS

by the Program Operating Agent
Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110 USA

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Price: Printed Copy A05

Microfiche A01

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FOREWORD

THE SOLERAS PROGRAM: A UNIQUE EFFORT IN COOPERATIVE SOLAR ENERGY RESEARCH

In October 1977, Saudi Arabia and the United States signed a Program Agreement for Cooperation in the Field of Solar Energy. The Program, named SOLERAS, is the first of its kind in purpose, funding, organization, and results. It is based on the respective commitments of the United States and Saudi Arabia to advance the development of solar energy as a viable cost-competitive energy alternative, by combining the technical and other unique resources of each country. SOLERAS has made significant progress in demonstrating the effectiveness of solar energy—progress that would have been difficult for either country to achieve on its own.

SOLERAS is sponsored by the government agencies responsible for energy research and development in each country: the Saudi Arabian National Center for Science and Technology (SANCST) and the United States Department of Energy. The Program is under the auspices of the United States-Saudi Arabian Joint Commission on Economic Cooperation, formed in 1974 by the Saudi Arabian Ministry of Finance and National Economy and the United States Department of the Treasury.

Although SOLERAS is only one of more than 30 such projects under the direction of the Joint Commission, it is the only one that is funded by both countries. All other projects are funded completely by Saudi Arabia. This jointly funded program is evidence, therefore, that both countries recognize the mutually beneficial results expected to be generated by the cooperative research projects undertaken by SOLERAS.

The administration of SOLERAS also reflects the philosophy of cooperation underlying this unique Program. Senior officials from SANCST, the Ministry of Finance and National Economy, the U.S. Department of Energy, and the U.S. Department of the Treasury comprise an eight-member Executive Board which governs all aspects of the SOLERAS Program. The Board establishes the goals, objectives, and policies of SOLERAS and oversees the technical and financial management of the projects undertaken to implement those goals and objectives.

A four-member Project Selection Committee, with two members from each government, assists the Executive Board in selecting and evaluating projects. Its members combine their technical expertise and experience in renewable energy technologies and demonstration projects to review proposals, designs, plans, reports, operations, and data for the various projects.

The daily technical and administrative management of the SOLERAS projects is the responsibility of Midwest Research Institute, an independent, not-for-profit research organization, which has been designated as the SOLERAS Operating Agent. MRI utilizes technical and managerial personnel from both countries in fulfilling its responsibility for implementing the decisions of the Executive Board and in managing the individual technical projects. This includes contracting with various companies and research organizations in both countries to design and install state-of-the-art solar systems. SOLERAS program offices are located at MRI's Kansas City, Missouri, headquarters, and in Riyadh and Yanbu, Saudi Arabia.

SOLERAS has initiated several major research projects: converting solar energy into electricity for everyday use by the inhabitants of several rural villages; testing solar energy as a source for space cooling and water treatment; developing agricultural systems using solar energy to control the entire growing environment; undertaking fundamental photovoltaic and solar thermal research; establishing high technology laboratories for advanced solar research at Saudi Arabian universities; and sponsoring basic solar energy research in universities in the United States.

In addition, SOLERAS has contributed to the dissemination of scientific and technical solar information through its sponsorship of technology workshops, short courses, and the publication of technical reports. These have provided an important means of informing the scientific research community about the solar energy technologies developed under SOLERAS and other relevant projects throughout the world.

تقديم

«البرنامج السعودي الأمريكي المشترك» للتعاون في ميدان أبحاث الطاقة الشمسية

وقعت المملكة العربية السعودية والولايات المتحدة الأمريكية في عام ١٩٧٧م اتفاقية برنامج التعاون في ميدان أبحاث الطاقة الشمسية . وكان هذا البرنامج الذي سُمي «سوليراس» الأول من نوعه من حيث الغرض والتمويل والتنظيم والنتائج . وهو معتمد على الالتزام المتبادل بين الولايات المتحدة الأمريكية والمملكة العربية السعودية بالعمل على تنمية الطاقة الشمسية ، بوصفها طاقة بديلة متجددة وذات كلفة منافسة ، عن طريق الجمع للموارد الفنية وغيرها من المصادر الطبيعية لكل من البلدين . ولقد حقق برنامج «سوليراس» تقدماً ملحوظاً ببيان فعالية الطاقة الشمسية ، وهو تقدم قد يكون من الصعب تحقيقه على أي من البلدين منفرداً .

يتم انجاز برنامج «سوليراس» تحت رعاية الهيئات الحكومية المسؤولة عن أبحاث وتنمية الطاقة في كل من البلدين ، أي المركز الوطني السعودي للعلوم والتكنولوجيا ووزارة الطاقة الأمريكية . وتشرف على البرنامج اللجنة الأمريكية السعودية المشتركة للتعاون الاقتصادي المكونة عام ١٩٧٤م من قبل وزارة المالية والاقتصاد الوطني في المملكة العربية السعودية ووزارة المالية في الولايات المتحدة الأمريكية .

بالرغم من أن برنامج «سوليراس» هو واحد من بين ما يزيد عن ٣٠ مشروعاً تديرها اللجنة المشتركة فإنه البرنامج الوحيد الذي يموله البلدان ، في حين أن جميع البرامج الأخرى تمولها المملكة العربية السعودية كلياً . فيبرهن هذا البرنامج ، المشترك التمويل ، على أن كلا البلدين يعترفان بالفوائد المتبادلة المتوقعة تحقيقها من خلال مشاريع البحث التعاوني التي يتداولها برنامج «سوليراس» . وتعكس إدارة «سوليراس» أيضاً فلسفة التعاون التي يستند عليها هذا البرنامج . فيشكل مسؤولون من المركز الوطني السعودي للعلوم والتكنولوجيا ومن وزارة المالية والاقتصاد الوطني ومن وزارة الطاقة الأمريكية ووزارة المالية الأمريكية مجلساً تنفيذياً يضم ثمانية أعضاء ويدير جميع جوانب برنامج «سوليراس» . فيحدد هذا المجلس أهداف وغايات وسياسة «سوليراس» كما يشرف على الإدارة الفنية والمالية للمشاريع المباشرة لتحقيق هذه الأهداف والغايات .

تقوم لجنة اختيار المشاريع المكونة من أربعة أعضاء ، اثنان من كل جانب بمساعدة المجلس التنفيذي في اختيار وتقييم المشاريع . فيجمع أعضاء هذه اللجنة خبرتهم الفنية وتجربتهم في مجال تكنولوجيا الطاقة المتجددة والمشاريع النموذجية لمراجعة المقترحات والتصاميم والمخططات والتقارير والعمليات والبيانات المتعلقة بالمشاريع المتنوعة .

أما الإدارة الفنية والإدارية اليومية لمشاريع «سوليراس» فهي تحت مسؤولية «مدوست ريسيرتش انستيتوت» (معهد «مدوست» للأبحاث) . وهو معهد أبحاث مستقل ليس ذا صبغة تجارية ، تم تعيينه كوكيل تشغيل لبرنامج «سوليراس» . ويستخدم معهد «مدوست للأبحاث» فنيين وإداريين من كلا البلدين للقيام بمسؤولية تنفيذ قرارات المجلس التنفيذي وإدارة المشاريع الفنية الفردية . ويشمل ذلك التعاقد مع مختلف الشركات ومعاهد الأبحاث في كلا البلدين لتصميم وتركيب أنظمة طاقة شمسية من أحدث تكنولوجيا . وتقع مكاتب برنامج «سوليراس» في المقر الرئيسي لمعهد «مدوست للأبحاث» بمدينة كنساس سيتي بولاية ميسوري وكذلك في الرياض وينبع بالمملكة العربية السعودية .

انبعث من برنامج «سوليراس» العديد من مشاريع الأبحاث الكبرى ، منها تحويل الطاقة الشمسية الى كهرباء للاستعمال اليومي لسكان العديد من القرى الريفية واختبار الطاقة الشمسية كمصدر طاقة للتبريد والتدفئة وتحمية المياه وتطوير أنظمة زراعية باستعمال الطاقة الشمسية للتحكم في كامل بيئة الانماء ، والقيام بأبحاث نظرية حول الخلايا الكهروضوئية والحرارة الشمسية وأنشاء مختبرات تكنولوجيا عالية للأبحاث الشمسية المتقدمة في الجامعات السعودية ورعاية أبحاث أساسية في الطاقة الشمسية في جامعات بالولايات المتحدة الأمريكية .

كما أن برنامج «سوليراس» ساهم في نشر المعلومات العلمية والفنية المتعلقة بالطاقة الشمسية من خلال رعايته للندوات العلمية والدورات القصيرة ونشر التقارير الفنية . ولقد كان ذلك وسيلة لنقل معلومات هامة لمجموعة الباحثين العلميين حول تكنولوجيا الطاقة الشمسية المطورة من خلال برنامج «سوليراس» والمشاريع الأخرى المرتبطة به عبر بلدان العالم .

ABSTRACT

This report contains the preliminary design of an SCEAS Engineering Test Facility (ETF). The ETF is essentially identical to the 5-hectare size commercial facility, described in the Task 3 report, in all features except size. The ETF is a 3600 m² fluid roof greenhouse with an inflated plastic film roof to maintain a clean environment for the fluid roof and to protect the inner glazing from hail and other small missiles.

The objective of the design was the faithful scaling of the commercial facility to ensure that the ETF results could be extrapolated to a commercial facility of any size. Therefore, all major features, including the photovoltaic power system, an integral water desalination system and even the basic structural module have been retained.

The design is described in substantial detail in the body of this report, with appendices giving the drawings and specifications. This report represents an effort substantially greater than a typical preliminary engineering design study. The added effort was required because of the need for realistic implementation schedules and high confidence cost estimates for the definition of Phase 2 (Task 5).

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Section 1

INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

This report presents the preliminary design of a solar controlled-environment agricultural system engineering field test (ETF) facility. The design is based upon the systems analysis work described in the Task 3 Report and the System Requirements described in the Task 2 Report. Consequently, descriptions of the operation of the greenhouse have been omitted from this report and emphasis has been placed upon the design. The bulk of the detail is contained in the drawings and specifications, Appendices A and B respectively. A simulation of the engineering test facility was made to verify the performance. The results are described in Section 4.

1.2 SUMMARY

The field test pilot plant design emulates the commercial size facility in all important aspects except size. The enclosed greenhouse area is 3600 m² with 3150 m² of growing area. There are four equal size growing compartments and a 7.5 m wide corridor thru the center that which provides access to the compartments and work space. The size and compartmentation are adequate for all experimental objectives.

The design is derived from the simulation program described in the Task 3 report and the system requirements definition contained in the Task 2 report. Accordingly, this report contains no discussion of the theory of operation or the derivation of sizes of the components. An analysis of performance using the simulation is included.

The only significant departure from the commercial system design is the powering of non-agricultural loads from the local utility. The housekeeping functions for the FPHP do not scale linearly and their inclusion in the power requirement for the photovoltaic system would have

resulted in a substantial cost increase without any experimental purpose. The utility is also used as a backup power source for the agricultural loads in lieu of diesel generators.

Test and inspection requirements are conventional in most respects with the participation of the architect and the mechanical and electrical engineers as on-site inspectors. Most of the key performance criteria are not related to the performance of individual equipments but rather to the harmonious functioning of all equipments in response to the control system. Key performance criteria will be verified as the construction schedule permits.

The performance analysis indicates a remarkably small energy requirement for operation of the facility. Prudent design dictates a slight oversizing of the solar energy system to account for reduced efficiencies resulting from smaller motors and a 4:1 increase in the ratio of unfiltered side walls to filter glass roof.

Appendix A contains 55 drawings which represent substantially more than required for a preliminary design. However, the greater detail is required to permit high confidence cost and schedule outputs from Task 5.

Appendix B contains the specifications for all major items.

SECTION 2

PERFORMANCE REQUIREMENTS

2.1 SCOPE

The performance requirements defined in this section are at the system level. They are those which can be verified by physical measurements during construction or shortly after completion of the field test pilot plant. They do not encompass the performance of crop production since that can be measured only after a prolonged period of operation. They do not relate to verification of specification data for individual equipments, but rather to the effect produced by the equipments when operating as part of the system. Section 5 treats test and acceptance data at all levels.

The performance requirements are derived from the greenhouse simulation program which quantified the environmental conditions required for optimum plant growth and the mass and energy balances needed to maintain that environment, and from Task 2 - Systems Requirement Definition Document. They are specifically scaled to the planned size of the field test pilot plant.

2.2 ROOF GLAZING

The transmissivity of the roof filter glass shall be as shown in Figure 2-1.

2.3 GROWING COMPARTMENT TEMPERATURE CONTROL

The glazing, - roof water circulation, ventilation and dehumidification subsystems shall be capable of maintaining the growing compartment temperatures within the limits shown in Table 2-1. These limits shall be attainable under automatic (computer) control or through manual control from the central control station.

FORD SUNGLASS 6mm

□ SOLAR SPECTRUM

— TRANSMITTANCE

+ TRANSMITTED SPECTRUM

Figure 2-1 Transmittance Versus Wavelength for Fluid Roof Glazing

	Peak Summer Condition	Worst Case Winter Condition
Outside Air Temperature	38°C	-7°C
Global Insolation	1050 w/m ²	0
Growing Compartment Dry Bulb Temperature	35°C	10°C
Growing Compartment Relative Humidity	80%	*

*Occasionally daytime relative humidity exceeds 90%

Table 2-1 Limiting Environmental Conditions

The limiting conditions shown in Table 2-1 represent extremes. When ambient conditions are between the extremes, the actual temperatures maintained will be those best suited to the crops under production.

2.4 GROWING COMPARTMENT CO₂ LEVEL

The CO₂ subsystem shall be capable of maintaining a CO₂ concentration of 2500 PPM when all louvers and dampers are closed.

2.5 FERTIGATION SUPPLY

The fertigation supply shall be capable of furnishing 4.5 liters per square meter per hour to each growing compartment.

2.6 DESALINATION AND WATER RECOVERY

The desalination subsystem shall be capable of producing 10 cubic meters of water per day. The composition of the product water shall be as indicated in Table 2-2.

ESTIMATED OPERATING RESULTS

Name University Farm Well Address East of El Paso, Texas
 1. Raw water sample collected after two hours pumping at 2,500 gpm, as
 2. 1 - converted to CaCO₃ & _____ substance.
 3. Estimated results from R.O. Unit 7. _____
 4. Estimated results from Demineralizer _____

Analysis of treated waters are typical of results anticipated. Any guarantees with reference to specific constituents are covered separately.

		mg/L (PPM) As CaCO ₃							
Substance	Symbol	1	2	3	4	5	6	7	8
Cations	Calcium	Ca++	108	270	1				
	Magnesium	Mg++	83.3	343	1				
	Sodium	Na+	781	1702	120	2			
	Potassium	K+	66.7	85	5				
	Hydrogen - Acidity	H+	-	-					
Total Cations			-	2400	127	2			
Anions	Bicarbonate	HCO ₃ ⁻	416	416	41				
	Carbonate	CO ₃ ⁻	0	0					
	Hydroxide	OH ⁻	0	0					
	Phosphate	PO ₄ ⁻	1.5	2.4	2				
	Chloride	Cl ⁻	719	1014	67	2			
Sulfate		SO ₄ ⁻	920	957	18				
Nitrate		NO ₃ ⁻	1.5	1.2					
Total Anions			-	2391	126.2	2			
Total Hardness			615	613	2	0			
Alkalinity A (Methyl Orange)			416	416	41	0			
Alkalinity B (Phenolphthalein)			0	0	0				
Boron		B	0.4		0.2	0.1			

		mg/L (PPM) As Substance Or In Units Indicated							
Free Carbon Dioxide	CO ₂	CALC.	26	26	0				
Silica - Total	SiO ₂	16.4	16.4	4.0	0.2				
Silica - Dissolved	SiO ₂	15.6	15.6						
Iron - Total	Fe	0.59	0.59	0.1	0.1				
Iron - Dissolved	Fe	0.40	0.40						
Manganese - Total	Mn	0.66	0.66	0.2					
Manganese - Dissolved	Mn	0.56	0.56						
Fluoride	F	1.15	1.15	0.4					
Oxygen Demand	KMnO ₄	-	5.6						
Suspended Solids		24	24	0.1					
Turbidity (NTU) (JTU)		1.7	1.7	0.1					
Silt Density Index		-	-	LT2					
Color - Apparent		-	-						
Color True (APHA)		50	50						
Total Organic Carbon C		2.2	2.2						
Conductivity mmho/cm		5166	5166	320					
Total Ions		-							
TDS (By Evaporation)		3488	3488	195	3				
pH Field									
Laboratory		7.5	7.5	6.6	7.0				
Calculated		-	-						

Barium <0.01

Strontium 9.0

1. Haze in sample cleared when acidified

2. Sample thru 0.45 U filter

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TABLE 2-2. UNIVERSITY FARM WELL WATER ANALYSIS

215-4-81

The dehumidification system shall be capable of recovering 60% of the fertigation water under summer conditions.

2.7 DEMINERALIZATION

The demineralizer subsystem shall be capable of processing 110 cubic meters of water per day. The TDS content of the output, when the input water is from the fresh water tank shall not exceed 3 PPM. The demineralizer subsystem shall be configured to recirculate water from the roof water tank to maintain purity at times when make-up demineralized water is not required.

2.8 PV SUBSYSTEM

The PV subsystem shall supply, on an annual basis, at least 90% of the electrical energy required to power the loads assigned to the solar energy bus. These loads are all those associated directly with the agricultural process and which vary in demand with the ambient conditions.

SECTION 3

ENGINEERING FIELD TEST FACILITY DESCRIPTION

In this section a brief description of the Engineering Field Test Facility (ETF) is given. Further details on the ETF can be found either in the Task 3 Report descriptions or in the detailed drawings and specifications presented in the appendices.

3.1 BASIS FOR DESIGN

In selecting the components/subsystems for the ETF, the following selection criteria were used:

- a) The ETF should meet the technical performance specifications of the Task 2--Systems Requirements Document. Several of the requirements were changed during the course of Task 4 and these changes are reflected in the ETF. The requirements imply that all of the major components of the commercial system should be included. We do propose to relax some of the "stand-alone" features which tend to increase the cost but provide no additional data.
- b) The ETF should be representative of the commercial system in the fundamental ways, so that the results from the test system can be used in a relatively straightforward manner in the design of commercial sized facilities. By "fundamental ways," we mean the ETF should include the fluid roof/roof filter greenhouse, a photovoltaic power system, a low energy RO desalination system and a central automatic control system. Furthermore, CO₂ enhancement is part of the proposed concept and must be included. The relationship of subsystem sizes should approximate those of the commercial facility.
- c) The ETF should be sized in such a way that the results can be extrapolated reasonably to a larger facility. The Systems Requirement Document specified a size in the range of 0.4-1.0 hectare. However, SAI and its subcontractors believe that a size of 0.36 hectare including access corridors is adequate. In this regard approval has been obtained for at least a 0.35 hectare greenhouse.

- d) The ETF should allow for the maximum transfer of technology to other hot arid (or humid) sites in the Kingdom of Saudi Arabia and the United States. In keeping with this requirement, the ETF should allow for the maximum gathering of useful data in both a short-term and long-term sense. These factors imply that a certain degree of flexibility needs to be included in the design, so that various operational modes and tradeoffs can be investigated. In this case, the ETF begins to vary somewhat from a commercial facility in which the operational modes and parameters are already defined. Principally, these criteria imply that energy, desalination, and environmental control systems are sized to be larger on a per unit area basis than for the commercial facility. In addition, these criteria require that a relatively sophisticated control and instrumentation system be included, so that detailed documentation and analysis of the system performance can be carried out.
- e) The above criteria should be met at the lowest cost to the SOLERAS program. In this regard, including all "stand-alone" features of the commercial facility into the ETF will be very costly. Some of these features add little to the knowledge which can be gained. Therefore, to reduce the Phase 2 cost without loss of objectives, the following power system features have been included:

- All power for support facility and housekeeping loads are provided by electric utility. This allows for a smaller photovoltaic system (10-15 kWp less).
- Emergency power is provided by utility which allows for elimination of diesel generators.
- Approximately 5-10 percent of greenhouse system power will be provided by the utility. Basically, this allows the storage battery capacity to be reduced by approximately 60 percent.
- By being grid-connected, any excess photovoltaic power can be consumed in the support facility and housekeeping loads or sold back to the utility at a rate close to the rate for purchasing power. Thus, operational costs can be reduced.

To ascertain the relative sizes of equipment to be selected for the test facility, the optimization program SYSOPT was run for a 5-hectare facility without the support facility and housekeeping loads and with the

backup system providing 0 percent and 5 percent of the required power. The results are shown in Table 5-1.

TABLE 3-1. SUMMARY OF SYSOPT RESULTS FOR 5-HECTARE FACILITY WITHOUT SUPPORT FACILITY LOADS AND WITH BACKUP SYSTEM PROVIDING 0% AND 5% OF THE REQUIRED POWER

Item	Size at 0%	Size at 5%
PV 20° tilt, kWp	0	237
PV 30° tilt, kWp	272	0
Battery Storage - kWh	1650	725
- kW	211	137
PCU, kW a.c.*	194	190
R.O., m ³ /h	3.04	3.04

*At unity power factor

Based upon a scaling factor of $\frac{5 \text{ ha}}{0.315 \text{ ha}} = 15.9$ (where 0.315 is ETF growing area), the scaled-down sizes at 5 percent backup power are: PV size (20° tilt) = 16.8 kWp, battery size 45.6 kWh PCU = 11.9 kW ac and RO = 0.19 m³/h (4.6 m³/day). However, as previously mentioned, for the ETF we believe these should be somewhat larger to give flexibility to carry out a variety of studies. Furthermore, several additional scaling factors relative to the reduced size and currently available technology of the test facility were not modified from the commercial facility case in the SYSOPT sizing. These factors (and the affected subsystems) include:

- efficiency factor for smaller pumps and fans (PV, battery, PCU) = 1.125
- higher power factor (PV, battery, PCU) = 1.25
- additional transmission loss factor (PV, battery, PCU) = 1.02
- additional inverter losses (PV, battery) = 1.045

- additional diode and shunt losses in array (PV) = 1.02
- additional module mismatch losses (PV) = 1.05
- Total Multiplication factor PV = 1.60
- " " " Battery = 1.50
- " " " PCU = 1.43

These corrections would yield a photovoltaic array size (20° tilt) of 26.9 kWp, battery size 68.4 kWh, and PCU size 20 kVA. Additional corrections have been applied to each based upon the actual discrete sizes available and uncertainties in the calculated loads. Another factor considered, but not rigorously quantified, is the greater heat gain of the smaller facility. The unfiltered exterior walls have an area equal to 20 percent of the roof area, whereas it is only 5.4 percent in the commercial facility. The final selected values for the major system components are as follows:

- Greenhouse Size = 0.3150 hectare growing, 0.360 hectare total
- PV system 20° tilt = 37.7 kWp (allows for uncertainty in draw-down in well at peak pumping.)
- Battery size (12 hr rate) lead antimony = 88.8 kWh (at 80% allowable depth of discharge)
- PCU = 37 kVA
- RO system = 10 m³/day.

The only difference between the ETF and commercial greenhouse structure is size. The materials, structural components, and shape are identical; the basic 7.5 x 15m structural model has been retained. The mechanical systems are identical, except that they are fewer in number (dehumidification units, louvers, ventilation fans, etc.). The control subsystem uses identical sensors, actuator types, and an identical data acquisition system and computer.

3.2 CONTROLLED ENVIRONMENT AGRICULTURAL SYSTEM

This subsection presents a brief description of the ETF with emphasis on quantitative data and the interrelationships among its elements. Detailed data is presented in the drawings and specifications contained in the appendices.

3.2.1 Site

The ETF will be located on the Texas A&M Research and Extension Center Farm, El Paso, Texas. Drawing S-1 shows the site and key plans. The site is on level land adjacent to an improved road. The water table varies from two to three meters below the surface. The site is convenient to the office and research facilities of the center.

3.2.2 Greenhouse Structure

The greenhouse is a square building of 60 meter width and length and provides the envelope for the controlled environment. It incorporates the actual planting space of 3150m^2 and a transverse working corridor 7.5 meters in width which facilitates planting, plant care and harvesting. The planting space is subdivided into four compartments which are separated by transparent walls. These spaces facilitate the culturing of different crops and are individually controllable.

The greenhouse structure is composed of 1.8 meter deep steel trusses spanning 15 meters between columns supporting the roof structure (see Figure S-4). These trusses are spaced parallel, 7.5 meters apart and support the glass roof by means of downward sloping cross braces anchored at the top of the truss at 3 meter intervals. At the crossing point of the braces a grid of roof mullions is suspended supporting the roof glass, and sloping towards the bottom chords of the trusses. Here, a gutter collects the cooling water (Drawing S-5, Detail B), which is sprayed on the top of the glass via a feedpipe with nozzles located below the brace crossing point, and at the ridge of the glass roof (Drawing S-5, Detail C). A highly transmissive (95% for visible light) Tefzel plastic film cover spans from the

top of the roof trusses to the intersection of the cross braces and provides protection from dust and dirt. To collect the rainwater from the roof, a gutter is installed at the cross brace intersection (Drawing S-5, Detail C). To stabilize the roof film, the airspace between the film and the glass is pressurized to 25 kpa/m². This feature is solely designed to prolong the life of the film. The space between the glass and the Tefzel film is accessible along the roof trusses.

The roof supporting trusses and the columns form a portal frame system which resists the lateral wind loads. Perpendicular to the trusses the building is braced through horizontal cross bracing over the central corridor. This bracing terminates in two vertical cross braces at the perimeter walls of the greenhouse.

The exterior walls are free standing and only laterally held at the roof level (Drawing S-5, Detail D). Intermediate mullions support the wall glazing. The glazing consists of Gyro Exolite Twinwall Polycarbonate panels.

A 800 mm high curb above grade level forms the base of all side walls. All columns sit on 500 mm high concrete piers to protect them against impact from service vehicles (See Drawing S-2). Foundations are spread footings:

The plans and details are contained in drawings S-2 through S-6.

The principal dimensions are:

Structural Bay Module	7.5m X 15m (24.6' X 49.2')
Total Enclosed Area	3600 m ² (38,750 ft ²)
Total Growing Area	3150 m ² (33,906 ft ²)
Volume of Growing Compartment	9450 m ³ (333,722 ft ³)
Number of Compartments	4
Area of Each Growing Compartment	787.5 m ² (8477 ft ²)

3.2.3 Greenhouse Environmental Control

Mechanical systems are provided to maintain optimum conditions for plant growth within the growing compartments. These consist of the roof water circulation system, the dehumidification and ventilation units and a CO₂ supply system.

a. Roof Water System

Two identical roof water systems (Drawing M5) serve the east and the west portions of the greenhouse. Each is configured to provide a flowing film of water over the surface of the inner glazing to remove the heat from absorbed radiation or to provide warming in cold weather. The roof water circulation system is the primary means for controlling leaf temperatures.

Details of the roof water circulation system are shown in drawings M2, M5 and M12. Each system includes an 18 m³ (4800 gal) fiberglass storage tank, pumps, heat exchangers and the piping, valves and nozzles to distribute the water to the roof and return it to the tank. The tanks are filled with demineralized water. This water also serves as an emergency reserve for fertigation. The heat exchangers transfer heat to or from the well water to maintain the roof circulation water at the desired temperature.

An additional pump is configured to withdraw heated water returning from the roof and route it through reheat coils in the dehumidifiers. This function is more described in Section 3.2.3b below.

The principal features of the roof water circulation systems are:

Roof Water Pumps:

Number	Six (three each side)
Capacity	29.7 l/sec (470 gpm) each
Total Dynamic Head	95kPa (13.8 psi)
Motor HP	5 HP each
Controls:	One variable & two constant speed each side

Reheat Pumps:

Number	Four (two each side)
Capacity	18.9 l/sec (300 gpm) each
Total Dynamic Head	47.7 kPa (6.9 psi)
Motor HP	2 HP each
Controls	Constant speed.

b. Dehumidification

The fluid roof feature permits control of leaf temperature without the introduction of outside air. However, humidity in the closed system must be maintained at the proper level to promote plant growth and to prevent disease. A dehumidification system is incorporated with each compartment for the function.

Drawings M3 and M7 show the details of the dehumidification system. Each growing compartment has four fan coil units (Drawing M3), each with an air handling capacity of 3400 cfm. This provides for ten compartment air volumes per hour through the fan coil unit. Each of the fan coil units contain two coils, the first is a condensor coil which dehumidifies the air (Drawing M7), and the second is a reheat coil to lower the relative humidity of the air. The condensor coils require 40 gpm of well water and the reheat coils require 8 gpm of water being returned from

the roof. The water recovered from the air is collected in a drip pan and returned to the fresh water tank. During the peak summer months about 66% of the water transpired by the plant is recovered.

The principal characteristics of the fan coil units are:

No. of Fan Coil Units	16 (4 per compartment)
Fan Capacity	0.59 m ³ /s (3400 cfm)
Motor HP	3/4 HP each
Total Static Head	29 mm H ₂ O (0.75")
Condensor Coil Capacity	2.5 l/sec (40 gpm) each
Reheat Coil Capacity	0.5 l/sec (8 gpm) each

The exhaust fans provide active ventilation. Active ventilation provides up to ten air changes per hour.

The principal characteristics of the ventilation system are:

Vent Fans

No. of Vent Fans	12 (3 per compartment)
Capacity	2.2 m ³ /sec (4710 cfm) each
Fan HP	1/2 HP each
Fan Type	Propellor
Static Pressure	3.2mm (.124") H ₂ O

Intake Vents

No.	4 (1 per compartment)
Throat Area	5.2 m ² (56 ft ²) each
Velocity	2.54 m/s (500 fpm)
Static Pressure Loss	1 mm (0.04") H ₂ O

c. Well Water System

The well water system (Drawing M6) provides water to the heat exchanger for the roof water circulation system and the condensor coils in the dehumidification fan coil units. There are two well pumps, one for each side of the greenhouse. Their principal characteristics are:

Type	Vertical Turbine
Capacity	93.4 l/sec (1480 gpm) each
Motors	25 HP each
Control	Variable speed

d. CO₂ System

Bulk CO₂ is stored in a refrigerated storage tank at -18°C at 1000 kPa. The CO₂ is gasified, as required, by a heat exchanger through which glycol is pumped to heat the CO₂. The glycol loop transfers heat to a second heat exchanger loop which passes through an 8.3 m³ (2200 gal) fiberglass chilled water tank (Drawing M9). This tank is used for air conditioning of the support structure. If this tank becomes too cold the water is rejected to the dehumidification loop and make up well water is sent to the tank.

The CO₂ is distributed to the greenhouse through a main transfer line, and separate distribution manifolds are provided for each growing compartment (Drawing M8).

Solenoid valves provide for individual control of the CO₂ level in each compartment.

Details of the CO₂ system are shown in drawings M4, M8 and M9. The system is capable of injecting up to 70 gms of CO₂/m²/hr. This injection rate is sufficient to provide 2500 PPM CO₂ when all vents and louvers are closed and allows for operational levels of at least 600 - 1000 PPM CO₂ as required by the Task 2 Report.

3.2.4 Crop Production

a. Growing Medium

The growing medium is coarse silica sand with a minimum depth of 30 cm. The indigenous soil and backfill in each growing compartment will be sloped 0.3% toward an E-W line thru the center of the greenhouse. This soil will be covered with two layers of a plastic membrane (see drawing S4). A drainage network is laid on top of the membrane to collect leachate and fluids used for fumigation and salt leaching (see drawing P2). The coarse sand will then be spread and leveled. A leachate sump is provided at the east side of the greenhouse to collect the leachate.

b. Fertigation

Fertigation water is supplied to each growing compartment by a 40 psi fresh water main. Each compartment is equipped with a tank for concentrated nutrient solution, a fertilizer injector to provide 20:1 and higher dilutions, and a clock actuated controller to meter the diluted nutrient solution to the plants. The controllers can accommodate up to six different time schedules for each compartment to meet the needs of different crops.

Drawings P3 thru P6 show the plumbing arrangements for each compartment. It should be noted that the configurations are easily rearranged to suit any crop. The specific arrangements shown are tailored to the planned cropping schedule and were developed to ensure an adequate outfit of tubing and fittings for the Phase 3 Operation.

c. Planting and Harvesting

The planting and harvesting operations are the same as those in the Task 3 report.

3.3 WATER DESALINATION SYSTEM

The desalination system is a scaled down version of that described in the Task 3 report for the commercial size SCEAS. It has the capacity to produce 10m^3 (2640 gal) of water per day and to demineralize $4.55\text{ m}^3/\text{hr}$ (20 gpm) of fresh water input or $1.14\text{ m}^3/\text{hr}$ (5 gpm) of water being recycled from the roof circulating system. The analysis of the saline water feedstock and the predicted results of the desalination and demineralization units are shown in Table 2-1.

The desalination unit will be preassembled at the factory and will be delivered to the site on three skids, one each for pretreatment equipment, reverse osmosis equipment and demineralization equipment. Design details on each skid are given in Appendix B.

The skids will be installed on the south side of the indirect support building, adjacent to the loading dock.

The P&I diagrams for the desalination system are contained in Appendix A, drawings TE-1520-B02 through B04.

3.4 ENERGY SYSTEM

The energy system includes a photovoltaic array, DC to AC converter, inverter, battery storage, a utility tie contactor and a utility service connection. Appendix C contains specifications for the following equipments for the energy subsystem:

- Power conditioning and storage subsystem
- Branch circuit switching and monitoring panel
- Energy system monitoring instrumentation
- Photovoltaic modules

Appendix A contains the following drawings for the energy subsystem:

- Energy system block diagram and P&I diagram (E-01)
- PV array schematic (E-02)
- PV Branch Circuit switching schematic (E-03)
- PV Field layout (E-04)
- PV supporting structure and foundation (E-05)
- Power distribution single line drawing (E-9)

The power and energy requirements for the ETF are described in Section 4, performance analysis.

The photovoltaic power system services all agricultural loads and those support functions closely related to the agricultural function. The housekeeping loads and constant level loads are served by the utility. The utility also provides back-up power in lieu of the diesel generators that were incorporated in the commercial facility.

3.4.1 Photovoltaic Array

a. Module

An ARCO module was selected as the basis for a point design. The module has the following characteristics.

Size: 60.9cm x 121.9 cm (24" x 48")

Frame: 6063-T5 Aluminum Extrusions, 1.5" in depth

Electrical Output: 5.2V, 13.4A (69.7W) at 25°C cell temperature
and 1kW/m² AM1 insolation

Cell type, single crystal silicon, 10 cm (4") diameter

Cell configuration: 11 series x 6 parallel

Superstrate: 3.2 mm (.125") water-white "tempered glass.

The modules are available with receptacles for AMP "SOLARLOCK" connectors or with integral pigtails.

The module is not in current production. It is an enlarged version of a 1'x4' module which has been produced in quantity. It differs only in overall size and cell configuration (11S x 6P versus 11S x 3P) from the smaller module. A structural stiffener will be incorporated in the frame along the long dimension to give the same bearing strength as the smaller module.

The larger module permits economies in installation and wiring.

b. Branch Circuit

A nominal 300V branch circuit is used, comprised of 60 modules in series. The modules are not equipped with by-pass diodes. By-pass diodes will be installed in the branch circuit wiring between the positive and negative receptacles for each module. This configuration has the advantage of preserving the continuity of the branch circuit even if a module is removed, and of limiting the voltage across an open circuit within a module to the forward voltage of the diode. The problems of arcing within a faulty module and of loss of the safety achieved by shorting a branch circuit are thus eliminated.

The branch circuit power output, ignoring I^2R losses, is 4.182 kW.

c. Supporting Structure

A modular supporting structure has been selected. The basic structural element supports 20 modules in an 8' x 20' arrangement. Three such structural elements support a branch circuit. The structure is shown in drawing E-05.

The structure is made up of 3" x 5# and 3" x 6# steel channels supported by cylindrical concrete foundations. There are four foundations

for each 20' structural element. Dimensions have been selected for compatibility with standard lengths of structural steel and there is virtually no waste if 20' lengths are used. The cylindrical foundation dimensions have been selected to permit the use of standard size fiber tube forms.

The entire structure has been designed for minimum first cost and maintenance. Corrosion resistant high strength alloys (e.g., ASTM 242 or ASTM 588) were not selected because they are not ordinarily available in the small shapes required, and the quantity required (less than 7 tons) is too small for a special mill operation. ASTM A-36 steel with a high quality shop coat has been specified. It is adequate for the benign environment of El Paso.

The structure design is adequate for dead and live loads that exceed the extreme conditions for the El Paso area. The foundations are adequate for soil having bearing strengths as low as 945 psf. Their size is dictated by lift forces rather than bearing pressure.

d. Array Field

The array is comprised of nine branch circuits configured in two rows (see drawing E-02 in Appendix A). The N-S. spacing is 18' on centers, leaving approximately 2.59 m (8' 6") clear between rows for service vehicles during installation, servicing or array clearing. A 12' clear space is left between the rows to allow for cable runs and vehicle access.

e. Array Field Wiring

In general conductor sizes have been selected to equate the cost of the conductors to the incremental array cost required to offset conductor losses. This would require AWG #6 for the branch circuit wiring. However, the practical problems of connecting the branch circuit wiring to the by-pass diodes and receptacle terminals limit the conductor size for that portion to AWG #8. Cabling from each branch circuit to the equipment room is AWG #6.

Losses from all sources, based upon a typical branch circuit current of 10A (rather than the 13.4A peak) are as follows:

(1) Branch circuit wiring, including module pigtails, (450'/ branch circuit), 9 branch circuits, AWG #8	238W
(2) Branch circuit cables to equipment room, average <u>loop</u> length of 250', AWG #6, 9 branch circuits	89W
(3) Blocking diodes, 2 per branch circuit	126W
(4) Meter shunts, 3.33 Ω each	3W
(5) Main bus, 40' loop, 350 MCM	<u>10W</u>
Total	466W

The nominal array power is 37.6kW, but only about 22 kW are produced under typical conditions that result in a 10A branch circuit current, resulting in a power loss of 2.3%.

f. Array Monitoring

In addition to the monitoring of voltage, power and energy for the entire array output as described in paragraph 3.5.5, provision is made for monitoring the individual branch circuit currents during operation, and for measurement of branch circuit short circuit currents and open circuit voltages.

Figure 3-1 is a schematic of the circuit for measuring branch circuit currents during operation. Because the DC circuits are floating, the module is isolated from ground and interfaced with the data acquisition system through optical isolators.

Drawing E-03 is a schematic of the branch circuit switching arrangement. Any or all branch circuits can be connected to the shorting bus.

BRANCH CIRCUITS INPUTS FROM $3.3\text{ m}\Omega$ SHUNTS
NORMAL PEAK INPUTS WILL BE 45 mV

FIG 3-1

By shorting one at a time, the short circuit currents can be measured on an individual basis. Any or all branch circuits can be switched to an "open bus" to measure open circuit voltage.

Selected modules will be instrumented with temperature sensors to measure the module temperature.

3.4.2 Power Conditioning Subsystem

The Power Conditioning Subsystem (PCSS) includes a DC to DC converter which maintains the PV array at its peak power point. It is connected to the inverter and the battery by a regulated DC bus. The PCSS controls maintain the regulated DC bus at a voltage that will permit charging or discharging of the battery in response to variations in the power output of the PV array and the load demand.

The inverter output is 480V 60 Hz, 3, 4 Wire. The inverter will operate in any of three modes:

- a. Parallel with the utility
- b. Independent of the utility
- c. Independent, but in phase with the utility.

The PCSS includes a utility tie contactor which is normally open. It closes when:

- a. PV power is in excess of demand and the batteries are fully charged
- b. PV power is inadequate to carry the load and the batteries are exhausted
- c. The PCSS is shut down.

The PCSS is rated at 37 kW at 0.7 lagging to 0.9 leading power factors. It will carry a 50% overload for five seconds.

The demand distribution is shown in Figure 3-2. Self commutated inverters are relatively inefficient at part load, and a multiple unit configuration may be required by the nature of the distribution. Vendors have been requested to address this factor in their proposals.

Operation of the PCSS is fully automatic. It requires manual reset to turn it on in response to a shutdown caused by a manual command, internal fault or utility under or overvoltage (when operating with the utility i.e., contactor closed).

3.4.3 Electrical Storage

A 71 kWh (12 hour discharge rate) battery is provided. Electrical Storage is made up of 120 EXIDE PHv-DL25 deep cycle batteries. The nominal battery life is 1800 days with one deep discharge cycle per day.

A battery charger, capable of charging the battery at the 10 hour rate is provided. The charger is not intended for normal operation. When the charger is in use, the battery bus is disconnected from the regulated DC bus.

Three spare cells are provided. They are maintained at full charge with an automatic 6V battery charger.

3.5 CONTROL SYSTEM

The control system is essentially identical to that described for the commercial facility in the Task 3 report. Fully automatic control of all functions is provided, either by a computer in the central control station or by distributed control modules for specialized functions. Where distributed control functions are used, the central station computer effects control by an enable-inhibit command and status and alarm functions are monitored by the central computer.

POWER DEMAND DISTRIBUTION

FIG 3-2

Appendix A contains the following drawings for the control system:

<u>Dwg. No.</u>	<u>Title</u>
C-01	Control System Block Diagram
C-02	Growing Compartment Display-Control Panel
C-03	Well & Roof Water Display-Control Panel
C-04	Misc. Subsystem Display - Control Panel
C-05	Typical Equipment Control Circuit
C-06	Temperature Instrumentation
C-08	Meteorological Station

Appendix C contains specifications for the following elements of the control system:

- Display-Control Panels
- Data Acquisition and Control Equipment
- Central Computer
- Branch Circuit Current Monitoring Module.

3.5.1 Overview of Control System

Drawing C-01 (Appendix A) is a block diagram of the control system. In normal operation, the control signals from the computer go directly to the controlled elements. The status of those elements is displayed on the display-control panels.

All key parameters are displayed on the display-control panels. Their inputs are derived directly from sensors, independently of the processor where practical. Some parameters must be generated by the computer. Relative humidity, for example, is not directly measurable, and, in the absence of the processor must be derived from a psychrometric chart. The same is true for leaf temperature and it will be necessary to develop a nomogram to facilitate manual control.

The operator can assume manual control of any function by operating the auto-manual switch for that function. For example, the dehumidification function for growing compartment 3 can be put on manual control by flipping a switch in the central control room.

A single switch will be provided for assuming manual control of all functions normally controlled by the computer. A second master switch will permit shutdown of the PV system (inverter off, main array bus shorted and utility tie contactor closed).

Simple local control panels are provided in the A corridor to permit local control of compartment function. Key parameters required for local control will be displayed as required.

The following equipments and subsystems will have integral control modules:

- Desalination
- Demineralization
- Well water pumps
- Roof water pumps
- Roof inflation
- Fertigation system

3.5.2 Automatic Central Control Functions

Figure 3-3 shows the real-time scheduling of the computer. The major frame (repetitive time for cycling through all control functions) has a duration of five minutes. At the beginning of each major frame, all parameters to be logged are read and transferred to disc storage. Many of these parameters are not used for control purposes but are required for analysis of overall system performance. Software routines will be developed to analyze them for diagnostic purposes. For example, the individual

PRELIMINARY REAL-TIME SCHEDULING
OF CONTROL SYSTEM COMPUTER

FIG 3-3 (Notation shown in Table 3-2)

PV branch circuit currents will be compared for consistency to detect faults, and the array output, as a function of global insolation and the sun's position will be evaluated to detect the need for array cleaning.

The computer will update running averages for certain key control parameters such as global radiation, PAR (Photosynthetically Active Radiation) and wind speed and direction. Running averages are necessary to avoid rapid cycling of equipment in response to short term variations caused by clouds and windgusts.

As shown in Figure 3-3, there are five minor frames to each major frame. During each minor frame, all control functions are serviced. Figures 3-4 through 3-10 show the flow charts for the several control functions and Table 3-2 lists the notation used.

3.5.3 Display-Control Panels

The preliminary arrangement of display-control panels are shown in drawings C-02, C-03 & C-04 (Appendix A). They are largely self explanatory. A separate panel for each growing compartment permits immediate assessment of its status. The manual control switches have no effect when the auto-manual switch for their function is in the auto position, but their lamps indicate the on-off (or open-closed) status in both the auto and manual positions.

Alarms are displayed on illuminated push button switches with red lamps. When an alarm is set, the lamp will pulsate and an audible signal will be activated. When the operator acknowledges the alarm by depressing the switch, the lamp will remain on and cease to pulsate, and the audible signal will cease.

A separate panel provides for display and controls of the roof-inflation, roof water circulation and well water function.

A third panel type is provided for display and control of the desalination, demineralization and CO₂ subsystem functions.

3-25
SERVICE GROWING COMPARTMENT
DH FUNCTION

FIG 3-4

REPRODUCED FROM
BEST AVAILABLE COPY

SERVICE GROWING COMPARTMENT
ROOF WATER CIRCULATION FUNCTION

FIG 3-5

REPRODUCED FROM
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CO₂ LEVEL (PPM)

SP_G + 50

SET POINT (SP_G)

SP_G - 50

SP_G - 100

--- CLOSE CO₂ VALVE

--- OPEN CO₂ VALVE

--- ALARM LEVEL

SERVICE GROWING COMPARTMENT
CO₂ SUPPLEMENTAL FUNCTION

FIG 3-6

3-27

SERVICE ROOF WATER AND REHEAT
PUMPS (EAST AND WEST SIDES IDENTICAL)

FIG 3-7

SERVICE CO₂ SYSTEM

FIG 3-8

NOTE:
DESALINATION WILL INDICATE
"NOT READY" IF ALARM CONDITION
EXISTS.

SERVICE DESALINATION UNIT

FIG 3-9

REPRODUCED FROM
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DEMINERALIZATION SERVICE TANK

FIG 3-10

TABLE 3-2. NOTATIONS USED ON CONTROL FLOW CHARTS

CO_2	CO_2 - or CO_2 Concentration in PPM
E	East Roof Water Tank
F	Fresh Water Storage Tank
Ids	Global Insolation (running average)
K_1	Limiting level of Ids for operation of fan coil units and roof water pumps
K_2	Limiting ΔT_1 for efficient operation of fan coil units for dehumidification
K_3	Upper limit of dead band for leaf temperature control
K_4	Lower limit of dead band for leaf temperature control
K_5	Limiting volumetric air flow (in air changes per hour) for CO_2 supplementation
K_6	Limiting available volume for operation of desalination unit
LAH	High Level Indication
LAL	Low Level Indication
RH	Relative Humidity
RW	Roof Water
SP_D	Set Point for Dehumidification (% RH)
SP_C	Set Point for CO_2 Concentration (PPM)
SP_{TLH}	Set Point, High Leaf Temperature Limit
SP_{TLL}	Set Point Low Leaf Temperature Limit
TL	Leaf Temperature
W	West Roof Water Tank
ΔT_1	Compartment Drybulb Temp. Minus Well Water Temp
σ	Conductivity (Salinity) Indication

Figure 3-11 shows the physical arrangement of the central control station.

3.5.4 Local Control Panels

The layout of a typical compartment local control function is shown as an inset to drawing C-02. Whenever local control for any function is selected, a "LOCAL" alarm for that function is set. This alarm is transmitted to the display-control panel in the central control station and to the computer.

It is anticipated that the local control panels will be used only during checkout and alignment or in conjunction with repairs to equipments or subsystems.

3.5.5 Instrumentation

a. Meteorological Station.

A self contained meteorological station is provided. The instruments provide for measurement of wind speed, wind direction, air temperature, relative humidity, precipitation, barometric pressure and solar radiation. Two pyranometers are provided, one to measure global radiation and the other to measure the radiation that will be received in the greenhouse. The latter will be installed under a "mini-greenhouse" made up of the same materials as the greenhouse roof.

All instruments except the precipitation gauge and the second pyranometer are mounted on a 30' guyed tower. The tower has a lightning rod and grounding system. Signal conditioning equipment integral to the meteorological station provides outputs to drive a display panel in the control room and 0 to 5 volt outputs for all measurements to the data acquisition system.

CONTROL ROOM LAYOUT

FIG 3-11

b. Energy Monitoring.

Control panels for monitoring the energy system parameters are provided. They include meters to display cumulative energy at key points. Outputs are provided to the data acquisition system for monitoring. Table 3-3 lists the parameter measured.

c. Temperature Measurements.

Drawing C-06 (Appendix A) shows several configurations used for temperature measurements. In all cases, a readout is provided independently of the processor to facilitate manual control in the event of processor failure. Thermistors have been used where possible to provide high accuracy, good resolution and repeatability. RTDs would have been the preferred sensor, but the cost of bridge assemblies and additional wiring to compensate for losses and temperature coefficients in conductors was judged to exceed the worth of the improved accuracy.

d. Portable Instrumentation.

An outfit of portable instruments will be provided for calibration of installed devices and for special experiments. The requirements list is not complete at this time, but includes standard mercury thermometers, a 0 to 19.999 V DC calibration source, a portable radiometer with PAR filter, an HVAC anemometer and the usual assortment of portable meters.

3.6 SUPPORT FACILITIES

The support facilities include a support building, storage tanks, miscellaneous mechanical system and roads, fencing and other civil works required to make the SCEAS a self contained experimental facility.

MONITOR POINT	DESCRIPTION	PARAMETERS	RANGE	DISPLAY	OUTPUT TO COMPUTER
1	PV ARRAY OUTPUT	VOLTAGE	200 - 300 VDC	METER	0 - 10V DC
		POWER	0 - 40 KW	METER	0 - 10V DC
		ENERGY	--	COUNTER	100 Wh pulses
2	BATTERY	ENERGY IN	0 - 30 KW	COUNTER	100 Wh pulses
		ENERGY OUT	0 - 30 KW	COUNTER	100 Wh pulses
		CURRENT	-110 to +110A	METER	-10V to +10V DC
3	INVERTER INPUT	VOLTAGE	180 to 290 VDC	METER	0 - 10V DC
		POWER	0 - 40 KW	METER	0 - 10V DC
		ENERGY	--	COUNTER	100 Wh pulses
4	INVERTER OUTPUT	VOLTAGE	480V $\pm$ 10%	METER	0 - 10V DC
		POWER	0 - 40 KW	METER	0 - 10V DC
		ENERGY	--	COUNTER	-100 Wh pulses
		P.F.	~.5 lead - .5 lag	METER	-10 to +10V DC
5	UTILITY TIE	POWER (IN OR OUT)	0 - 40 KW	METER	-10 to +10V (or separate signals)
		ENERGY IN	--	COUNTER	100 Wh pulses
		ENERGY OUT	--	COUNTER	100 Wh pulses

TABLE 3-3 SCEAS ENERGY SUBSYSTEM MONITORING

3.6.1 Indirect Support Building

A 465 M² (5000 ft²) prefabricated steel building is provided to house the offices, sanitary facilities, water treatment equipment, shop and work spaces, electrical equipment and the control room. The building is located immediately north of the greenhouse and is connected to it by a 7.4 X 7.3 (24' 2" x 24') linking corridor. The linking corridor includes loading docks for two trucks.

Drawings S7 and S8 show the plan and sections of the indirect support building. Details of the electrical and mechanical system are shown in drawings E-4, E-5 and M-11.

3.6.2 Storage Tanks

The following storage tanks are provided:

<u>FUNCTION</u>	<u>SIZE</u>	<u>CONSTRUCTION</u>
Freshwater	22.7 m ³ (6000 gal)	Fiberglass
Roof Circulation Water (2)	18.2 m ³ (4800 gal)	Fiberglass
Chilled Water	8.3 m ³ (2200 gal)	Fiberglass
Leachate Sump	380 l (100 gal)	Concrete
Well Water Storage	5.3 m ³ (1600 gal)	Fiberglass

3.6.3 Miscellaneous Systems and Facilities

The access roads parking and other paved areas, perimeter fence, etc., are shown on drawing S-1.

A low volume well is located to the west of the indirect support building. This well serves the desalination system and provides for displacement of water from the chilled water tank when its temperature becomes too low for efficient operation of the glycol loop (for gasification of CO₂).

A 250 m² holding pond is provided for temporary storage of the water treatment system blowdown at times when insufficient well water is being used for proper dilution.

3.6.4 Miscellaneous Facilities

The following additional facilities are included in the ETF:

- a. Cold Storage--A 9 m³ (2400 ft³) cold storage room is provided for produce storage.
- b. Septic Tank--A septic tank and leaching field are included for sewage disposal.
- c. Potable Water.

City water will be provided for sanitary purposes. While the desalinated water is adequate for this purpose, it would not be in literal compliance with the Texas water quality standards. These standards require chlorination to 1 mg/l and a contact time of 20 minutes. The use of city water is more economical than the provision of a chlorination system and the required tankage.

SECTION 4

SYSTEM PERFORMANCE

A detailed performance simulation of the greenhouse test facility was conducted for the entire year on an hour-by hour-basis. Weather data were obtained from the SOLMET Typical Meteorological Year tape for El Paso. Documentation of the detailed analysis for both energy supply and greenhouse loads of the methodology was provided in the Task 3 Report. Key Subsystem sizing and performance parameters are summarized in Table 4-1. The greenhouse environment is generally controlled to maintain leaf temperatures in the range 10-35°C and humidity less than 80%. The discussion which follows summarizes monthly and annual performance totals for the system.

For all of the performance results, the subsystem data that is provided should be interpreted as follows:

- PV output is dc power including field wiring and module mismatch, but not regulator losses
- Power conditioning output is the total reactive power at the inverter output terminals (before transmission and distribution losses)
- Well power includes total brackish water reactive pumping power for greenhouse and desalination including transmission, distribution and power factor losses.
- Utility backup and excess power are AC power at the power conditioner terminals
- Utility back up includes reactive power and provides for transmission and distribution losses
- Excess power is first consumed in the support facility and then sold back to the utility.

All data presented below is in kJ or kJ/h. These units can be expressed in kWh or kW by dividing by 3600.

TABLE 4-1. SUBSYSTEM PERFORMANCE PARAMETERS

Subsystem	Rated Capacity	Key Performance Parameters
Photovoltaic Array	37.7 kWp	<ul style="list-style-type: none"> ● ARCO Solar flat plate modules ● 44° NOCT @ 0.8 kW/m² insolation, 20° C ambient ● 0.5%/°C cell temperature coefficient for power ● 2% field wiring losses ● 20° tilt angle, south facing
Array Regulator	37 kW	<ul style="list-style-type: none"> ● Maximum power tracking ● 94% efficiency
Battery	88.8 kWh (100% discharge)	<ul style="list-style-type: none"> ● 80% round trip efficiency ● Allowable discharge 80% of rated capacity
Power Conditioning	37 kVA	<ul style="list-style-type: none"> ● DC-AC inverter ● 90% efficiency ● 25% kVA/kW power factor applied to all loads
Transmission/Distribution	-	<ul style="list-style-type: none"> ● 2% losses
Utility Backup	-	<ul style="list-style-type: none"> ● Sellback and backup power available
Desalination	10m ³ /d	<ul style="list-style-type: none"> ● RO pumping power 1.51 kWh per /m³ fresh water ● 40 psi line pressure required ● 75% recovery ratio ● 62% efficient pumps
Well Pumps	2-25 hp 1-5 hp	<ul style="list-style-type: none"> ● 6 m lift ● 1m drawdown ● 1m friction head ● 62% efficiency
Greenhouse Loads	0.315 hectare growing area 0.36 hectare total area	<ul style="list-style-type: none"> ● 70% efficient pumps ● 35° C maximum leaf temperature ● 10°C minimum leaf temperature ● 80% relative humidity control ● 1000 ppm CO₂ enhancement ● 75% crop area utilization
Support facility loads		<ul style="list-style-type: none"> ● Supplied from excess power or from utility

Annual energy totals for the test facility performance are presented in Table 4-2. The photovoltaic system provides 96% of the total loads of the greenhouse itself. In addition, about 38 MWh/y of excess energy is available for consumption in the support facility and for sellback to the utility. The utility provides backup energy for about 4% of the greenhouse loads, necessary during winter nights. The net utility energy balance is a positive net sellback, since greater excess occurs than backup requirements. moreover, the sellback occurs during the peakload summer months. The amount of excess and backup energy is extremely small relative to the total greenhouse loads. This close matching of energy supply and consumption is a consequence of the direct correlation between greenhouse loads and the insolation resource.

Figures 4-1 through 4-6 provides plots of monthly energy balances for PV output, battery charging energy, battery discharging energy, utility backup, excess energy and brackish water pumping energy (the latter is the dominant load). A typical hour-by-hour plot for a cold day in January and a hot day in July are shown in Figures 4-8 and 4-9; power shown is kJ/h; it should be noted that each plot is normalized separately so that the scales change significantly. Both the monthly profiles in the figures and the detailed hourly plots in the computer printout addendum demonstrate the effective matching between PV system outputs and loads and provide a comprehensive verification of the test facility performance.

Table 4-2. Annual Energy Totals for the Test Facility

	Annual Energy Total	
	<u>GJ</u>	<u>MWH</u>
PV subsystem output	297.1	82.5
PCU reactive energy to loads	90.6	25.2
PCU AC excess (to support (to support facility and loads)	153.9	42.8
Battery charging energy	20.7	5.8
Battery discharging energy	16.6	4.6
Utility backup to loads	3.4	0.9
Total Loads	93.9	26.1

Figure 4-1. Monthly Photovoltaic Array Output (GJ/mo)

Figure 4-2a. Monthly Battery Charging Energy (GJ/mo)

Figure 4-2b. Monthly Battery Discharging Energy (GJ/mo)

Figure 4-3. Monthly PCU Output Direct to Loads (GJ/mo)

Figure 4-4. Monthly Utility Backup Energy (GJ/mo)

Figure 4-5. Monthly Excess Energy (GJ/mo)

Figure 4-6a. Monthly Total AC Reactive Loads (GJ/mo)

Figure 4-6b. Monthly Brackish Water Well Energy (GJ/mo)

SECTION 5

TEST, INSPECTION AND ACCEPTANCE

5.1 SCOPE

Acceptance is the final result of satisfactory test and inspection at the various levels of assembly of the SCEAS. The acceptance criteria for the SCEAS include the satisfactory completion of all tests and inspections to verify compliance with the specifications and the functional verification of the system as a whole to meet the criteria enumerated in Section 2.

Tests and inspection vary in method and detail with the items and level of assembly. Items to be tested and inspected include the following:

- Construction Materials. This includes structural metal, concrete, glazing, gasketing bolts, concrete, etc. Tests and inspections will verify the sizes, quantities, physical properties, finish, etc.
- Equipment to be Furnished and Installed by the Contractor. This category includes the pumps, motors, tanks, fan coil units, fans, louvers, distribution panels transformers, motor controllers, valves, HVAC equipment, fixtures, etc. In general, test and inspection will include quantity, nameplate data and first order operating checks. The specifications designate a specific model for each item, "or equivalent." The contractor is required to obtain approval for equivalents prior to installation.
- Site Preparation. This category includes all clearing, grading, excavation, tamping, backfill, etc. Test and inspections include verification of dimensions, compliance with material inspection, verification of density, etc.
- Workmanship. This category includes all steps associated with the physical construction of the facility. Test and inspection shall include verification of dimensions, welding, assembly of reinforcements, torqueing of bolts, application of finishes.

- Subsystem Procured as Owner Furnished Equipment. This category includes the desalination equipment, power conditioning of subsystem, control system, meteorological station, etc. Where practical, tests will be conducted at the factory, with SAI personnel witnessing the test. Otherwise, they will be conducted after installation. The testing will verify compliance with specifications for construction and performance.
- Components Procured As Owner Furnished Equipment. This category includes photovoltaic modules, batteries, certain instruments and sensors, etc. For standard catalogue items, the manufacturers certified test data will be accepted, subject to subsequent proof of performance under the warranty terms. The testing of about 10% of the photovoltaic modules will be witnessed by SAI personnel on an unannounced basis.
- Progressive Performance Testing. As construction progresses, tests will be conducted to ensure that combinations of components and equipments meet the acceptance criteria. Compartment integrity (infiltration), inflated roof leakage, roof water films, etc, are included in this categories.
- Final Acceptance Testing. The acceptance criteria enumerated in Section 2 will be verified when construction is essentially complete.

5.2 RESPONSIBILITIES

SAI is ultimately responsible for all tests, inspections and acceptance activities. The first prerequisite is approval of the final drawings and specifications, since all test and inspection procedures are derived from these documents. Authority will be delegated to the architect and to the mechanical and electrical engineer to conduct tests and inspections in accordance with procedures and criteria to be approved by the SAI project manager.

There will be an SAI representative on site at all times during construction, and representatives of the architect and the mechanical and electrical engineer will be on site as required.

5.3 DEVELOPMENT OF TEST PLANS

The general contractor is required to submit a construction schedule prior to commencement of construction. The test schedule will be developed to coincide with the construction work and to ensure timely approvals of satisfactory work.

A test procedure will be prepared for each item or sequence to be tested or inspected. The procedure will include a verbatim extract of the applicable specification and references to pertinent drawings; the state of completion required prior to test or inspection; a measurement list indicating what is to be physically measured, the instruments or tools required for measurement, the tolerances, etc; the data to be recorded, and the requirements for sign-off by the inspector and the SAI on-site representative. For certain items such as concrete, welding, product water quality, etc, samples will be submitted to an independent laboratory for verification of conformance with specifications.

For subsystems to be tested as an entity, the test plan will include a check-off list to verify each item of the specification and to ensure the adequacy of start-up and shut-down sequences.

5.4 PROGRESSIVE TESTS

Key performance functions will be tested as the work progresses. The more important tests are summarized in Table 5-1.

Control System Test and Acceptance

The control system components and most of the sensors will be assembled at the SAI/McLean, Virginia laboratory as early as practical in Phase II. All hardware interfaces will be checked out and the software will be developed and debugged to the extent practical prior to shipment to the site.

Progressive Test

<u>Function</u>	<u>Prerequisites</u>	<u>Procedure</u>
Compartment Envelope Integrity	Completion of the construction of each growing compartment, CO ₂ manifold, CO ₂ analyzer and sample tubes installed. Meteorological station or portable anemometer available	Raise CO ₂ level to a value substantially above atmospheric level. Record compartment CO ₂ level, ambient CO ₂ level & wind speed vs. time.
Ventilation Fan Volumetric Flow	Same as above	Raise CO ₂ level to a value substantially above atmospheric level. Operate one vent set (louver, fan & intake damper). Record compartment CO ₂ level vs. time.
Inflated Roof Integrity	Inner glazing, plastic roof, air supply plenum complete	Fabricate air tight covers for air intake, install manometer, inflate roof, install covers & record pressure vs. time
Roof Water Circulation	Roofing complete, well & roof water circulation systems installed, roof temperature sensors and readout meters installed.	Select day with insolation > 750w/m ² . Operate roof pumps at flow rates from 30% to 100% in 10% increments. Record temperatures of roof, well water to and from heat exchangers and roof water to and from roof. Make visual inspection for leaks.

5-4

Progressive Test

Function

Prerequisites

Procedure

Dehumidification

As above plus installation of fan coil units and temperature probe aspirators and availability of desalinated water.

Select day with insolation $> 750 \text{ w/m}^2$. Hose down growing medium and operate lawn sprinklers within compartment. When relative humidity rises to 95%, stop sprinkler, turn on all fan coil units and roof water circulation system. Record wet & dry bulb temperatures vs. time.

PV Branch Circuits

Installation of a complete branch circuit & the branch circuit switching panel

Select a clear day, short branch circuit and record short circuit current & insolation vs. time. Once each hour open branch circuit & record voltage, operate for four hours.

PV Array Performance

PV array complete & PCSS installed. Energy monitoring panels installed.

Turn system on, close utility tie switch. Record cumulative energy from PV array and insolation vs. time.

PCSS Performance

Same as above

Same as above: Plus record cumulative energy to and from battery, from PCSS, PCSS Power factor vs. time.

Table 5-1 Sheet 2

The control system will be installed in the indirect support facility as a matter of priority, and will be wired to the control system side of the wire closet. As each sensor and actuator is installed and wired to the system side of the wire closet, it will be cross-connected to check the proper response. The calibration curves of all sensors will be verified and required changes to scaling routines will be made on the spot.

Verification of the control software will not be possible until construction is substantially complete. However, the prior check-out of input and output responses will have eliminated wiring and calibration errors. The set points for compartments will be varied and the system response verified by use of portable instruments. Some operating parameters will not be fully refined until well into Phase III. For example, the ventilation settings for temperature and humidity control will have been calculated, and may require modification after exposure to a wide range of ambient conditions. This does not present a significant problem nor does it preclude agricultural operations because of constant monitoring and correction. However, maximum efficiency cannot be achieved with rapid on/off cycling of the systems.

The software testing must be viewed as an ongoing experimental aspect of the engineering test facility.

5.5 FINAL ACCEPTANCE TESTS

An acceptance test plan will be prepared to demonstrate compliance with the criteria in Section 2. In addition, the specified performance levels for all supporting systems will be tested to the extent verifiable under the ambient conditions.

Performance will be verified under both automatic and manual control.

Section 6
SUPPORT REQUIREMENTS

6.1 SCOPE

This section enumerates the requirements for equipment, personnel and supplies required for the initial output of the FPHP and its continuing operation on an annual basis.

6.2 CAPITAL EQUIPMENT

Table 6-1 lists equipment, not otherwise included in the drawings and specifications, that are required for operation of the FPHP. Their estimated costs are included.

6.3 OPERATING REQUIREMENTS

Table 6-2 lists the estimated annual requirements for consumable supplies and general maintenance for the first full year of operation.

Table 6-1 Capital Equipment Requirements

Vehicles, 2 electric carts with batteries and charger, one produce truck	35,000
Greenhouse equipment, including scales, produce sizer, mist sprayer, automatic seeder, hand tools, etc.	20,000
Laboratory equipment, including pH meter, conductivity meter, electronic balance, microscope, miscellaneous glassware and lab hardware	14,500
Maintenance equipment, including hand and power tools	5,000
Portable instruments and calibration standards, data logger, etc.	9,000
Total	<u>83,500</u>

Table 6-2 Estimated Annual Requirements for
Consumables and Maintenance (dollars)

<u>Greenhouse Operation</u>	
Carbon Dioxide	20,000
Packaging Materials	15,000
Production Materials	16,000
Agrichemicals	35,000
<u>Water Treatment Chemicals & Filters</u>	1,150
<u>Utilities</u>	6,600
<u>Maintenance (services & materials)</u>	<u>30,000</u>
	\$123,750

6.4 PERSONNEL REQUIREMENTS

The staff requirements enumerated in this section are the absolute minimum to achieve the objectives of the engineering test facility. Obviously, the number of full-time staff can, and probably should, be increased as crop production and marketing conditions require. Funds received from the sale of vegetables could be used for this purpose.

The required qualifications for the personnel identified in the organizational chart (Figure 6-1) are as follows:

Texas Agricultural Experiment Station Project Manager (10%)

The Texas Agricultural Experiment Station Project Manager reports to the SAI Project Manager, and has overall responsible for operation and maintenance of the ETF. Reporting directly to him are the: Officer-in-Charge, El Paso; Director, Horticultural Operations, College Station; and Director, Environmental Systems, College Station. In addition, he is directly assisted by a one-half-time secretary.

FIG. 6-1 FTTP ORGANIZATION CHART

Officer in Charge - El Paso (10%)

The Officer-in-Charge at El Paso is responsible for the day-to-day operations of the ETF. All full-time staff at El Paso, including a secretary, report directly or indirectly to him.

Director - Environmental Systems (10%)

The Director - Environmental Systems is responsible for carrying out a comprehensive program of evaluation for the crop-production environment. He will be assisted by a full-time research associate for acquisition and analysis of all environmental data. The Director will maintain regular communication with, and will exercise technical authority over, the El Paso-based Engineer.

Director - Horticultural Operations (10%)

The Director - Horticultural Operations is responsible for the crop production program and for collection and analysis of all crop yield and quality data. He will be assisted by a one-half-time graduate assistant in College Station. He will maintain regular communication with, and will exercise technical authority over, the El Paso-based horticulturist.

Engineer - (100%)

The Engineer will coordinate all facility maintenance functions and is responsible for proper operation of all systems and equipment. He must maintain the inventory of essential spare parts and is responsible for purchasing maintenance contracts or services. He will also be responsible for collecting and transmitting the necessary data required to evaluate system performance. Administratively, he reports to the El Paso Officer in Charge; however, he is responsible to the Director - Environmental Systems for providing all technical information requested. He will be assisted by a Maintenance Technician.

Section 7
DRAWING LISTS FOR PHASE II

The degree of detail provided for the preliminary design will require a minimum number of additional drawings for the Phase II detailed design. All drawings in Appendix A will be reviewed and revised as necessary to reflect final design details and the results of soil reports, etc.

Table 7-1 lists additional drawings that will be produced for the final design.

Shop drawings to be prepared by the general contractor or his subcontractor during the construction phase are specified in the applicable specifications, Appendix B.

Table 7-1 Additional Drawings to be Provided
During Phase II

Site and Structural

Building Complex Plan
Site Preparation Drawing
Site Details
Additional Greenhouse Details
Indirect Support Building Details

Mechanical

Outline and Mechanical Interface, Pretreatment Skid
" " " " Reverse Osmosis Skid
" " " " Desalination Skid
Roof Inflation Blower Control and Pressure Sensors
Additional Detail Sheets, Plumbing
Additional Detail Sheets, Fan & Louver Installation

Electrical

Utility Interface
PV Array, Wiring, Conduit & Grounding Details
PV Branch Circuit Junction Box Details

Control & Instrumentation

Pressure & Flow Instrumentation
Wire Closet Details
General Arrangement, Electrical Equipment Room
" " Battery Room
Central Control Room Rack Face Elevations
Enclosure Arrangement, Corridor Control Panels
Wire Running Lists
Meteorological Station, Erection & Wiring Details

Horticulturist (100%)

The Horticulturist coordinates the day-to-day operation of the greenhouse facility and implements the crop-production and marketing program. He is responsible for setting the operating conditions of the greenhouse systems and coordinating the transplanting crop production, harvesting, packaging, and marketing of the greenhouse products. He is responsible for maintaining a detailed log of all operation and activities associated with the handling of crops and residual biomass.

Administratively, he reports to the El Paso Officer in Charge; however, he is responsible to the Director - Horticultural Operations for providing all technical information requested. He will be assisted by two Crop Production Workers.

Maintenance Technician (100%)

Working under the supervision of the Engineer, the Maintenance Technician will perform all regular maintenance on pumps, valves, piping, and tanks and structures for the complete facility. He must be familiar with procedures to purchase the required materials and expedite the work required for repair activities. He must be capable of assisting supervisory personnel in the conduct of tests relating to the mechanical system.

Crop Production Workers (100%)

Working under the supervision of the Horticulturist, the Crop Production Workers will perform all regular planting, harvesting, and other cultural operations as well as packaging of the produce and, if necessary, delivery to the marketplace.