NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

MBA PROFESSIONAL REPORT

OPERATION SOLAR EAGLE:
A Study Examining Photovoltaic (PV) Solar Power as an Alternative for the Rebuilding of the Iraqi Electrical Power Generation Infrastructure

---

By: **Curtis Austin,**
Ralph Borja, and
Jeffery Phillips

June 2005

Advisors: **Ron Tudor, and**
Brad Naegle

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** June 2005	**3. REPORT TYPE AND DATES COVERED** MBA Professional Report

4. TITLE AND SUBTITLE: OPERATION SOLAR EAGLE: A Study Examining Photovoltaic Solar Power as an Alternative for the Rebuilding of the Iraqi Electrical Power Generation Infrastructure	**5. FUNDING NUMBERS**
6. AUTHOR(S) Curtis Austin, Ralph Borja, and Jeffery Phillips	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School (NPS) Monterey, California 93943-5000	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**

11. SUPPLEMENTARY NOTES: The views expressed in this report are those of the author(s) and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited	**12b. DISTRIBUTION CODE**

13. ABSTRACT (maximum 200 words)

The purpose of this project is to examine the cost and feasibility of using photovoltaic solar power to assist in the rebuilding of the Iraqi infrastructure. The project will examine available solar equipment and technologies coupled with requirements for operation, installation and maintenance of such systems. The report begins with an analysis of the current state of the Iraqi infrastructure with special emphasis placed on identifying potential candidates for initial solar PV system installation. Next, the report addresses available commercial solar equipment and emerging technologies that enhance such systems. This section will address areas including installation, operation, maintenance, and durability. Finally, the report will conclude with a cost estimate for using solar PV systems in the rebuilding of Iraq. At the conclusion of the project, information will be available for decision makers to include as part of an operations order or to attach as an annex to an existing operations order.

14. SUBJECT TERMS Solar Power, Photovoltaic, PV, Rechargeable Batteries, Logistics, BA-5590, BB-390, BB-2590, PVPC, Iraq, Power Grid, Infrastructure, Cost Estimate, Photovoltaic Power Conversion (PVPC), MPPT	**15. NUMBER OF PAGES** 187
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UL

OPERATION SOLAR EAGLE: A STUDY EXAMINING PHOTOVOLTAIC (PV) SOLAR POWER AS AN ALTERNATIVE FOR THE REBUILDING OF THE IRAQI ELECTRICAL POWER GENERATION INFRASTRUCTURE

Ralph Borja, Major, United States Army
Jeffery Phillips, Major, United States Army
Curtis Austin, NH-III, Department of Army Civilian

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF BUSINESS ADMINISTRATION

from the

NAVAL POSTGRADUATE SCHOOL
June 2005

Authors: Ralph Borja

Jeffery Phillips

Curtis Austin

Approved by: Ron Tudor, Lead Advisor

Brad Naegle, Support Advisor

Douglas A. Brook, Dean
Graduate School of Business and Public Policy

THIS PAGE INTENTIONALLY LEFT BLANK

OPERATION SOLAR EAGLE: A STUDY EXAMINING PHOTOVOLTAIC (PV) SOLAR POWER AS AN ALTERNATIVE FOR THE REBUILDING OF THE IRAQI ELECTRICAL POWER GENERATION INFRASTRUCTURE

ABSTRACT

The purpose of this project is to examine the cost and feasibility of using photovoltaic solar power to assist in the rebuilding of the Iraqi infrastructure. The project examines available solar equipment and technologies coupled with requirements for operation, installation and maintenance of such systems. The report begins with an analysis of the current state of the Iraqi infrastructure with special emphasis placed on identifying potential candidates for initial solar PV system installation. Next, the report addresses available commercial solar equipment and emerging technologies that enhance such systems. This section addresses areas including installation, operation, maintenance, and durability. Finally, the report concludes with a cost estimate for using solar PV systems in the rebuilding of Iraq. At the conclusion of the project, information will be available for decision makers to include as part of an operations order or to attach as an annex to an existing operations order.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGMENTS

We would like to express our gratitude to Professor Ron Tudor, Professor Brad Naegle, and Professor Mark Eitelberg whose interest, expertise, and guidance were essential in directing and completing our MBA project. In addition, we appreciate the time and data exchange between Stefan Matan and Bill Westbrock. We also offer special thanks to Lewis Phillips and Steve Ansley for their support and assistance with PVPC information, test data, and system analysis.

THIS PAGE INTENTIONALLY LEFT BLANK

EXECUTIVE SUMMARY

The purpose of this MBA project is to examine the cost and feasibility of using photovoltaic (PV) solar power to assist in the rebuilding of the Iraqi electrical infrastructure. This project examines available solar equipment and technologies coupled with requirements for operation, installation and maintenance. The project begins with an analysis of the current state of the Iraqi infrastructure. It provides an example of how solar power can be used in Iraq and presents case studies of several countries that have successfully implemented solar power projects at some level. Next, the project addresses commercially available solar equipment and emerging technologies that enhance the performance of solar PV systems while reducing the overall cost. The preceding topics provide details on the installation, operation, maintenance, and durability of PV systems. Finally, the project addresses the financial cost of using solar PV systems in the rebuilding of the Iraqi electrical infrastructure. Test data are gathered and analyzed to determine potential benefits of emerging solar technologies.

In Iraq, a country of 25,374,691 citizens covering 437,072 square kilometers[1] (km), the availability of electrical power is essential to support the population's existence. Prior to Operation Iraqi Freedom (OIF), Iraqi citizens were forced to live with programmed electrical blackouts because of an insufficient power grid.[2] The outbreak of war worsened the pre-existing problem and caused a temporary loss of power in many cities throughout Iraq. Once the United Stated (U.S.) forces entered Iraq, they quickly realized that they had to get electricity flowing in order to prevent a humanitarian disaster.[3]

A major challenge for U.S. Forces in Iraq, and Afghanistan, is post-conflict development. For post-conflict development to be sustainable, the infrastructure must be rebuilt using technology that can be operated and maintained in the future; equally important, a solution cannot benefit one part of the population at the expense of another

---

[1] Download from www.cia.gov/cia/publications/factbook/geos/iz.html on April 6, 2005.

[2] Ibid, 24.

[3] Ibid, 22.

part of the population; and finally, a plan must be developed and efforts must be financed in order for the rebuilding to be effective.[4] For the electrical grid in Iraq, solar PV power unquestionably meets the first two characteristics in that it can be operated and maintained in the future and it does not benefit one part of the population at the expense of another. This MBA project examines the third aspect by assisting in the planning efforts for implementation as well as assessing solar PV systems' feasibility in supporting rebuilding efforts in Iraq.

Iraq's electrical infrastructure shortcomings are a pre-existing problem that has left the population with limited power for many years. Saddam Hussein and his regime neglected the electrical infrastructure of Iraq for decades. To compensate for the ever-growing shortages, electricity was distributed to desired areas but it was not distributed equitably across the country. There were certain parts of the country that received power 24 hours a day, while others only had as little as 10 hours a day, to none at all. Starting in September 2004, a new more equitable electrical power distribution plan was implemented and most areas in Iraq were receiving between 11 to 15 hours of electricity daily.

Improvements to the Iraqi electrical infrastructure have been made but a delta remains between supply of electrical power and the current demand for electrical power with the problem expected to worsen in the future as Iraq's industry recovers and the citizens' electrical demands increase. The Iraqi electricity minister informed an Iraqi newspaper in March 2005 that the electrical grid was providing 5,000 megaWatts (MW) and by the end of April 2005, the power grid should provide 18 hours of daily power. He estimated that in order to provide continuous electrical power to the citizens of Iraq, it would cost $1 billion per year. These funds would be used to make improvements and build facilities that would enable the grid to provide 15,000-MW in the future. The 15,000-MW requirement is based on studies that predict Iraq will grow at 20 percent per

---

[4] G. Junne, & W. Verkoren, 2005. *Postconflict development.* Lynne Rienner, Boulder, Colorado. 103.

year for the next five years and that amount of electrical power will be needed to meet demands.[5]

Currently in Iraq, insurgent attacks on the electrical infrastructure are a significant problem and the application of resources is required to provide protection of pipelines, power lines and facilities. The requirement to secure the Iraqi electrical infrastructure from insurgents is an existing long-term and expensive problem. During Saddam Hussein's reign, he used local tribes and parts of two Iraqi Army divisions to protect the 4,350 miles of pipelines and 11,000 miles of electrical power lines that stretch across Iraq. After Hussein's regime fell, insurgents attacks increased due to the infrastructure being temporarily unprotected. In August 2003, a South African firm was awarded a $40 million contract to provide 6,500 guards to protect the infrastructure. It was ultimately determined that this quantity of guards was not sufficient to counter the insurgency attacks, and the contract was expanded in September 2004 to $100 million for 14,000 guards. In December 2004, Iraqi officials estimated that insurgent attacks had cost the country more than $7 billion in damages to infrastructure and lost productivity since the war began.[6]

Iraqi and U.S. officials in Iraq are growing more concerned because insurgent attacks against Baghdad's oil supplies and electricity generating capability seem to be increasing in their degree of coordination and sophistication despite the increased security measures. It appears that the insurgency made up of Sunnis, Shiites, and foreign fighters have an understanding of the supply network and are attacking key nodes, thus improving the effects of their efforts. Consequently, if the insurgency can shut down services to Baghdad's six million person population then the new government is weakened and put under tremendous pressure to prevent future attacks and restore services. This same scenario could be effective in any large city in Iraq. Overall, in 2004 there were 264 attacks on the oil infrastructure in Iraq.

---

[5] March 20, 2005. Iraqi electricity minister says 18 hours of daily power expected by April. Global News Wire – BBC Monitoring International Reports. Downloaded from LexisNexis on April 13, 2005.

[6] P. Hess, January 20, 2005. Iraq oil attacked 196 times since war. *United Press International.* Downloaded from LexisNexis on April 13, 2005.

The United States Agency for International Development (USAID) identified three significant challenges for the Iraqi electrical system in December 2003. First, they feared that the country's anticipated improving economy would increase the demands for electrical power. Next, they were concerned that the years of neglect on the power infrastructure would be difficult and slow to resolve. Finally, they were concerned that the looting and sabotage would continue to slow repair and cause electrical power to be unreliable.[7] Two years after USAID identified these challenges, they are still proving to be valid concerns for the ongoing Iraqi infrastructure rebuilding.

Iraq's electrical infrastructure problems are not unique and other countries have faced similar problems and have found solar PV systems to be a viable solution. There are numerous case studies that demonstrate uses of solar in regions similar to Iraq. This MBA project describes characteristics of four cases with similar problems as Iraq and how solar PV systems could potentially improve the Iraqi economy, environment, and energy independence.

Currently, 21 countries participate in the research and development program named the International Energy Agency Photovoltaic Power Systems Programme (PVPS).[8] The intent of the program is to "enhance the international collaboration efforts which accelerate the development and deployment of PV solar energy as a significant and sustainable renewable energy option."[9] At the end of 2003, a total of 1.8-GW of solar power had been installed in the 21 countries.[10] From 1993 to 2003, the use of PV applications has increased from a yearly low of 20 percent to a high of 40 percent. These figures alone show that solar technology is being accepted as an alternate form of energy around the world.

---

[7] December 2003, Restoring Iraq's Infrastructure. Downloaded from www.usaid.gov on April 1, 2005.

[8] Australia, Austria, Canada, Denmark, Finland, France, Germany, Israel, Italy, Japan, Korea, Mexico, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, the United States.

[9] IEA, "Trends in Photovoltaic Applications Survey report of selected IEA countries between 1992 and 2003,"2004, Download from www.oja-services.nl/iea-pvps/topics/i_dc.htm on April 21, 2005, p. 1.

[10] Ibid, 4.

Security of solar PV systems installed in Iraq should be a major concern for a successful implementation. Realizing that the economic value of a solar PV system makes it an ideal target for pilferage in a sluggish Iraqi economy, we examine the use of Radio Frequency Identification (RFID) technology to deter theft. Saboteurs may try to remove individual solar components in order to disrupt a stabilized solar electric infrastructure, so security of these systems and components must be taken into consideration. This MBA project provides a general idea on how an RFID security feature would work in Iraq.

The conventional PV systems of today can be costly and this likely prevents wide-scale interest in fully implementing solar PV solutions. However, the emerging capability built by Atira Technology is the Photovoltaic Power Conversion (PVPC). It improves performance, reduces cost, and makes solar power solutions a more attractive alternative. The use of the PVPC technology could aid the U.S. in providing a more resilient economy and secure future for Iraq. The PVPC process enhances the performance of PV systems by increasing the amount of sunlight that can be used in the solar PV power conversion process. This is primarily accomplished through power mode conversion that adjusts the sun’s energy passing through the solar panels. The percentage of the increase in the sun’s energy is directly proportional to exposure of sunlight on the solar panels. “The PVPC continuously optimizes the input generated from the solar panels to maximize the output.”[11]

In this MBA project, we provide primary and related test data to illustrate the results of PVPC technology when used with commercially available solar components. A side-by-side comparison test of a conventional solar PV system to a solar PV system integrated with PVPC provides the test data. This data is analyzed to compare the performance of these two solar PV systems. The test results of the PVPC are a key component in our recommendation to use a solar solution to assist in the rebuilding of the Iraqi electrical infrastructure.

---

[11] Atira Technologies Photovoltaic Power Conversion Technology, Alexander Wolf, March 2005.

In addition to test data, a model has been created to compare the costs of PVPC technology to conventional solar PV systems. The cost model is an intuitive Microsoft Excel spreadsheet with adjustable input cells that automatically calculate costs of a particular sized solar PV system. The cost model accepts the percentage increase in performance of the PVPC technology determined from analysis of the test data to calculate cost variations and component requirements.

While the concept of using solar PV systems to assist in the rebuilding of the Iraqi infrastructure may initially seem impractical due to the cost, its advantages far outweigh the cost issues. This project helps explore the possibilities and provides a cost comparison of conventional versus PVPC solar PV systems which are specifically configured for Iraq. Although the cost to install solar PV systems on every home in Iraq may not be unfeasible, a tiered approach, such as installing these systems in a major city or in limited situations can help lessen the overall country's power shortages.

I. INTRODUCTION

A. PREFACE

The purpose of this project is to examine the cost and feasibility of using photovoltaic (PV) solar power to assist in the rebuilding of the Iraqi infrastructure. The project examines available solar equipment and technologies coupled with requirements for operation, installation and maintenance of such systems. The report begins with an analysis of the current state of the Iraqi infrastructure with special emphasis placed on identifying potential candidates for initial solar PV system installation. Next, the report addresses available commercial solar equipment and emerging technologies that enhance such systems. Finally, the report concludes with a cost estimate for using solar PV systems in the rebuilding of Iraq. At the conclusion of the project, information is available for decision makers to include as part of an operations order or to attach as an annex to an existing operations order.

In a country of 25,374,691 citizens covering 437,072 square kilometers[12], electrical power is essential to support the population's existence. Iraq's power production is based on the availability of petroleum, while the availability of petroleum requires electricity.[13] Before the war even began, Iraqi citizens were forced to live with programmed electrical blackouts because of an insufficient power grid.[14] The outbreak of war caused a temporary loss of power in many cities within Iraq. When the United States (U.S.) forces entered Baghdad, Iraq as part of Operation Iraqi Freedom (OIF), they quickly realize that they had to get electricity flowing in order to get potable water, utility services, and medical care to the citizens in order to prevent a humanitarian disaster.[15]

In order for post-conflict development to be sustainable, there are three basic characteristics that have to be present. First, the infrastructure must be composed of

---

[12] Downloaded from www.cia.gov/cia/publications/factbook/geos/iz.html on May 20, 2005.

[13] S.R. Hawkins, & G.M. Wells, February 2005, U.S. military engineers in Iraq, ARMY, Vol. 55, Number 2, p. 26. The Association of the United States Army.

[14] Ibid, 24.

[15] Ibid, 22.

technology that can be operated and maintained for a long period of time. Secondly, the solution cannot benefit one part of the population at the expense of another part of the population. Finally, a plan must be developed and efforts must be financed in order for the rebuilding to be effective.[16]

As defined by Postconflict Development: Meeting New Challenges[17], it appears that solar power potentially meets the first two characteristics. Solar technology can be operated and maintained for long periods of time and its benefits do not adversely affect another part of the population. This project was designed to assist in supporting the requirements for solar power to meet the third characteristic of post-conflict development.

B. RESEARCH OBJECTIVES

1. Provide an overview of the Iraqi infrastructure with emphasis placed on their power generation capabilities so we can determine where solar technology could be of most benefit in the rebuilding efforts.

2. Provide a market analysis of commercial solar equipment identifying specifics on installation, operation, maintainability, and durability.

3. Provide a cost estimate for using solar PV systems to support the rebuilding of the Iraqi infrastructure.

---

[16] G. Junne, & W. Verkoren, 2005. Postconflict development. p. 103. Lynne Rienner, Boulder, Colorado.

[17] Ibid, 103.

C. RESEARCH QUESTIONS

1. Can photovoltaic solar power sufficiently meet the power requirements currently placed on Iraq’s power production/electrical infrastructure at varying levels of implementation?

2. Does available commercial solar power equipment coupled with emerging solar technologies provide the solution for Iraq’s infrastructure shortcomings?

3. What is the cost for a solar power solution for the Iraqi infrastructure shortcomings?

II. IRAQI INFRASTRUCTURE

A. GENERAL GUIDELINES FOR INFRASTRUCTURE REBUILDING

An overview for infrastructure rebuilding is provided in order to identify key areas that must be emphasized during the period following the conflict. This section is generic in nature, but provides information that is very applicable to our study of the Iraqi electrical infrastructure rebuilding efforts.

A functioning infrastructure is a key component in a viable economy and it is a major concern after a conflict has concluded. The components that make up infrastructure include "water supply, storm drainage, sanitary drainage, waste-water treatment, waste disposal facilities, electricity supply, fuel supply, highways, railways, seaports, airports, telecommunications systems, medical facilities, educational facilities, and administrative facilities."[18] These components are often interdependent, thus improving the electricity supply has positive effects on all the components, but especially the telecommunications systems, medical facilities, educational facilities, and the industrial facilities.

During times of conflict, a country's infrastructure can be destroyed, neglected, or a combination of both. This neglect occurs because necessary maintenance and upgrades are postponed or cancelled due to limitations of money and the diversion of personnel to support the conflict. Quite simply, resources are prioritized and decision makers decide that the limited resources are better used elsewhere. With decreased resources and increased usage, the infrastructure suffers in both the short and long-term.[19] If the neglect is continued over an extended time, the infrastructure deteriorates to a state where significant effort is required to bring it to a functioning level again.

---

[18] G. Junne & W. Verkoren, 2005. Postconflict development; Meeting new challenges. Lynne Rienner Publishers, Boulder Colorado, p. 100.

[19] Ibid, 101.

Immediately following a conflict, there are short-term decisions made that focus on providing relief for the citizens; however, the rebuilding decisions must also have long-term sustainability. The two elements of long-term sustainability that should be considered are reconstruction and development. Reconstruction is the immediate rebuilding of an infrastructure to the point that it is as effective as the pre-conflict capabilities. An example of reconstruction in Iraq is the repair and replacement of existing power lines. Development is best described as upgrading or improving upon the pre-existing capabilities to a level that is better than pre-conflict levels. An example of development is replacing a power generation plant with a new facility with increased capability. For both reconstruction and development, people and sustainability are critical.[20] The local populace must benefit in the short and long-term, and be able to sustain the reconstruction and development efforts in the future.

The key to having short and long-term benefits from the infrastructure is that it must be sustainable. Sustainable infrastructure is defined as, "physical assets that provide net benefits to a community, its neighbors, and the environment on a long-term basis."[21] In order for the infrastructure to be sustainable, it must have an appropriate level of technology. The long-term sustainability depends on available materials, working technology, and the ability to train a local work force that can operate and maintain the equipment. The infrastructure should not use technology that is so sophisticated that members of the local population cannot operate and maintain it after they have been properly trained.[22]

Any effort to improve infrastructure can have positive impacts on the population after a conflict concludes. To the local population, the rebuilding of infrastructure can be perceived as a positive sign of growing stabilization in the region. The rebuilding effort can have significant effects on the population's future actions, such as a decreased likelihood of participating in insurgent activity or an increased likelihood of supporting

---

[20] G. Junne & W. Verkoren, 2005. Postconflict development; Meeting new challenges. Lynne Rienner Publishers, Boulder Colorado, p. 102.

[21] Ibid, 104.

[22] Ibid, 104.

the reconstruction effort. A functioning infrastructure supports local trade and employment, which can assist in reducing conditions for civil unrest.[23]

B. BACKGROUND

This section provides specific information on the events that led to Iraq's degraded electrical infrastructure. It shows that the degrading of the electrical infrastructure was a long process due to years of conflict and neglect. This section also provides specific information on Iraq's geographic, demographics, and economic standing that helps the reader understand the difficulty and scope of the problem when attempting to rebuild the country's infrastructure.

Iraq's infrastructure has been degraded due to 25 years of nearly continuous conflict from 1980 until the present. From 1980 to 1988, Iraq was at war with Iran fighting over border and territorial disputes. It is estimated that the war with Iran cost Iraq $100 billion from economic loss. In August 1990, Iraq invaded neighboring Kuwait and was defeated by a United Nations' (UN) coalition, led by the United States. After the conflict, the UN imposed economic sanctions on Iraq, which caused additional neglect to the infrastructure due to the slow growth of their economy. The UN Security Council imposed resolutions on Iraq that restricted weapons of mass destruction, long-range missiles, and required compliance with UN inspections. In March 2003, a U.S.-led invasion force entered and removed Hussein's political regime after he failed to comply with many of the UN resolutions. Due to military action and simple neglect, Iraq's 25 years of nearly continuous conflict has caused the country's infrastructure to degrade to a level that cannot adequately support its population.[24]

The geography of Iraq is described as follows: it has 437,072 square kilometers of area with 432,162 square kilometers of land and 4,910 square kilometers (km) of water. Iraq is bordered by Iran (1,458 km), Jordan (181 km), Kuwait (240 km), Saudi Arabia (814 km), Syria (605 km), and Turkey (352 km). Figure 1 depicts Iraq and its relationship to its neighbors. The climate can be described as mostly desert with mild to

---

[23] G. Junne & W. Verkoren, 2005. Postconflict development; Meeting new challenges. Lynne Rienner Publishers, Boulder Colorado, p. 107.

[24] Downloaded from www.cia.gov on April 18, 2005.

cool winters and dry, hot, and cloudless summers. There are mountains along the Iran and Turkey borders, which receive heavy snows during the winters and floods in the spring. Other natural hazards include dust storms and sandstorms.

Figure 1 Map of Iraq and Border Nations.
(From: www.cia.gov on 6 April 2005)

Table 1 Population Statistics for Iraq.

Total Population	25,374,691	(as of July 2004)
Population Growth Rate	2.74 percent	(as of 2004)
Total Fertility Rate	4.4 Children	Born/woman (2004)

(From: www.cia.gov on 6 April 2005)

Table 2 Economic Statistics for Iraq.

Gross Domestic Product (GDP)	$37.92 billion	(as of 2003)
GDP Real Growth Rate	-21.8 percent	(as of 2003)
GDP Per Capita	$1,500 purchasing power	(as of 2003)
Labor Force	7.8 million	(as of 2004)

(From: www.cia.gov on 6 April 2005)

C. COALITION EFFORTS TO BEGIN THE RECONSTRUCTION PROCESS

Once Saddam Hussein and the Ba'ath regime were removed from power in April 2003, the coalition formed the Coalition Provisional Authority (CPA). One of the main reasons for forming the CPA was to prevent a humanitarian crisis following the takeover of Hussein's regime. The U.S. led coalition teamed up with international agencies and nongovernmental organizations to form aid systems to help with the rebuilding of Iraq. From the start, the CPA was to serve as the transitional administration in order to establish the right conditions for the Iraqi people to take over their own country.[25] The CPA disbanded on June 28, 2004 and transferred full governmental power to the Iraqi people.

The lead agencies for reconstruction were the U.S. Department of State, the U.S. Department of Defense (DOD), and the United States Agency for International Development (USAID), and the United States Army Corps of Engineers (USACE). The USAID took the lead in the reconstruction efforts. The objective of the USAID was "to improve the reliability and quantity of electrical generation for Iraqi citizens through maintenance, rehabilitation, and reconstruction of power plants."[26] The USAID also utilized the USACE to provide technical expertise and oversight on projects that were being planned and worked throughout Iraq. The USACE participated in the planning and execution of reconstruction efforts even before the war actually started. Prior to the U.S. handing over governmental power to the new Iraqi government, priorities were determined by the Joint Iraqi Needs Assessment document and the CPA. Other countries and organizations provided input into the rebuilding of the Iraqi infrastructure, but the U.S. continued to lead this effort. The Joint Iraqi Needs Assessment is discussed in more detail in a later section.

---

[25] Bureau of Near Eastern Affairs, "Background Note: Iraq," U.S. Department of State, August 2004. Downloaded from www.state.gov/r/pa/ei/bgn/6804.htm on April 1, 2005.

[26] U.S.AID, "Restoring Power, U.S.AID's Role in Restoring Electricity to Iraq," U.S.AID From the American People, September 2004, Downloaded from www.usaid.gov on April 1, 2005, p. 1.

1. Managing the Funds Earmarked for Rebuilding

While the CPA existed, they were responsible for the allocation of U.S. and Iraqi funds earmarked for the reconstruction effort. The Department of State, the DOD, the USAID, and the USACE controlled the funding for reconstruction projects in Iraq. As of April 2003, $58 billion was pledged to the reconstruction of Iraq. Funding for reconstruction efforts came from four primary areas: 1) U.S. appropriated funds, 2) the international community, 3) the Development Fund for Iraq, and 4) vested assets and assets seized in Iraq.[27]

The money used for the rebuilding of the Iraqi infrastructure was collected from multiple sources. The U.S. pledged $24 billion in appropriated funds through supplemental congressional appropriations and previously appropriated funds. Out of the $24 billion, $4.5 billion was appropriated in Fiscal Year 2003 and $19.6 billion was appropriated in Fiscal Year 2004. The international community pledged $13.6 billion. All money donated from other countries was deposited in a fund known as the Development Fund for Iraq (DFI), which was created by the CPA in May 2003 and recognized by the UN in Resolution 1483. The fund was developed to benefit the Iraqi people and assist reconstruction. Funds were also deposited from various sources such as the UN Oil for Food program and the sale of Iraq petroleum products. The DFI amounted to $18 billion. Finally, another $2.7 billion was recouped from the assets seized from Saddam's former regime. These assets are Iraqi funds that were deposited into U.S. financial institutions that were confiscated in March 2003.[28]

---

[27] United States General Accounting Office, "Rebuilding Iraq: Resource, Security, Governance, Essential Services, and Oversight Issues," GAO Accountability Integrity Reliability, June 2004, Downloaded from www.gao.gov/new.items/d04902r.pdf on April 1, 2005, p. 9.

[28] Ibid, 12.

It is important to note that of the $58 billion pledged for reconstruction efforts, not all of it was dedicated to the restoration of power. The funds for reconstruction included the costs for restoring water and power, the creation of the new Iraqi Army, and various other requirements. The restoration of power generation capabilities was only allocated 13 percent of the total funds available for reconstruction. Projects to restore electricity totaled $7.7 billion. Due to increasing security concerns with restoring power, funds that were previously earmarked for the rebuilding of the electrical infrastructure had to be used to pay for the cost of security forces required to defend electrical grids. These security premium expenses are discussed in greater detail later in this section. The charts below depict the amount of money dedicated for total reconstruction efforts and the amount dedicated to the restoration of electricity.

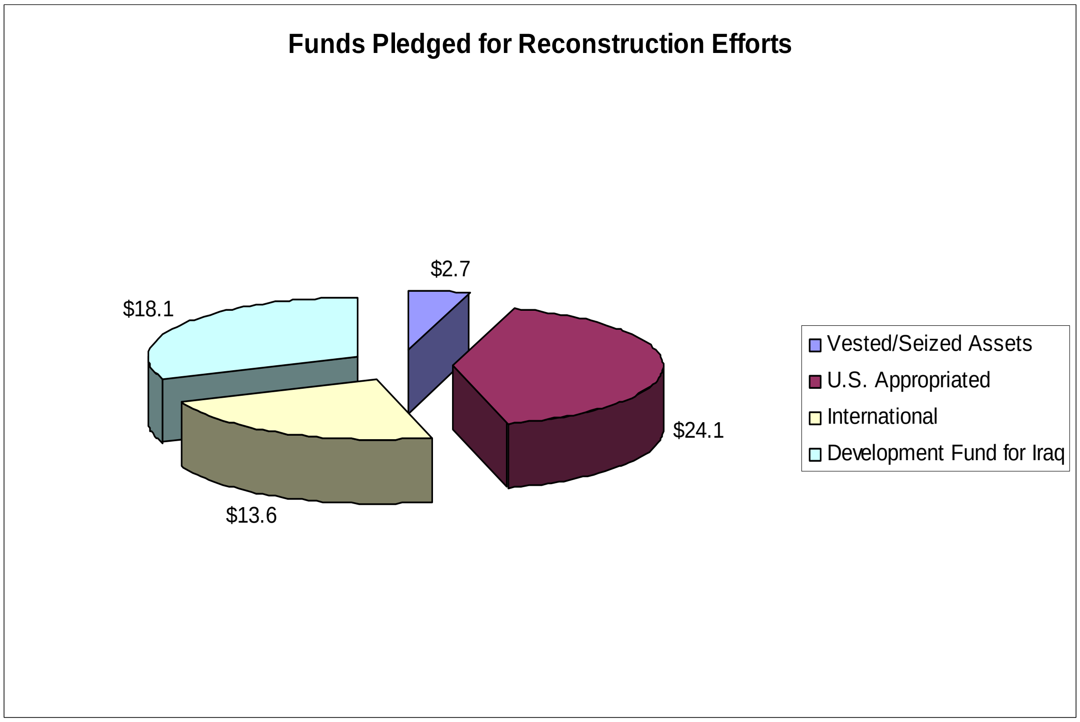


Figure 2 Funds Pledged for Reconstruction Efforts.
(From: GAO Report)

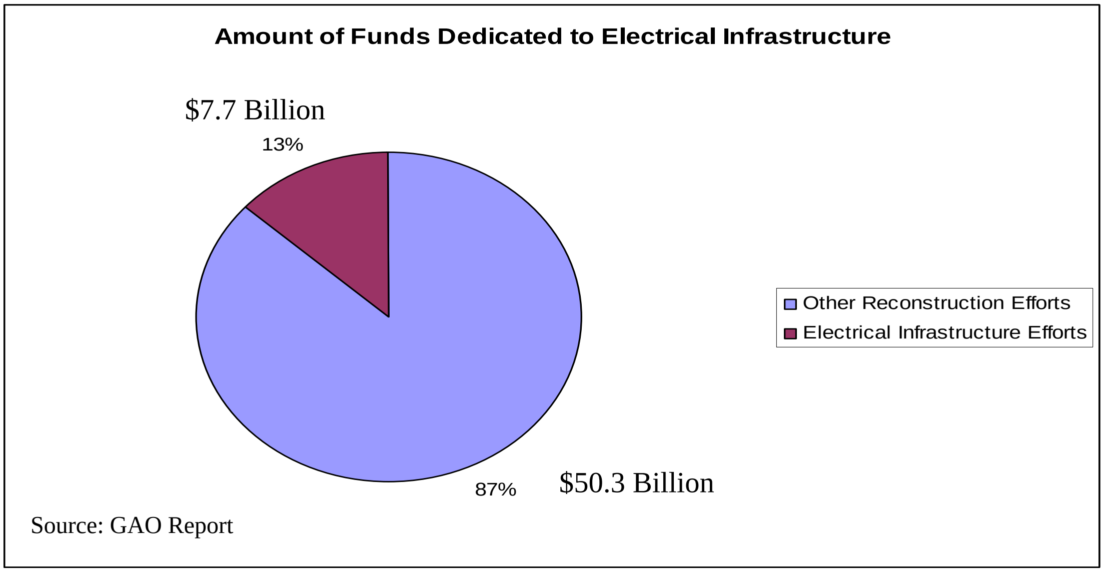


Figure 3 Amount Funds Dedicated to Electrical Infrastructure.

2. Initial Assessments of Iraq's Infrastructure Needs

The UN and the World Bank Group produced the Joint Iraq Needs Assessment in order to document an up-to-date status of the country's infrastructure and to help in identifying priorities for reconstruction and development. The results of this assessment guided the decisions made at subsequent meetings concerning the rebuilding of Iraq. The assessment was conducted by Iraqi experts, the CPA, several non-governmental organizations, and a number of experts from the European Commission, Australia, Japan, and countries of the European Union. However, it was difficult for analysts to physically examine all areas after major combat operations concluded because of the continuing dangers in Iraq. The Needs Assessment identified sector areas when addressing reconstruction priorities and they declared fourteen priority sectors. Electricity, education, health, and water were four of the priority sectors. The assessment identified priorities for 2004 and for 2005 through 2007. "Actions conducted in 2004 were known as immediate needs. Actions scheduled in 2005 to 2007 were known as medium-term priorities."[29]

---

[29] United Nations/World Bank, "United Nations/World Bank Joint Iraq Needs Assessment," The World Bank Group, United Nations/World Bank, October 2003. Downloaded from lnweb18.worldbank.org/mna/mena.nsf/Attachments/Iraq+Joint+Needs+Assessment/$File/Joint+Needs+Assessment.pdf on April 1, 2005, p. v.

The basic goal stated in the Needs Assessment was to rebuild the electrical infrastructure to pre-conflict power generating capabilities achieved prior to 1991. The recommendation was to do this by setting an immediate needs goal followed by goals for its medium-term priorities as shown in Table 3. The goals of the CPA are also provided. Table 4 below summarizes past capabilities, current capabilities at the time of the assessment, the electricity demand to be expected, and goals stated in the assessment.

Table 3 Goals for Power Production.

Joint Iraq Needs Assessment Goals	
Immediate Needs Goal (2004)	Medium-Term Priorities Goal (2005 to 2007)
4,775-MW	8,760-MW
Coalition Provisional Authority Goals	
October 2004 Goal	June 2004 Goal
4,400-MW	6,000-MW

Table 4 Capability and Demand Requirements Based Off of Assessment.

Power Generation Capabilities				**Forecasted Demand**
Prior to 1991 Persian Gulf War	Post Persian Gulf War	Prior to Operation Iraqi Freedom	Summer 2004	Potential Future Demand
9,295-MW	2,325-MW	4,500-MW	3,300-MW	6,500 to 7,000-MW

The Needs Assessment realized that in order to meet potential demand due to economic growth in the future, it required extensive maintenance on the current electrical infrastructure and the installment of new power generation plants. The assessment estimated it would take until 2007 to meet current demand requirements. Nevertheless, the CPA set an intermediate goal for the country's electrical infrastructure to produce 6,000-MW by June 28, 2004.[30]

---

[30] United Nations/World Bank, "United Nations/World Bank Joint Iraq Needs Assessment," The World Bank Group, United Nations/World Bank, October 2003. Downloaded from lnweb18.worldbank.org/mna/mena.nsf/Attachments/Iraq+Joint+Needs+Assessment/$File/Joint+Needs+Assessment.pdf on April 1, 2005, p. v. 30.

3. The Restore Iraqi Electricity Program

The USACE was responsible for the Restore Iraqi Electricity (RIE) Program. The program consisted of a total of 66 projects and began rebuilding efforts in September 2003. It was funded with $1.4 billion by the U.S. The USACE completed 59 out of 66 projects by May 2004.[31] The RIE projects provided an additional 1,348-MW of power to the Iraqi electrical grid. As of June 1, 2004, the USACE had helped improve generating capacity to 4,200-MW; however, the intermediate goal of 6,000-MW was not met. Although there was an improvement in generating capacity, the output of electricity was not significantly better than what was produced once major combat operations had ended. Additionally, security concerns due to insurgent activities made it more difficult to complete projects on time and within budget.

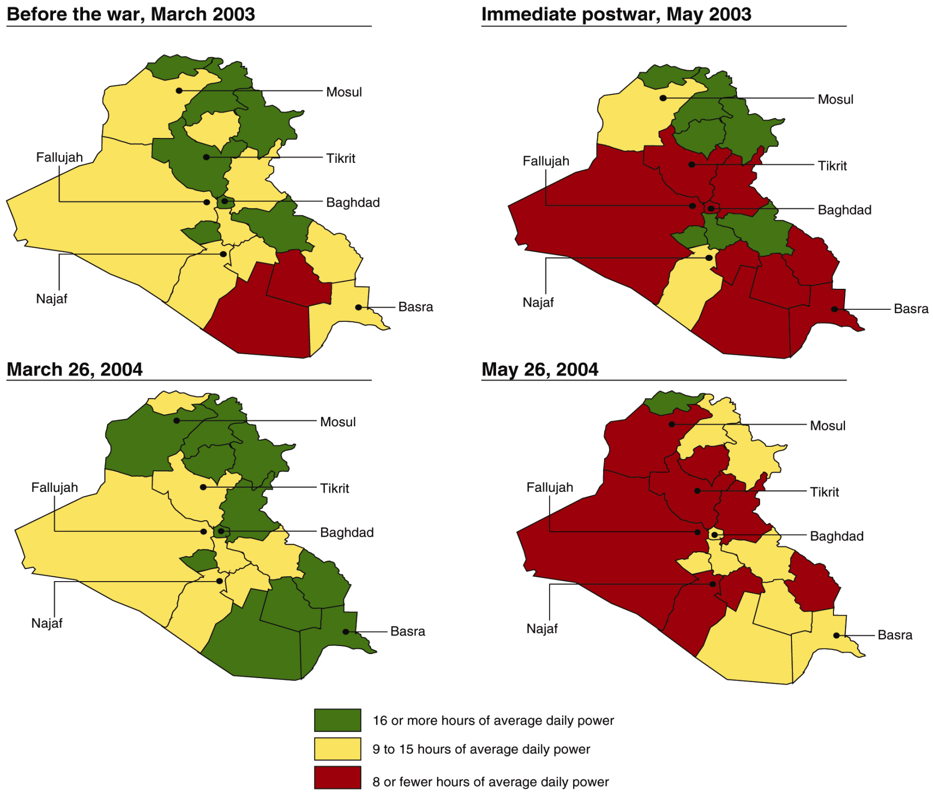
4. Power Overview and Distribution Policy

Saddam Hussein and his regime neglected the electrical infrastructure of Iraq for decades, so in order to compensate, electricity was concentrated in certain areas and not distributed across the country equitably. There were certain parts of the country that received power 24 hours a day while others only had as little as 10 hours a day to none at all. Figure 4 depicts how power was distributed throughout the country.

As of September 2004, a new more equitable electrical power distribution plan was in place and most areas in Iraq were receiving between 11 to 15 hours of electricity daily. Figure 4 also illustrates the electricity available at different stages from before the beginning of the war through May 2004.

---

[31] United States General Accounting Office, “Rebuilding Iraq: Resource, Security, Governance, Essential Services, and Oversight Issues,” GAO Accountability Integrity Reliability, June 2004. Downloaded from www.gao.gov/new.items/d04902r.pdf on April 1, 2005, p. 85.



Before the war, March 2003

Immediate postwar, May 2003

March 26, 2004

May 26, 2004

Sources: GAO (analysis); USAID and the CPA (data).

Figure 4 Iraq Power Distribution.

D. U.S. ENGINEERS ACTIONS UPON ENTERING IRAQ

In April 2003, the U.S. forces entered Baghdad, Iraq as part of OIF and found that the city had no electrical power. Lieutenant General (LTG) McKiernan, the Combined Forces Land Component Commander, and his staff knew that restoring electrical power was critical to prevent a humanitarian disaster. LTG McKiernan formed a team of engineers and doctors in order to quickly find solutions to the electrical problems. The team searched for and located Iraqi electrical engineers who were familiar with the local power system and who could assist with restoring power while combat operations were ongoing. Everyone involved shared the opinion that potable water, sewage systems, and hospitals needed electrical power to function properly or millions of Iraqi civilians would severely suffer.

The coordination between USACE and Iraqi engineers that began in April 2003 continued for many months and it was critical because the Iraqi engineers were working together for the first time.[32] The utility infrastructure was in need of extensive repair and the engineers met daily to prioritize efforts and update the status of continued rebuilding efforts. The coordination effort was more difficult because of the previous government's tendency to keep Iraqi services compartmentalized. In Saddam Hussein's government, the different services were kept apart and working together was not the norm. Additionally, the situation was worsened by the fact that the chief of water and sewer utilities and the chief of electrical distribution could not show the U.S. engineers specific details about their systems on a map. Under Saddam Hussein, maps were controlled items and not commonly used. The new coordination between the Iraqi services smoothed the initial efforts.

The greatest problem that the U.S. engineers faced in working with the Iraqi engineers was not their technical abilities - it was the differences in organizational cultural. The Iraqi engineers were reluctant to work or make suggestions across functional lines, because this was not the normal way of doing business. Multidisciplinary teams were not used in Iraq before the war began where information was held on to and decision-making was centralized at a high level. There was great emphasis placed on structure and procedures, which was not particularly conducive to rapid decision-making. Despite all these obstacles, the engineers were able to succeed in getting power restored to Baghdad within a week and a potential humanitarian disaster was prevented.

Before the war had even begun, Iraq's electrical grid could not meet the citizens' power demands. The Iraqi population had grown accustomed to daily scheduled blackouts, which was part of Iraq's centralized load-shedding program, which is depicted in Figure 4. By May 2003, it was estimated that the average Iraqi citizen had more hours of electricity than before the war began. This was credited to engineering improvements,

---

[32] Hawkins S.R. & Wells, G.M. February 2005. U.S. military engineers in Iraq, *Army Magazine*. Vol. 55, No. 2. The Association of the U.S. Army. 22.

the new electricity distribution plan, and the decreased power usage by the Iraqi military and industry.[33]

Iraq has two ways of generating electricity - hydroelectric and thermal power plants. Using a series of dams, they are able to produce a limited amount of power using hydroelectric plants, but the majority of the country's power is supplied by thermal units powered by petroleum products or natural gas. In April 2003, the war temporarily halted the production of petroleum so the thermal units, or the primary source of electricity, could not produce power. The problem was that the power production was completely tied to the petroleum industry and they were required to work in tandem. The U.S. and Iraqi engineers had to focus their efforts on getting the hydroelectric plants to produce power, which was normally the secondary source of electricity. The engineers were cautious when using the hydroelectric plants because this method used water which was also needed for future drinking purposes.[34] Once the hydroelectric plants starting producing power, the petroleum industry was restarted and soon the thermal plants came back on line.[35]

E. INCREASE OF ELECTRICAL POWER REQUIREMENTS AND CAPABILITIES

U.S. Army Brigadier General (BG) Thomas Bostick, commander of the USACE in the Gulf Region, told reporters in February 2005 that technicians were working hard to meet the increased electricity demands of Iraq's population. These increased demands were caused by the increased numbers of air conditioners, refrigerators, and other appliances being purchased by the Iraqi population. In 1991, prior to Operation Desert Storm, Iraqi power plants were capable of producing 9,000 megaWatts (MW) of electricity but by 2003, electricity generating capacity had declined to only 4,400-MW. The decline was caused in part by the Saddam Hussein government's lack of both maintenance and spare parts for the electrical grid. BG Bostick let reporters know that ten power plants were scheduled for maintenance and once this was completed, they

---

[33] Hawkins S.R. & Wells, G.M. February 2005. U.S. military engineers in Iraq, *Army Magazine*. Vol. 55, No. 2. The Association of the U.S. Army. 24.

[34] Ibid, 24.

[35] Ibid, 28.

would be capable of producing an additional 1,300-MW of power. He estimated that the current demand for electricity in Iraq is around 8,000-MW due to the population's increased use of electrical appliances and the coming hotter weather.[36]

1. Increased Use of Electrical Appliances

Increased demand for electricity began almost immediately with the fall of the Saddam Hussein regime in early 2003. One reason for this increase was Iraqi citizens purchasing appliances that increased power demand. One very popular electrical appliance was satellite television dishes. Under Saddam Hussein, the possession of a satellite TV was punishable by up to two years imprisonment. After Saddam Hussein's reign, satellite TV sales boomed throughout Baghdad. The dishes were sold in appliance stores as well as on street corners. The prices for dishes ranged from $125 to $300, which was easily more than an average Iraqi worker made in a year. Many citizens bought dishes because they were curious since the technology had been previously banned. During Hussein's reign, there were only four state-run channels that usually only ran pro-Saddam news. The citizens' biggest complaint concerning their new satellite televisions was that the electrical grid could not supply sufficient power to watch more shows.[37]

The Iraqi electricity minister informed the Iraqi newspaper Al-Nahdah in March 2005 that the electrical grid was producing 5,000-MW and by the end of April 2005, the power grid should provide 18 hours of daily power. He felt that despite the actions of terrorists and insurgents, the electrical grid would be able to add 1,500 additional megaWatts, which would be necessary to reach the 18 hour goal for the households of Iraq. He estimated that in order to provide continuous electrical power to the citizens of Iraq, it would cost $1 billion per year. The cost would be used to fund improvements that

---

[36] G. J. Gilmore, February 28, 2005. Democracy sparks Iraq's need for more electricity. U.S. Fed News. Downloaded from LexisNexis on April 12, 2005.

[37] M. Basu, May 27, 2003. Iraqi's tune in satellite TV; with Saddam gone, sales of dishes sour. The Atlanta Journal-Constitution. P 14A. Downloaded from LexisNexis on April 12, 2005.

would enable the grid to provide a total of 15,000-MW. The 15,000-MW requirement is based on studies that predict Iraq will grow at 20 percent per year for the next five years.[38]

Because reconstruction and rebuilding of the electrical grid is not progressing rapidly enough to meet current demand, new and different attempts to acquire enough electricity are already being tried. In an attempt to help resolve western Iraq's electricity shortage, Iraq, Jordan and Egypt agreed in March 2005, that Jordan and Egypt would provide power across the border through a 200-km electricity line. Although this attempt will not provide large quantities of electricity throughout the country, it will provide relief to an isolated region of Iraq.[39] Dr. Ahmad Hiyasat, the general director of the Jordanian National Power Company said that "the 200-km electricity line would provide 132 kilovolts to the Ukashat area in western Iraq."[40]

2. Cost of Insurgent Attacks

Continued insurgent attacks have delayed the reconstruction efforts in Iraq. These attacks have been costly and have delayed the completion of many infrastructure improvement projects, which has contributed to a very dissatisfied population. This section provides some detail on the cost of these attacks and helps to describe the urgency of restoring electrical power to the population.

Currently in Iraq, insurgent attacks on the electrical infrastructure are a significant problem and the application of resources is required to provide protection of pipelines, power lines and facilities. The requirement to secure the Iraqi electrical infrastructure from insurgents is an existing long-term and expensive problem. During Saddam Hussein's reign, he used local tribes and parts of two Iraqi Army divisions to protect the 4,350 miles of pipelines and 11,000 miles of electrical power lines that stretch across Iraq. After Hussein's regime fell, insurgents attacks increased due to the infrastructure being temporarily unprotected. In August 2003, a South African firm was awarded a $40

---

[38] March 20, 2005. Iraqi electricity minister says 18 hours of daily power expected by April. Global News Wire – BBC Monitoring International Reports. Downloaded from LexisNexis on April 13, 2005.

[39] March 12, 2005. Jordan, Egypt to provide western Iraq with electricity. United Press International. Downloaded from LexisNexis on April 13, 2005.

[40] March 20, 2005. Iraqi electricity minister says 18 hours of daily power expected by April. Global News Wire – BBC Monitoring International *Reports.* Downloaded from LexisNexis on April 13, 2005.

million contract to provide 6,500 guards to protect the infrastructure. Ultimately, it was determined that this quantity of guards was not sufficient to counter the insurgency attacks, and the contract was expanded in September 2004 to $100 million for 14,000 guards. In December 2004, Iraqi officials estimated that insurgent attacks had cost the country more than $7 billion in damages to infrastructure and lost productivity since the war began.[41]

Iraqi and U.S. officials in Iraq are concerned because insurgent attacks against Baghdad's oil supplies and electricity generating facilities and pipelines seem to be increasing in their degree of coordination and sophistication despite the increased security measures. It appears that the insurgency believed to be made up of Sunnis, Shiites, and foreign fighters have an understanding of the supply network and are attacking key nodes, thus improving the effects of their efforts. Consequently, if the insurgency can shut down services to Baghdad's six million people then the new government would be weakened and put under tremendous pressure to quickly prevent future attacks and restore services. This same scenario could be effective in any large city in Iraq. Overall, in 2004 there were 264 attacks on the oil infrastructure in Iraq.

It appears that the choices of targets selected by the insurgents are being more carefully analyzed than in the past. Early on, it appeared that targets were randomly selected. In January and February 2005, there were 30 attacks on the country's oil infrastructure, and none were directed against the southern crude oil pipelines, which are Iraq's main source of export revenue. The attacks were conducted against gas and oil lines used to supply electrical power plants and fuel predominately used in Baghdad. The selected targets are the ones that have the greatest impact on the perceptions of the population. The end-state could very well be a resentful population that feels the newly elected government is ineffective and that their country's infrastructure cannot stabilize or attract and keep businesses.

---

[41] P. Hess, January 20, 2005. Iraq oil attacked 196 times since war. *United Press International.* Downloaded from LexisNexis on April 13, 2005.

When analyzing the locations and frequencies of attacks, it appears that the facts support the previous assumptions that the insurgents are planning their attacks to influence the population's attitudes. The Iraqi oil minister, Thamir Ghahban, plotted the attacks that occurred in November 2004, December 2004, and January 2005 and found that multiple and simultaneous attacks were conducted against three crude oil pipelines that supply Baghdad's Doura fuel refinery, which is the nation's largest supplier of gasoline, kerosene, and other refined petroleum products. During the same time, another 20 attacks occurred on other pipelines that move refined petroleum products from the north into Baghdad. All these attacks targeted resources that were to be used in Iraq. The region's crude oil pipeline that carries products for export was not attacked at all.

The directed attacks were effective in isolating Baghdad on numerous occasions during the winter timeframe. The attacks caused fuel shortages for Baghdad's citizens. The Iraqi oil minister tried to fix the fuel shortages by shipping fuel by truck; however, the convoys and bridges into the city became targets as well.

As mentioned earlier in this research project, Iraq's oil and electricity production are linked so the supply of electricity was affected during this same timeframe. An attack on one part of the infrastructure affected the other. Despite investments of billions of dollars on numerous projects aimed at improving the electrical grid, electricity production fell below pre-war levels for a period of time. There were unscheduled blackouts and shortages of fuel due to the insurgent attacks. Lieutenant Colonel Joseph Schweitzer, who served as the Director of the Reconstruction Operations Center for Iraq during the timeframe, said that "the enemy was adapting and becoming smarter in target selection."[42] He felt that the insurgents had a plan that specifically targeted Baghdad.[43]

3. Security Premiums

As early as December 2003, the USAID identified three significant challenges for the Iraqi electrical system. First, they were concerned that "the country's anticipated improving economy would increase the demands for electrical power." Next, they were

---

[42] J. Glanz, February 21, 2005. Insurgents wage precise attacks on Baghdad fuel. The New York Times. Tactics; p 1.

[43] Ibid, 1.

concerned that “the years of neglect on the power infrastructure would be difficult and slow to resolve.” Finally, they were concerned that “the looting and sabotage would continue to slow repair and cause electrical power to be unreliable.”[44] Two years after USAID identified these challenges; these concerns are still proving valid for the Iraqi infrastructure rebuilding.

The expenses associated with providing security for infrastructure or the rebuilding of infrastructure after an attack has occurred is being referred to as a security premium. A U.S. diplomat overseeing Iraqi reconstruction efforts says that “there is a definite security premium attached to projects being worked in Iraq because of the increased violence by insurgents.”[45] He estimates that an additional and unanticipated $1 billion has been spent on providing security for ongoing projects and convoys to date. This large security premium was not budgeted for when the U.S. Congress approved $18.4 billion in November 2003 to help rebuild the Iraqi infrastructure. Initially, U.S. planners expected security to cost around 10 percent of total cost or approximately $2 billion. Due to the security premium, projects are being completed slower while other projects will just not be started because of the shortage of funding.

Iraqi officials and citizens are frustrated by the slowed pace of project completion. Many Iraqis are protesting in the streets because of the lack of essential services. The Iraqi government is concerned that continued delays will only strengthen the insurgency’s efforts to influence the population. The expected future cuts, due to paying for the security premium, will likely be water and electricity programs. These cuts in water and electricity programs will probably add to the population’s frustration.

Private contractors’ increased need for security has caused an increase in cost that was not initially budgeted. This unexpected cost will have to be indirectly paid by the U.S. or Iraqi governments. It is estimated that the security premium range has increased 5 to 25 percent on the various types of projects. The requirements for up-armored cars

---

[44] December 2003, Restoring Iraq’s Infrastructure. Downloaded from www.usaid.gov on April 1, 2005.

[45] T. C. Miller. February 21, 2005. Violence trumps rebuilding in Iraq. Los Angeles Times. Part A; p. 1. Downloaded from LexisNexis on April 6, 2005.

and security guards for a single convoy have been estimated to cost a company up to $5,000 per day. Additionally any delays or shortages drive up costs for the contractors and these costs are eventually passed on to the governments as well.[46]

F. UNANTICIPATED CHALLENGES AFFECTING REBUILDING

1. Increased Needs in School Systems

Because electricity is needed for oil production, a shortage of fuel and electricity has created a very different kind of concern in Iraq. A January 2005 survey of Iraqi students and parents indicated that 83 percent of them were very concerned that shortages were going to lead to poor academic achievement in school. The cost of public transportation has increased causing less student contact outside of class. They consider student contact outside of class as an important contributing factor to academic achievement. The parents have pressured the new government to fix the shortages as soon as possible because they feel that education and academic achievement will be even more critical in the future.[47]

2. Maintainability of U.S. Improvements

Early in the study, we identified that a critical factor in selecting appropriate technology in infrastructure rebuilding is maintainability. The question of maintainability is becoming a major concern in Iraq because it already appears that the Iraqi officials are failing to properly operate and maintain the electrical plants that were refurbished beginning in 2003. The U.S. officials think that because the plants were not operated and maintained properly, this has led to multiple power shortages this past winter. An important note, of the 19 electrical facilities that have been refurbished by U.S. funding, it is believed that none are being properly operated.

The United States and Iraqi officials are blaming each other for the maintainability problems of the infrastructure. The U.S. officials claim that the Iraqi workers are insufficiently trained and have an indifferent work ethic, which cause the problems. Iraqi officials counter by arguing that the problems were caused by American

---

[46] T. C. Miller. February 21, 2005. Violence trumps rebuilding in Iraq. Los Angeles Times. Part A; p. 1. Downloaded from LexisNexis on April 6, 2005.

[47] January 14, 2005. Iraqi students, parents worried over fuel crisis impact on academic performance. British Broadcasting *Corporation.* Downloaded from LexisNexis on April 13, 2005.

engineers excluding them during the planning phases and then not providing enough funding for required maintenance. Both parties are concerned that after so much effort and billions of dollars invested, the final product may be no better than when the effort started.

The Mayor of Baghdad, Alaa Tamimi, says that the problems being currently worked were caused earlier in the process. He said that many of the problems could have been avoided if the U.S. had channeled the money through the Iraqi government. He feels that the Iraqi government better understood where efforts should have been directed, the types of equipment that could be maintained, and the overall scope of the different projects. The U.S. State Department figures may support Tamimi's assessment because their numbers indicate that daily production of electricity is no better than it was before the war began in 2003.[48]

---

[48] T.C. Miller, April 10, 2005. Millions said going to waste in Iraq utilities. Los Angeles Times. Part A; p. 1. Downloaded from LexisNexis on April 13, 2005.

III. SUCCESSFUL IMPLEMENTATION OF SOLAR POWER

Iraq’s electrical infrastructure problems are not unique. Other countries have faced similar problems and have found PV solar power systems to be a viable solution. The following section contains four cases that have relevance to our research.

A. USE OF PHOTOVOLTAIC TECHNOLOGY

Our study of using solar power to support electrical infrastructure is not a new or unproven concept. There are multiple examples where solar power has been successfully used. This section provides an examination of such cases and provides insight by examining successes and lessons learned from solar implementation. Before examining specific cases, it is important to look at the use of PV applications from a global perspective. This provides a broad overview of how solar technology is progressing and how it is being accepted as a viable means of providing power around the world.

Since 1993, the implementation of solar PV applications has increased every year. In the past few years, Japan, Germany, and the United States have led the market in number of PV systems installed. Some of these systems were bought by the individual citizen; some were part of a research and development program, while others were subsidized by the government to encourage the use of alternate forms of energy. Table 5 lists all the countries that have installed PV systems and the total amount of power being produced.

Table 5 Installed PV systems and total amount of power (MW) produced in 2003. (From: IEA Report T1-13:2004)

Australia	45.6	Morocco	7
Austria	16.8	Nepal	2,7
Brazil	3	Netherlands	45.9
Canada	11.8	Norway	6.6
China (incl. Tibet)	58	other European countries[1]	0.7
Denmark	1.9	Portugal	2.1
Finland	3.4	South Africa	11
France	21.1	Spain	28
Germany	410.3	Sri Lanka	Est. 2
India	83	Sweden	3.6
Indonesia	28	Switzerland	21
Israel	0.5	Thailand	6
Italy	26	United Kingdom	5.9
Japan	859.6	United States	275.2
Kenya	3.2 (1999)	Vietnam	5.4
Korea	6.4	Zimbabwe	4 (1999)
Mexico	17.1		

In order to accurately document progress in solar technology, the International Energy Agency (IEA) has undertaken research around the world. As the lead agency, the IEA began its research in 1993. Currently, 21 countries participate in a research and development program called the IEA Photovoltaic Power Systems Programme (PVPS).[49] The intent of the program is to "enhance the international collaboration efforts which accelerate the development and deployment of photovoltaic solar energy as a significant and sustainable renewable energy option."[50] At the end of 2003, a total of 1.8 gigaWatts (GW) of solar power had been installed in the 21 countries.[51] They also show that from 1993 to 2003, the use of photovoltaic applications has increased from as little as a 20 percent to as much as a 40 percent.

---

[49] Australia, Austria, Canada, Denmark, Finland, France, Germany, Israel, Italy, Japan, Korea, Mexico, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, the United States

[50] IEA, "Trends in Photovoltaic Applications Survey report of selected IEA countries between 1992 and 2003,"2004, Downloaded from www.oja-services.nl/iea-pvps/topics/i_dc.htm on April 21, 2005, p. 1.

[51] Ibid, 4.

B. TRENDS IN OFF GRID AND ON GRID SYSTEMS

There are basically three solar PV configurations: 1) off-grid, 2) on-grid, and 3) hybrid. An off-grid or stand-alone PV system is independent of the commercial utility power. Electricity from an off-grid system is only used at the site of installation. The generated power is stored in batteries and used as needed. An on-grid or grid solar PV system essentially uses the existing commercial utility power and has no storage capacity. An on-grid PV system is installed into the electrical system of a home or facility for use during daylight hours only. A combination of an on-grid and off-grid PV system is known as a hybrid and has the advantages of both. A hybrid system is connected to the commercial utility power grid in case of poor weather or night use, but also has a battery bank to store electricity for use if grid power is lost. Additional information on these three solar PV systems is contained in section IV.

From 1992 to 1999, the majority of systems installed were off-grid solar PV systems. Off-grid solar PV systems typically dominate the rural and developing countries that do not have access to the electrical grid. This trend shifted in 1999. Now the majority of systems installed are systems connected to the electrical grid.[52] Figure 5 illustrates both of these trends.

---

[52] IEA, "Trends in Photovoltaic Applications Survey report of selected IEA countries between 1992 and 2003,"2004, Downloaded from www.oja-services.nl/iea-pvps/topics/i_dc.htm April 21, 2005, p. 5.

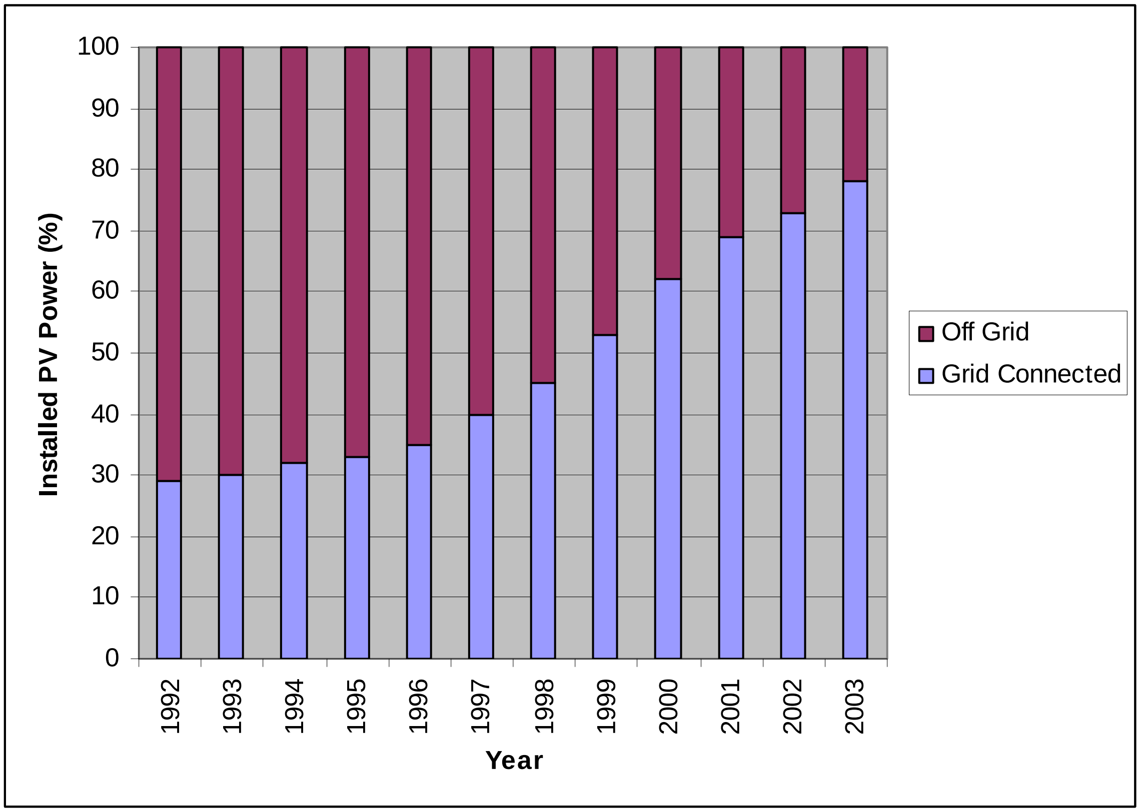


Figure 5 Cumulative installed PV power in the reporting countries by application Percentage in Years 1992 to 2003.
(From: IEA Report T1-13:2004)

Even though the installation of grid connected solar PV systems has been on the rise since 1999, grid connected systems still did not dominate the participating countries. In fact, out of 20 countries, only eight had a majority of their systems connected to the grid. The remaining twelve countries utilized mostly off-grid solar PV systems as illustrated in Figure 6.[53] This figure appears to contradict the previous figure that shows on-grid systems dominating the market. The reason it appears this way is that three countries in the last three years have installed the majority of on-grid systems. As a result, the numbers have been skewed.

---

[53] IEA, "Trends in Photovoltaic Applications Survey report of selected IEA countries between 1992 and 2003,"2004, Downloaded from www.oja-services.nl/iea-pvps/topics/i_dc.htm on April 21, 2005, p. 6.

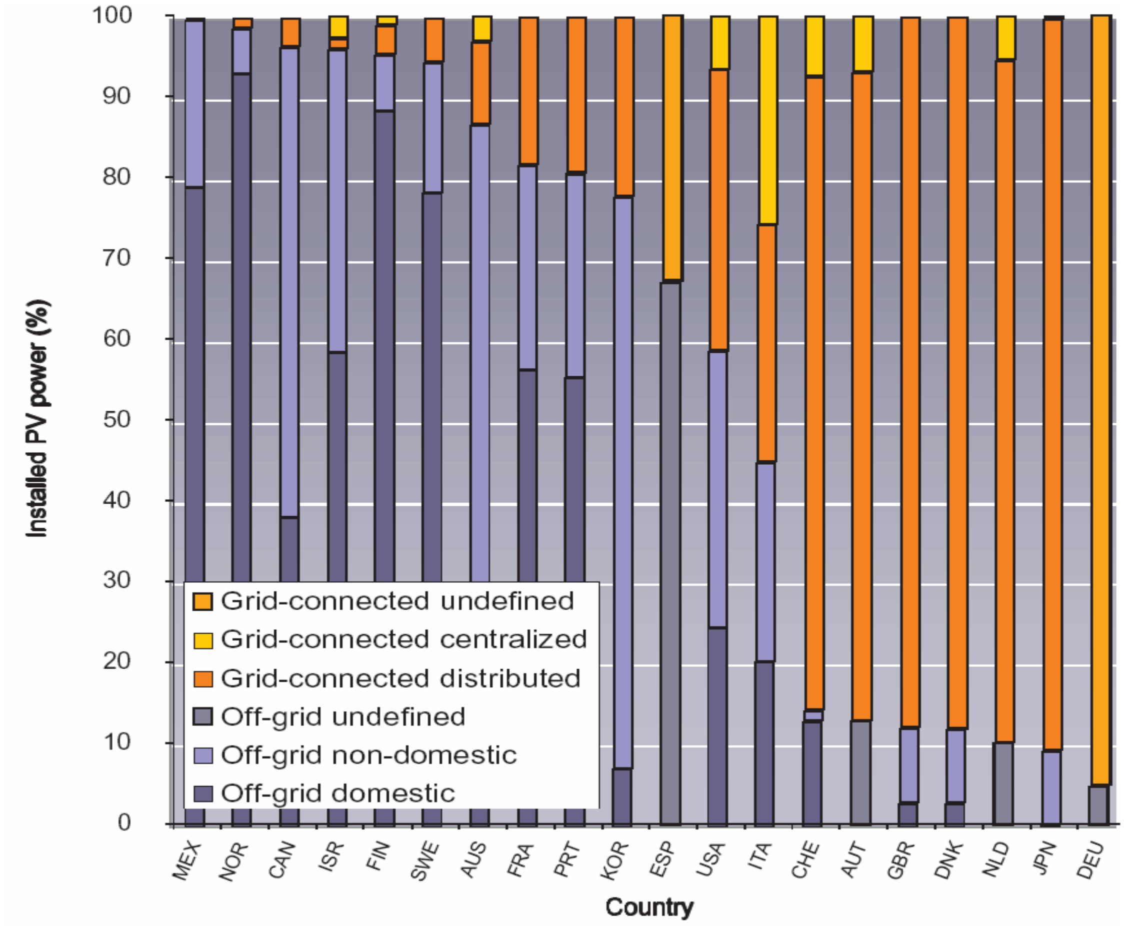


Figure 6 Installed power in the reporting countries by application Percentage in 2003. (From: IEA Report T1-13:2004)

The documented trends from the IEA show that the use of solar technology continues to rise each year and it is used worldwide. While the preponderance of PV use is with off-grid systems, on-grid connected systems are on the rise.

Key statistics discussed from the research are summarized below:

- At the end of 2003, a total of 1.8 GW of PV solar power had been installed in the participating countries;
- From 1993 to 2003, the use of PV applications has increased from 20 percent to 40 percent;
- In the past few years, Japan, Germany, and the United States have dominated the market on installed PV applications;

- From 1992 to 1998, there were more off-grid systems installed in the participating countries. From 1999 to 2003, the majority of systems installed were on-grid systems; and
- In 2003, twelve countries predominantly installed off-grid PV systems and eight countries installed on-grid connected systems.

C. CASE STUDIES

1. Grid Connected Implementation

a. Sacramento Municipal Utility District (SMUD)

In 1984, the Sacramento Municipal Utility District (SMUD) in the state of California commenced with a solar program like no other. The county chose to replace their aging and highly unreliable nuclear power plants with two PV power plants. The PV power plants in the Sacramento district are the two largest in the world. Both plants are capable of producing 2-MW of electricity.[54] Improvements since then have brought the system to a total of 3.5-MW for the district. Another big part of SMUD's solar program is their residential neighborhoods. Under the PV Pioneer program, 558 homes had installed PV systems by the year 1999.[55] The systems installed in homes ranged from 1-kW to 4-kW.

All residential solar PV systems in SMUD were grid connected. The PV system provides electricity for the home and excess is given back to the grid. This is done through the district's "net metering" configuration. The meter is able to record power going to the home and any excess given back to the grid. As a result, during times when there is no sunlight, the power provided to the grid can be used as credit. This reduces the cost of electricity for residents during the evening hours.

The installation of the systems on homes was led by the utility company. Initially, the utility company would simply install solar panels on rooftops and charge a $4 monthly fee. Now the utility company has a program that allows residents to pay a subsidized amount for their system and gain full ownership.

---

[54] Donald W. Aitken, et al., SMUD PV Program Review, 30 December 2000, p. 3

[55] Ibid, p. 5.

The SMUD program is truly a success story. Even today, the district remains solar powered and the numbers of residential homes continues to rise. Some key points and lessons learned stated in the SMUD Program Review[56] are the following:

- No single type of PV application was chosen in order to gain both "technical and economic experience from multiple applications";
- "PV modules were purchased in substantial quantities in order to progressively reduce the cost of their installed PV systems";
- Residential PV systems provided: "grid support, eliminated costs and losses in transmission and distribution, no special impact assessments, approvals or permits required, were fielded rapidly";
- "Real estate comes "free" with the building – the system is simply installed on building";
- "No site development costs – the PV is simply placed on the roof"; and
- "Utility interconnection already exists to serve the building".

b. Australia

In Australia, solar PV power is being used to power schools. There are currently a total of 75 schools that are using PV applications. The Solar Schools Program is a community based program that donates PV systems to the school. In addition to providing solar PV systems, schools also receive educational materials that teach students the benefits of using solar power. The power produced by each system is from 1.5-kW to 2-kW and they are connected to the grid. The installed PV systems allow the school to save money by offsetting the amount of electricity needed.[57]

Some key lessons learned from Australia's programs are the following:

- PV systems are linked into internet websites to show how systems are performing under different conditions and to alert administrators in the event of problems; and
- Each school promotes the benefits of PV technology with their education modules.

---

[56] Donald W. Aitken, et al., SMUD PV Program Review, 30 December 2000, p. 3.

[57] Downloaded from www.oja-services.nl/iea-pvps/countries/australia/index.htm on May 3, 2005.

Figure 7 Solar School in Australia.[58]

2. Off-Grid Implementation

a. Mexico

In Mexico, a distance education program has been implemented for rural communities and this has been made possible by installing PV applications. Under this program, education is brought to the classroom in remote areas by leveraging satellite technology and other audio visual systems. Students learn over a network broadcasted throughout the country. The problem is that thousands of rural communities are isolated and do not have access to an electrical grid. In the past, electricity was provided by diesel or gas generators. However, there were many problems with these systems. They were difficult to maintain, transportation and fuel costs were high, there was significant downtime, and voltage fluctuations damaged sensitive electrical equipment. Consequently, PV systems were chosen as the alternative. Mexico has installed more than 400 off-grid PV systems.[59] These systems typically power a one room school that

---

[58] Downloaded from www.oja-services.nl/iea-pvps/countries/australia/index.htm on May 4, 2005.

[59] Michael Ross, et al. Applying solar energy to extend distance education to remote communities in Mexico and Central America. Paper presented at American Solar Energy Society Annual Conference, Downloaded from www.sandia.gov/pv/docs/PDF/Ross%20ASES.pdf on April 25, 2005, p. 1.

contains a satellite signal receiver and parabolic antenna, a large screen television, and a videocassette recorder.

The use of PV applications to power schools was not an immediate success. There were reliability and efficiency problems. The U.S. Department of Energy and the USAID got involved to evaluate the country's systems. The following lessons were captured from a technical assistance visit:

- There was no standardization, each system had its own unique design, installation, components, and usage;
- There was a very low quality selection of components;
- Inexperienced system designers and installers were employed;
- "Under-sizing of battery cables, thus limiting battery recharge";
- "Improper orientation and location of panels";
- "Incorrect type of batteries used for application"; and
- "Lack of end user knowledge on proper orientation and maintenance, and on limitations of the system".[60]

Figure 8 A PV powered one room Telescundaria school in Quintana Roo, Mexico.[61]

---

[60] Michael Ross, et al. Applying solar energy to extend distance education to remote communities in Mexico and Central America. Paper presented at American Solar Energy Society Annual Conference, Downloaded from www.sandia.gov/pv/docs/PDF/Ross%20ASES.pdf on April 25, 2005, p 4.

[61] Ibid, p. 2.

b. South Africa

There are currently 3.7 million families in South Africa that do not have electricity. The South African government is undertaking efforts to extend the electrical grid to rural communities. In the interim, the government has utilized PV applications. The use of these systems has increased in South Africa over the past decade. In the Northern and Eastern Cape Province in the Republic of South Africa, PV systems have been installed in 1,000 schools to power lights and audio visual equipment.[62] The main components of a typical system are an 880-W PV array, a charge controller, a 24V battery bank and an inverter.

Some of the key lessons from the African schools projects are the following:

- Formal training was provided by the utility company to teachers on the systems;
- A quality control program for the systems was conducted a year after the project had been completed. This program uncovered several problems like installation issues, theft, and vandalism. One of the key lessons from this action was to begin quality control actions earlier in the process;
- As a result of the quality control program, corrective actions were implemented to correct problems;
- Liaisons with the community were set up to help monitor and report problems, promote security, and train teachers in the operation and maintenance of the system; and
- To deal with theft and vandalism, a solar panel array security frame and steel enclosures were provided. Additionally, schools were expected to install fences, burglar bars on classroom windows, and hire night watchmen.

---

[62] International Energy Agency. 2003. 16 case studies on the deployment of photovoltaic technologies in developing countries. IEA-PVPS T9-07:2003, www.oja-\services.nl/iea-pvps/topics/i_dc.htm accessed April 25, 2005, p. 58.

D. SUCCESSFUL SOLAR IMPLEMENTATION CONCLUSION

While only four case studies were analyzed, they all demonstrate PV options that can be explored in Iraq. Additionally, each project highlighted the benefits of solar energy and also the problems that were encountered. It was evident that government and community involvement contributed to a successful program. For instance, the users of the system need to know the basics of maintaining the system. This was especially important in the developing countries. Educating the community improved many of the initial problems that plagued many rural communities.

The government plays a vital role in maintaining quality control. Follow up visits, technical inspections with the contractors, and periodic reviews of progress are just some of the key actions for major solar projects. An important lesson learned from the South African school project was how the government reacted to vandalism. The actions in South Africa could be used in Iraq to mitigate similar problems. Finally, as in the Sacramento Municipal Utility District, buying solar equipment in bulk resulted in economies of scale. This helped make the costs of projects a more attractive option for the home owner.

THIS PAGE INTENTIONALLY LEFT BLANK

IV. SOLAR PV SYSTEMS FOR IRAQ

This section describes the various configurations of solar PV systems, illustrates their community applications, and gives detail on the emerging technology that makes solar power a more feasible solution. Finally, this section addresses the use of radio frequency identification (RFID) as a solution to reduce the vulnerability and security issues associated with using solar PV systems.

Solar PV systems produce electricity through interconnected components. The arrangement of Photovoltaic (PV) cells into an array known as a solar panel produces electricity when subjected to sunlight and generates power to operate electrical devices or loads. The solar panels of a solar PV system generally produce 6 to 24 Volts direct current (Vdc). To generate electricity that is valuable for home use, the direct current (dc) must be converted into alternating current (ac). With the use of solar PV panels, an inverter, batteries, and a charge controller a solar PV system can produce 120 Volts alternating current (Vac). If 220 Vac are needed, either a transformer is added or two inverters placed in series are used to produce the required voltage. Together, these four components; solar panels, inverter, charge controller, and batteries account for around 80 percent of the cost of a solar PV system. The other significant expense is in the installation.

The amount of power produced by a solar PV system varies throughout the day as the intensity of the sunlight reaching the PV panels changes. The term peak sun hours (PSH) are used as a method to average the accumulated sunlight reaching specific locations on the earth. The sun’s energy is expressed in hours of full sunlight per square meter (m^2). It is presumed that 1000-W/m^2 of energy reach the surface of the earth at sea level. Therefore, one hour (h) of full sunlight provides 1-kWh/m^2. The intensity of the sun’s energy also changes with the hour of the day and the time of year. This is where the PSH has an effect on performance of or amount of power produces by solar PV systems. The PSH is not a window of time or a specific time of day that an exact amount of sunlight reaches the earth. It is an averaged annual amount of sun available per day that solar PV systems are able to produce sufficient power to meet an electrical demand. The average PSH for Iraq of five is shown in Figure 9. The colors represent the average hours of PSH per day. For example, a color denoting a Wh/m² per day of 4,000 to 5,000 is an average of 4 to 5 hours of peak sun per day.

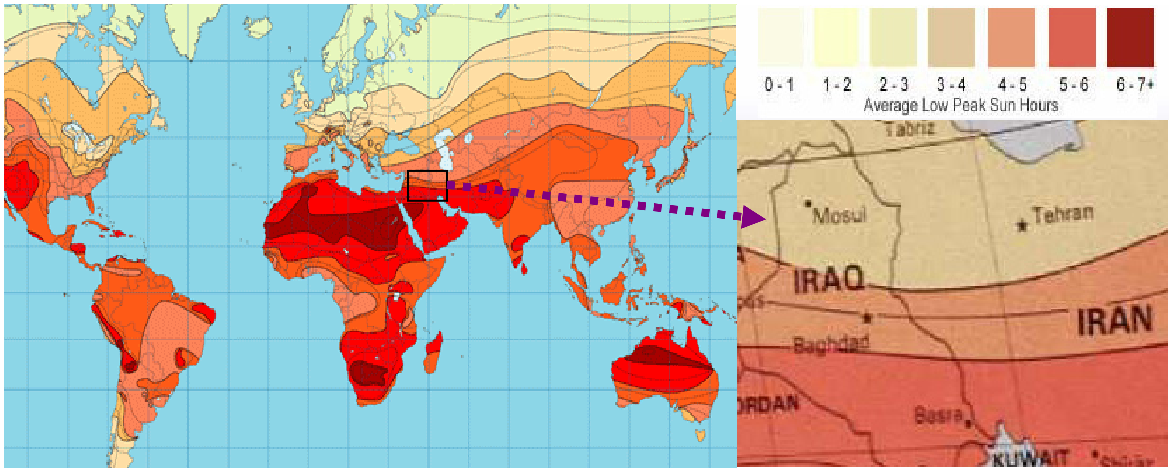


Figure 9 Iraq Solar Power.[63]

A. INSTALLATION CONFIGURATIONS

When considering the installation of a solar PV system, there are several configurations that can be selected. There are stand-alone or off-grid solar PV systems, a utility connected system (on-grid or grid system), and a hybrid solar PV system (a combination of both an off-grid and an on-grid configuration) to choose from. The choice of an installation configuration is dependent on the user needs, applications, and objectives. Details of each configuration are shown in Table 6.

---

[63] Downloaded from sunwize.com/info_center/insolmap.htm and www.solar4power.com/map13-global-solar-power.html on 30 March 2005.

Table 6 Type of Solar Power Configurations.

Configuration	Primary Power Source	Secondary Power Source	Storage	Example
On-grid solar PV System	Grid	Solar Panels	None	Use solar power in the day and grid at night.
Off-grid and On-grid System, "Hybrid" (Iraq recommendation)	Grid or Solar Panels	Solar Panels or Batteries	Batteries	Solar power or batteries used during the day or when grid is unavailable.
Off-grid System	Solar Panels	None	None	Water pump or feeder
Off-grid with Storage	Solar Panels	Batteries	Batteries	Remote homes for lighting and a few appliances
"Hybrid" Stand-alone without Grid	Solar Panels	Generator, Turbine, other	None	Remote that needs continuous power such as relay towers

1. On-Grid Solar Power System

An on-grid solar PV system essentially uses the existing commercial utility system for power and does not store electrical power. A grid connected solar PV system is shown in Figure 10. A solar PV system is installed into the electrical system of a home or facility for use during daylight hours or when grid power is down. It also works the other way, when the solar PV system does not produce enough electricity, it can draw power from the grid. When using the solar PV system, if more electricity is produced than what is needed the excess can be put back on the grid. This is done automatically through a device that monitors the available power and switches between solar and grid power. A second utility meter can be added to keep track of how much electricity has been put back on the grid. Advantages of grid interconnection include having uninterrupted access to standard utility power and avoiding the cost of a battery back-up system. A disadvantage is the utility interconnection fee, reliability of solar components, and the initial cost of the solar PV system.

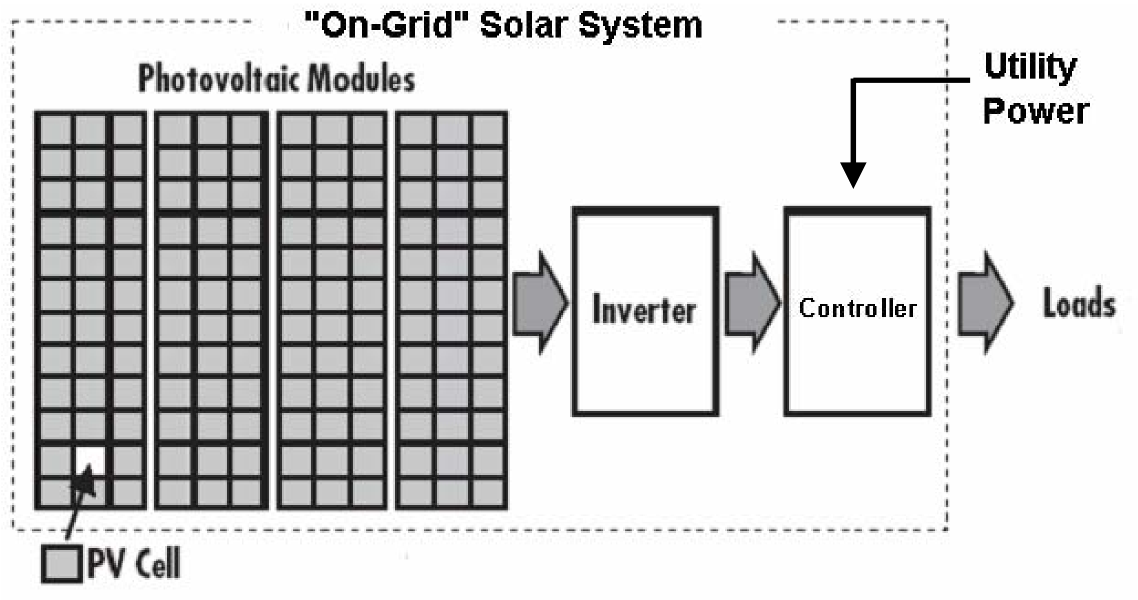


Figure 10 On-grid Solar PV System.[64]

2. Off-Grid Solar Power System

An off-grid or stand-alone solar PV system is independent of the utility grid, see Figure 11. Electricity from a stand-alone system is only used at the site of installation. The generated power is stored in batteries and used as needed. A typical U.S. off-grid house using a solar PV system is usually rated at 3 kilowatts (kW) or 15-kWh/day and provides power only for essential devices. The advantages of an off-grid system are freedom from the commercial utility system and in the long-run lower electrical cost. The disadvantages are limitation on power consumption, which is dependent on the capacity of the battery bank to supply electrical power during bad weather days, and being self-sufficient on power.

---

[64] Downloaded from www.nrel.gov/docs/fy99osti/26591.pdf on March 31, 2005.

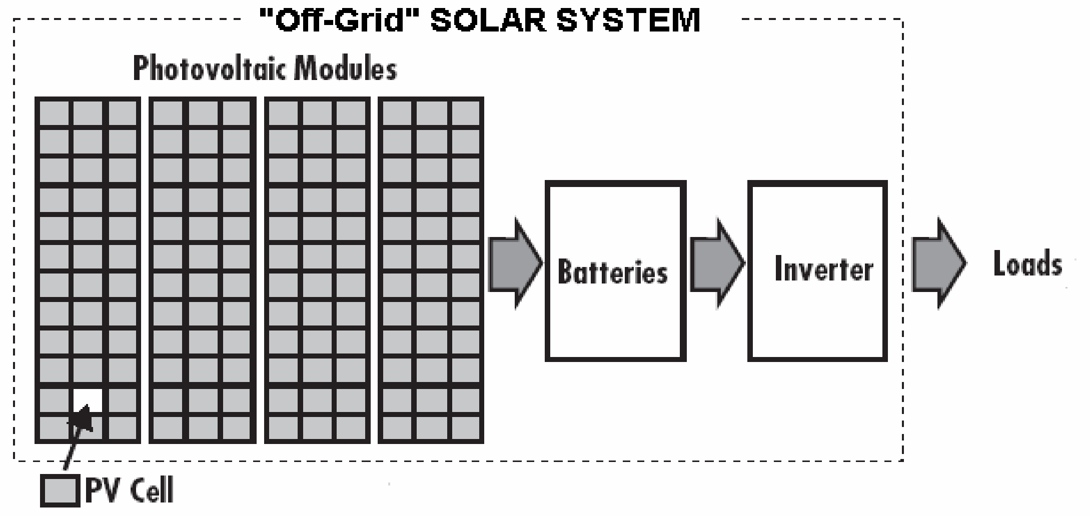


Figure 11 Off-grid Solar PV System.[65]

3. Hybrid Solar Power System

A combination of an on-grid and off-grid solar PV system has the advantages of both. A hybrid system is connected to the utility grid in case of poor weather or night use, but also has a battery bank to store electricity in case utility grid power is lost. The design and installation of hybrid systems is more complicated and expensive, but they are the most effective in providing constant, reliable electricity. Figure 12 depicts a hybrid solar PV system.

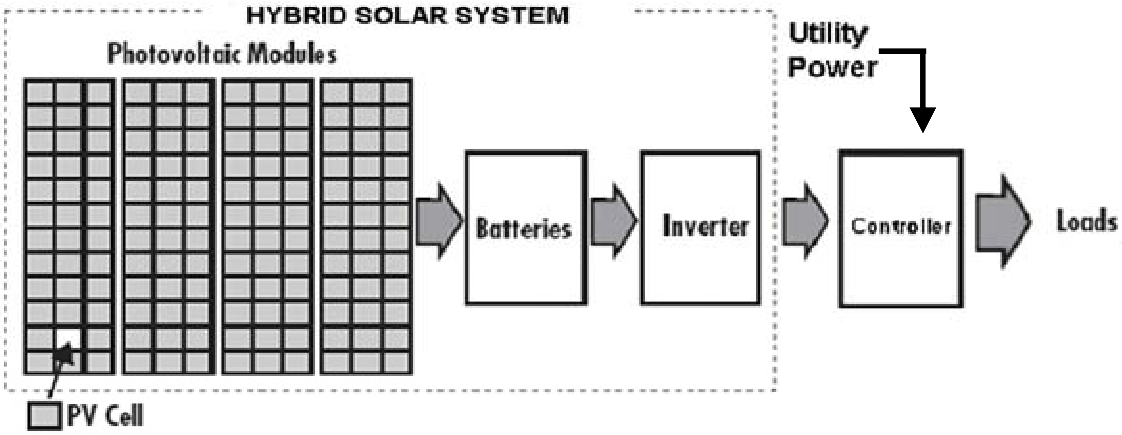


Figure 12 Hybrid Solar PV System.[66]

---

[65] Downloaded from www.nrel.gov/docs/fy99osti/26591.pdf on March 31, 2005.

[66] Downloaded from www.nrel.gov/docs/fy99osti/26591.pdf on March 31, 2005.

B. SOLAR TECHNOLOGY’S POSITIVE AND NEGATIVE ATTRIBUTES

The effective and efficient use of solar PV systems in Iraq could mean a stronger economy, an improved environment, and greater energy independence as compared to the current electrical tribulations. By investing in solar energy, Iraq could look forward to a more resilient economy and secure future. The use of solar PV systems not only benefits residential housing, but could also contribute to the communities, industries, and overall well-being of the country. With a hybrid (on-grid/off-grid) solar PV system connected bidirectional, a home or business can literally provide power on the grid for others to use. It could produce more electricity than what is needed on days when few people are at home. When people return home, they draw grid power or use power stored in the battery bank. The advantages of solar power contribute to:

- an improved Iraqi national energy infrastructure;
- an increase and diversification to the existing energy supply;
- a stronger government; and
- no noise emission.

A drawback to solar PV systems is the reliance on the sun, which has variations in the amounts or levels of energy reaching the earth each day and its unavailability at night. Consequently, there are barriers to extended use of daily sunlight and the inability to economically store it, use it, and convert it to electricity. Other disadvantages of solar power consist of:

- high initial capital cost;
- energy storage; and
- weather conditions and maintenance, “characteristically one to three percent of capital cost per year”[67]; and
- clear access to the sun's rays.

As previously indicated, without sunlight there is no solar power generated; however, this can be partially compensated through batteries, or a connection to the utility grid. The biggest concern compared to all the advantages and disadvantages of a solar PV system is the return on investment. The initial cost can be expensive and deter

---

[67] Downloaded from www.harbornet.com/sunflower on April 12, 2005.

prospective or ideal candidates from investing in solar PV systems. However, if there are irregular or scheduled power outages and/or unanticipated grid failures, solar PV systems are very valuable assets, especially with batteries because of the seamless uninterruptible continuous supply of electricity. Solar PV systems can be a practical power source for remote, residential, and commercial electricity.

C. VULNERABILITY AND SECURITY

The value of a solar PV system makes it an ideal target for pilferage in the sluggish Iraqi economy. However, if an area has been converted to solar energy, individual homeowners or businesses (police stations, schools, and hospitals) will not be inclined to rid themselves of their power supply. Further, although saboteurs may try to remove individual solar components in order to disrupt a stabilized solar electric infrastructure, they are faced with removing a very large number of solar PV systems in order to achieve any significant system disruption; and they are faced with taking away individuals' power systems, something almost certainly guaranteed to alienate the local population. A low cost technological solution in the form of Radio Frequency Identification (RFID) is available to help prevent systemic pilferage. (This thesis does not consider the issue of in-place destruction of solar PV system installations as the typical Iraqi home is flat roofed, which provides a semi-secure environment. Further, solar panels will still function with the PVPC technology installed even if they are shot.)

The RFID technology is an automatic identification (ID) capability that uses radio frequency (RF) waves to transfer information between a reader and a moveable item for identification, tracking, and location. The RFID is not and should not be compared to the Global Positioning System (GPS). Like other auto-ID systems such as bar codes, smart cards, and optical character recognition, the RFID offers traceability of numerous types of items. For example, they can be used during manufacturing of a product, in transit, or even the location and identification of a vehicle, animal, good, or individual. The RF communication link carries data either unidirectional or bidirectional. The following figure illustrates when an item with a tag comes into range of a reader, its data is captured by the reader and transferred through standard interfaces to a host computer, printer, or programmable logic controller for storage or action.

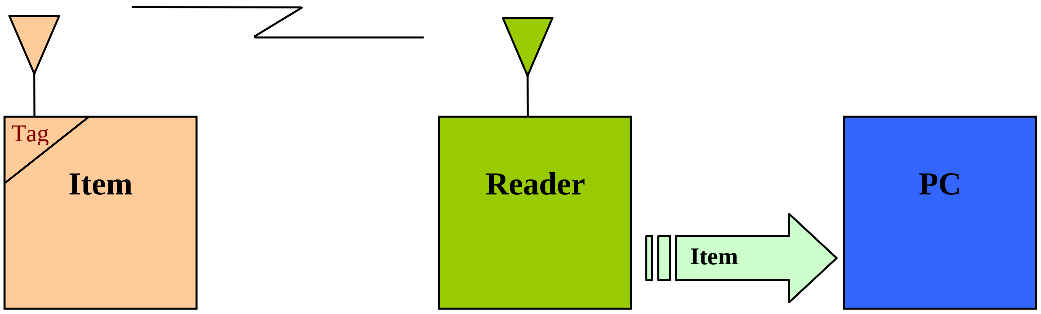


Figure 13 RFID Functional Process.

1. RFID Capabilities

The RFID technology is built on three main components: a tag or label, an antenna, and a reader. The key component is the tag that contains unique programmed information. It transmits information held in its memory chip by transmitting RF to a reader, which also contains an antenna. The tag is an integrated circuit with a coiled antenna that can be passive or active. The active tags incorporate an onboard battery and transmitter. The passive tags must be positioned near a reader that excites the tag and captures the data. Passive tags are the most popular in the market today because of their lower cost, flexible construction, programmability, and easy integration into a variety of applications. The passive tag is an un-powered electronic circuit that requires no batteries or maintenance and can be intermittently powered from a distance by a reader that broadcasts energy to it. When powered, the passive tag exchanges information with the reader.

A reader is an RF transmitter and receiver that captures data from the tags then passes it to a computer for processing. Readers can be affixed to a stationary position such as check-points, on a conveyor belt in a factory, or specific locations where they are integrated into a computer and database for classification or identification of specific information.

The RFID readers communicate with tags on various frequencies, low, intermediate, and high, depending on the type of antenna. "The low-frequency tags function on the 20 to 500 kilohertz (kHz) frequency range and have a reading distance of up to a foot. The intermediate-frequency tags, at 10 to 15 Megahertz (MHz), can be read up to about three to five feet (ft) away. The high-frequency tags, which operate from 850 to 950 MHz can be read from 10 to 20 ft away or can operate at 2.4 to 5.8 Gigahertz (GHz) and read at distances greater than 20 ft."[68] Table 7 summarizes these three frequency ranges, their system characteristics and some of the typical applications.

Key attributes of RFID include:

- Non line-of-sight ability to read
- Data can be transmitted and received through non-metallic materials
- Simultaneously capture data from many tags within range of the reader
- Capable of capturing tag identification codes at a rate of up to 1,000 tags per second
- Encased in hardened plastic coatings making them extremely durable
- Can store large amounts of data

Table 7 Operating Frequency Ranges.

Frequency Band	**Characteristics**	**Transmit Range**	**Typical Applications**
Low 20-500 kHz	Short to medium read range Inexpensive Slow Reading Speed	Less than 3 ft	Access control Animal identification Inventory control Car immobilizer
Intermediate 10-15 MHz	Short to medium read range Potentially Inexpensive Medium Reading Speed	3 to 10 ft	Access control Smart cards
High 850-950 MHz 2.4-5.8 GHz	Long read range High reading speed Line of sight required, Expensive	10 to 20 ft or distances greater than 20 ft	Railroad car monitoring Highway toll collection systems

---

[68] Downloaded from www.rfid.zebra.com/faq.htm on August 21, 2004.

2. Current Applications

The most common uses are found in security and access control systems, work-in-process tracking, supply chain management, and car immobilizers. They are also used at pay-at-the-pump and as freeway toll passes. “The RFID technology is being used by; the Ford Motor Company to track engine blocks, Gap Incorporated to track denim jeans through its supply chain to the in-store display shelf, Exxon Mobil Corporation's Speedpass cashless payment system, and they are applied to the shoelaces of all competitors in the Boston Marathon to track them at points throughout the course and to identify them the instant they cross the finish line.”[69]

3. Implementation

The integration of RFID into the proposed solar PV systems used throughout Iraq could be a viable solution to preventing theft. Tags and antennas could be embedded into the solar components (i.e. panels and the enclosed pallet); while the reader would be positioned at the military run checkpoints. Because these checkpoints are scattered throughout the country, the unauthorized movement of solar components would be easily detected. Once detected, the solar components can be recovered and returned to the owner. The consistent recovery of solar components could eventually prevent or at least deter further pilferage.

D. EMERGING TECHNOLOGY

The challenge of using solar PV systems is overcoming the variations in sunlight intensities that contact the solar panels throughout the day. The sunlight of the early morning and late evening produce less energy than in the afternoon. Likewise, cloudy or overcast days will produce less energy than on clear sunny days. And because of these fluctuations in sunlight, the designs of solar PV systems are based on the peak sun hours (PSH) per day of a specific geographical location. Additionally, reduced performance of solar PV systems is compounded not only with exposure to sunlight, but also with the power output required by the load or user needs. “On partly cloudy days solar PV systems may only produce up to 80 percent of their potential output power, on

---

[69] Downloaded from www.newburydata.co.uk/Main/fr_index.html?/Main/rfid.htm on September 1, 2004.

hazy/humid days they may produce about 50 percent, and on extremely overcast days, about 30 percent."[70]

The good news for solar PV systems is the improvements being made in solar cells and the emerging technology of power conversion. These far-reaching technology changes will be essential to Iraq's energy shortfalls. By investing in the power conversion technology, the U.S. can look forward to a more resilient economy and secure future for Iraq. An emerging capability built by Atira Technology is the Photovoltaic Power Conversion (PVPC) that has the potential to convert unused solar energy into a useable resource. This process enhances the performance of solar PV systems by increasing the PSH per day. This is primarily accomplished through power mode conversion that adjusts the sun's energy passing through the solar panels relative to the power requirements of the load. A percentage of the increase in the sun's energy is directly proportional to exposure of sunlight on the solar panels. "The PVPC continuously optimizes the input generated from the solar panels to maximize the output."[71]

Hypothetically, consider a 40 percent increase in power usage of a solar PV system configured with the PVPC. A geographical location that typically has 5 PSH would have an increase of 2 hours per day to use the solar PV system (5 x 1.4 = 7). The advantage is not only maximization of the sun's daily energy from early morning to late evening, but also the reduction in the number of solar components - panels and batteries. This increased solar capacity results in lower initial capital cost, yearly maintenance, panel size, and battery hazards.

---

[70] Downloaded from www.windfallcentre.ca/default/index.php on May 21, 2005.

[71] Atira Technologies Photovoltaic Power Conversion Technology, Alexander Wolf, March 2005.

Consider an Iraqi residential solar PV system of 3,000-W designed for 14.73 kWh/day at 5 PSH. This system would need the following basic components:

- 20 each panels,
- 16 each batteries,
- 1 each inverter, and
- 1 each charger controller.

Recall that 40 percent to 50 percent of the cost for a solar PV system is in the expense of solar panels. Figure 14 depicts the area needed to install twelve solar panels.

Figure 14 An array of Twelve Solar Panels.[72]

Now consider a solar PV system embedded with the PVPC. The load requirements remain the same however, the sun hours are extended. A 1,200-W PVPC configured solar PV system for 14.73 kWh/day at 5 PSH would consist of the following components:

- 10 each panels
- 8 each batteries
- 1 each inverter
- 1 each charger controller

---

[72] Downloaded from www.pathtofreedom.com/pathproject/offthegrid/solar.shtml on April 26, 2005.

This is a decrease in half the panels and batteries needed for the same residential house without the PVPC. Because the PVPC continuously optimizes the input to maximize the output, there is a reduction in components of a solar PV system. A more in depth description of the emerging technology, PVPC, is provided in the following sections.

1. PVPC Introduction[73]

This section of the paper will provide greater detail on how the PVPC works. This is an excerpt from The Photovoltaic Power Converter: A Technology Readiness Assessment written by Steven R. Ansley and Lewis H. Phillips in June 2005.

2. Product Description: Converting Solar Power

To understand what the PVPC does, it helps to understand the environment in which it operates. The power (Watts) generated by a PV panel varies significantly based on three primary factors: the efficiency of the panel itself, the amount of sunlight hitting the surface of the panel, and the load applied to the system. The efficiency of the panel is a function of the material used to construct it, and once constructed, cannot be changed. The amount of light hitting the surface of the panel depends on external environmental and geographical factors, such as the latitude at which the panel is located or the amount of shadow cast on the panel by terrestrial objects or clouds. In our tests, we measured the amount of light hitting the surface of the panel in Lumens per square meter (otherwise known as Lux). In our research, we found that another commonly used measure of the energy striking the surface of the panel is Watts per square meter (W/m^2). Lastly, the attached devices that require power (a laptop computer, calculator, or a battery in our case) represent the load applied to the system.

Commercially available panels, typically with low conversion efficiencies of 10 percent or less, have power outputs that are extremely sensitive to lighting conditions and the load factor placed on the system. As the amount of light energy striking the surface of the panel varies, the potential power the panel can produce is constantly in flux. If the

---

[73] The remaining sections for Emerging Technology were provided from an NPS thesis titled The Photovoltaic Power Converter: A Technology Readiness Assessment written by Steven R. Ansley and Lewis H. Phillips on May 18, 2005.

light energy falling on the panel is insufficient to generate the required Voltage or Amperage needed, the load will shut off or cease to charge. The panel is still producing power, but either the Voltage or Amperage components are insufficient to meet the threshold requirements of the load; therefore, as far as it is concerned, no usable power is being produced.

Figure 15 below shows a plot of Current, Amperage, (in milliamps on the Y axis) vs. Voltage (on the X axis) produced by a Solengy solar cell (red) and a competitors cell (blue) under decreasing light energy levels from 200W/m^2, 100W/m^2, and finally 50W/m^2 respectively. This figure graphically represents the decreasing light scenario mentioned above in which the light energy at 50W/m^2 does not generate enough voltage for the lowest blue line to intersect the 12V battery's charging window.

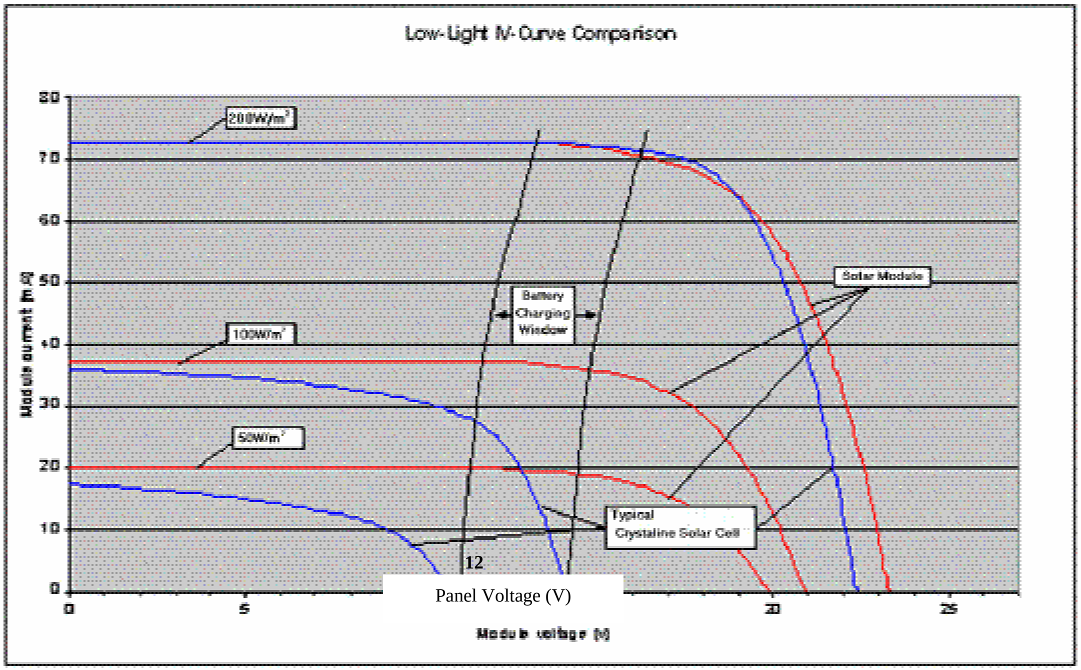


Figure 15 Low Light Effect on Battery Charging.
(From www.solengy.com/pages/whitepapers.html, April 2005)

Alternatively, if the load attached to the system attempts to draw too much current (Amps) from the panel, even in good lighting conditions, the Voltage across the circuit will drop to zero and no power is produced (0 V * X Amps = 0 Watts). This scenario is depicted in the figure above by starting at the left of any line and noticing that at maximum amperage achieved, the voltage is zero, which means no power is being produced.

To address the variability of the amount of light energy striking the panel and the varying demands of the load, the PVPC incorporates two critical technologies – Maximum Power Point Tracking (MPPT) and Switch Mode Power Conversion (SMPC). Both of these technologies are proven and have been commercially available for years. Making use of these two technologies, Atira claims it can recover as much as 25 percent of the available power that is currently wasted in conventional conversion techniques; thereby essentially increasing the overall efficiency of the PV system [not the cell itself] by this amount.[74] The PVPC is unique because it applies these technologies to an area of low power production, namely photovoltaic panels, which had previously received little attention from power conversion designers.

a. Maximum Power Point Tracking (MPPT)

The concept behind MPPT is that the circuit continuously monitors and optimizes the interface between the solar panel and the load/battery. The only way to continuously maximize the power output based on these two ever-changing inputs is for the output load to be constantly adjusted based on the level of exposure of the PV panel to the sun. However, current MPPT circuits are designed only to optimize the panel input within a narrow range, as shown in Figure 15. In other words, when the light energy striking the surface of the panel is sufficient to generate a voltage that is within the battery's charging window, the MPPT circuit will maximize the amount of power that can be produced by that amount of light. If the light energy is insufficient to cross the threshold, no power is produced – it only maximizes what makes it into the window. The result is a PV panel with a specific nominal voltage, such as the Solengy panel graphed above (12V panel) matched to the load of a 12V battery. The panel cannot charge a load that exceeds its voltage window, such as an 18V battery. Below in Figure 16 is a schematic of a standard MPPT circuit.

---

[74] Alexander Wolf, "Photovoltaic Power Conversion Technology Enhancements: Design a circuit that will track max pwr pt," (Unpublished Document, Atira Technologies, Los Gatos, CA: 2004), 2.

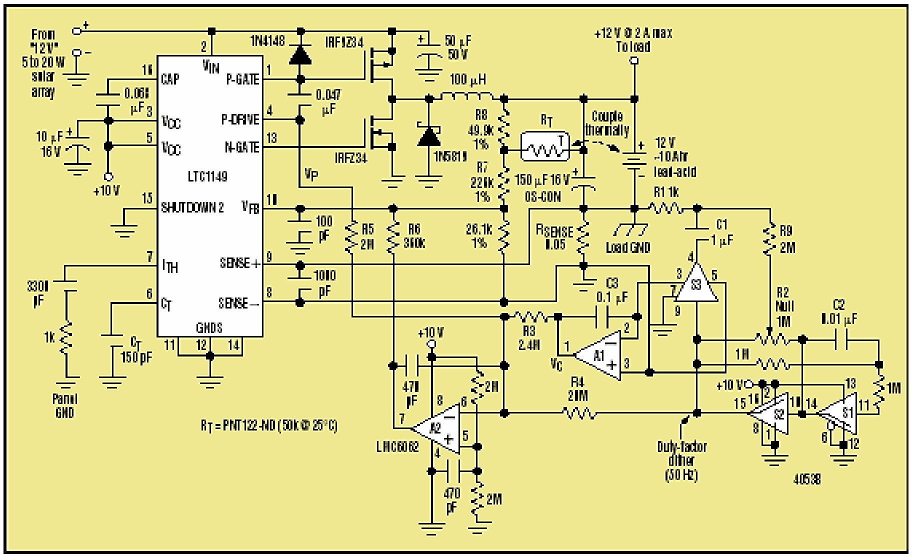


Figure 16 Schematic of Maximum Power Point Tracking Circuit.
(From www.elecdesign.com/Articles/ArticleID/6262/6262.html, April 2005)

b. Switch Mode Power Conversion

Switch mode power conversion is the method by which the PVPC continuously adjusts the output load based on the amount of sunlight striking the surface of the panel. "In all applications of switch mode power conversion, input power to the converter is equal to the output power generated by the converter, assuming no losses within the conversion process. Simply stated, 6 volts at 1 amp [output of the solar panel] is converted to 12 volts at 0.5 amps [by the PVPC]."[75] If the load on the PV system is a typical 12V battery, it has an approximate charging window between 11V and 14V. Voltages produced by the panel that are less than 11V or more than 14V are unusable for charging the battery and therefore wasted energy. However, if you changed the component characteristics of the power so that the 6V and 1A produced by the panel is converted into 12V and 0.5A, the threshold for battery charging is achieved. Also, if the SMPC can convert the 6V and 1A into 18V and .33A it can now charge an 18V battery, something a 12V panel could never do before. By using the second concept of switch

---

[75] David A. Besser, "Photovoltaic Power Conversion Technology: Reserved Backup Power," (Unpublished Document, Atira Technologies, Los Gatos, CA: May 12, 2004), 2.

mode power conversion, the PVPC can both expand the range of batteries it can charge or applications it can power and extend the usable range of input solar energy.

The PVPC changes the components of the power equation by switching the mode of the power, produced by the panel, from Direct Current (DC) to Alternating Current (AC). Once switched to AC, the energy now has another component characteristic – frequency, as measured in Hertz (Hz). By modulating the frequency to a higher level and then switching back to DC, the voltage is dramatically increased and the current is proportionally decreased to stay within the laws of V*A = W. The result is a usable voltage level being produced by the system that can satisfy the load, whereas before voltage produced was too low to be usable. In the situation just discussed in which the panel is only producing unusable power, it can be argued that PVPC infinitely improves the system. We designed our tests to determine if a solar PV system with the PVPC integrated produces more power than a system without the technology.

c. Relevant Range of the PVPC

Currently, Atira is building the PVPC by hand from commercially available components. Each PVPC is built to optimize a particular panel's power production. The three PC circuits we tested are known as the 0512, 0916, and the 1216 circuit boards. The first two numbers indicates the input Voltage of the panel the circuit was designed to optimize. While the last two numbers give the nominal upper Voltage limit the circuit can produce based upon that input voltage. For instance, the 0916 circuit is designed to optimize the power output of a 9V solar panel and can increase that Voltage up to about 16V. Therefore, as currently produced, one size does not fit all applications. When constructing the PVPC, designers must consider the particular power production characteristics of the solar panel as well as the power requiring characteristics of the load.

The original PVPC circuit was the 1216, designed to work with the 12V Solengy glass panel. The 1216 was then subsequently modified into the 0916 to work with the 9v Uni-Solar LM-3 panel. The modification was done as a proof of concept to show that with the 0916 PVPC a 9V panel could indeed charge a 12V battery. However, the design was never matured to optimize at the 9V input level.

d. Physical Description

Figure 17, below, shows the physical appearance of the PVPC at the time of our April 2005 tests. Atira currently builds the PVPC by hand, on printed circuit board with various capacitors, inductors, resistors, and input and output receptacles soldered on. It is 1.9375 inches (horizontally) by 1.625 inches (vertically) as shown below.

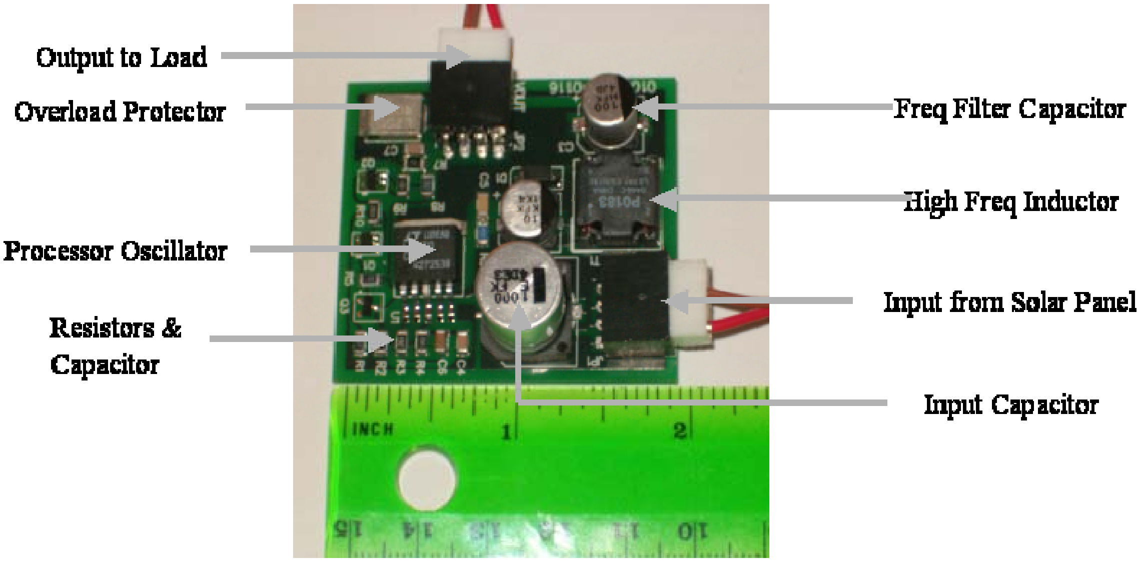


Figure 17 Digital Photograph of the PVPC.

e. Next Generation of the PVPC[76]

For any new technology or product, the ability to economically manufacture is an important consideration. Atira realizes that the current method of production cannot support large orders. With this in mind, the company is working with potential manufacturers to both miniaturize and mass-produce the technology. "In its final form, the PVPC will be an integrated circuit not much larger than a postage stamp". They also see the need to give the PVPC its own automated processor, so it can optimize electronically, over a far greater range of input panel voltage and power, what it is now doing with hand-soldered hardware. "The next generation PVPC will be designed with a built in microprocessor that will allow it to optimize input Voltage from zero to 30V and power from zero to 200W to meet the demand of the load".

---

[76] Stephan Matan, PVPC Inventor, telephone conversation with authors, May 4, 2005.

The manufacturing and miniaturization technologies to build microprocessors and other electronic components are mature. The ability to literally grow the silicon crystals and print the circuit pattern on the wafer is known as photolithography. This is a manufacturing method routinely applied in fabrication facilities where chips such as Intel or AMD microprocessors are manufactured, which allows the wafer to electronically replicate the hardware shown in Figure 17.

3. Summary of How It Produces Power

Based on the preceding explanation of the two critical PVPC operating characteristics, we provide the following concise description of how it produces usable power. Using switch mode power conversion, the PVPC continuously modifies the characteristics of the inherently variable power produced by the panel to provide the maximum amount of usable power, within a relevant range, to the attached load; it does this based on its changing power requirements, as determined by the maximum power point tracking circuit.

THIS PAGE INTENTIONALLY LEFT BLANK

V. TEST AND EVALUATION OF PVPC

A. METHODOLOGY

As stated in the previous section, the PVPC is designed to improve the output of solar PV panels. Other related tests have shown increases in power generated by a solar PV system integrated with the PVPC; however, this is the first time that it has been tested in a solar residential configuration. Two identical solar PV systems were installed in a residential house in Novato, California. The differences in the two systems are that the conventional system contained the MPPT and the other contained the PVPC. The MPPT or conventional system has been proven to increase performance of traditional solar PV systems up to 30 percent.[77] Our testing was designed to see if the PVPC was capable of outperforming the MPPT system, which is already a proven improvement over traditional systems.

The objective of installing these systems was twofold: first to collect comparison data for PVPC evaluation and analysis; and second, to compute any percentage of change between the two systems for input into the Operation Solar Eagle Cost Model.

The data collection of the two systems began on June 1, 2005. The two solar PV systems were connected to an acquisition system that distributed data over the internet for system monitoring at Monterey, California via computers. The data was recorded continuously on the Novato server and exported daily to a reduction station in Monterey.

The data were collected from the simultaneous operation of both solar PV systems for a quantitative analysis using descriptive statistics of graphical techniques and numerical measures. Data sets of continuous recordings were used to determine the performance difference of a solar PV system integrated with and without the PVPC technology. The solar PV systems used for analysis consisted of the configurations shown in Table 8.

---

[77] Downloaded from www.blueskyenergyinc.com/pdf/blue%20sky_what%20%20MPPT.pdf on June 13, 2005.

Table 8 Solar PV System Configurations used in Comparison Tests.

Components	**Conventional** (each)	**PVPC** (each)
Panels, 190-W	3	3
Batteries, 6-Vdc, 130-Ah	4	4
Load, 100-W bulb	1	1
Charge Controller (MPPT), 60-A	1	0
Atira Technology (PVPC)	0	1 per panel

B. DESCRIPTIVE STATISTICS

This section provides details of data collection, parameters, presentation, interpretation, analysis, and statistical results.

The data consisted of current (A) and apparent power (kVA) collected continuously and reported in 15 minute intervals derived from side-by-side operation of solar PV systems with and without PVPC. A sample of the data recordings are shown in Table 9. A complete list of data recordings are provided in Appendix E. The parameter of current is the output amperage or electrical current produced by the solar panels. The parameter of apparent power is the electricity applied to the load, in the case of our testing; the load consisted of batteries and a light bulb.

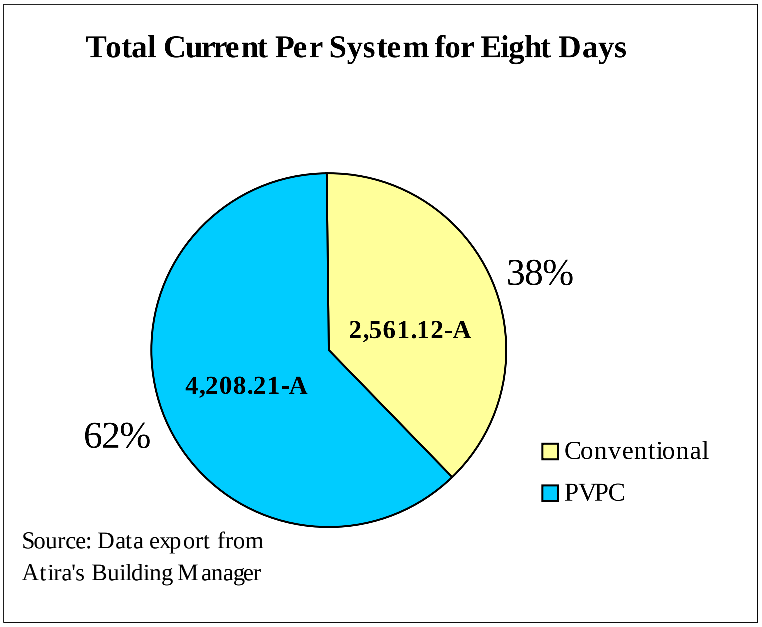
Table 9 Data Sample of Current and Apparent Power Used in Analysis.

Time (U.S./Pacific)	**Conventional Current (Amps)**	**PVPC Current (Amps)**		**Conventional Apparent Power (kVA)**	**PVPC Apparent Power (kVA)**
6/1/2005 8:00	0.055	0.629		0	0.1
6/1/2005 8:15	1.026	1.38		0	0.1
6/1/2005 8:30	2.576	2.405		0	0.096
6/1/2005 8:45	3.791	5.971		0	0.096
6/1/2005 9:00	4.799	7.228		0	0.096
6/1/2005 9:15	5.952	9.084		0	0.096
6/1/2005 9:30	6.911	10.629		0	0.1
6/1/2005 9:45	7.698	11.88		0	0.096
6/1/2005 10:00	8.217	12.924		0	0.096
6/1/2005 10:15	8.565	14.035		0	0.1
6/1/2005 10:30	8.773	15.024		0	0.1
6/1/2005 10:45	8.803	16.105		0	0.096
6/1/2005 11:00	9.56	18.687		0	0.1
6/1/2005 11:15	10.385	19.158		0	0.1
6/1/2005 11:30	10.226	20.275		0	0.096
6/1/2005 11:45	10.134	21.19		0	0.096
6/1/2005 12:00	9.86	21.819		0	0.096

The analysis was conducted using Microsoft Excel 2003 with data sets collected over multiple days. The data sets for electrical current consisted of a record of the amperage levels produced in a twelve hour period starting at 8:00 a.m. and concluding at 8:00 p.m. The dates of recording observations for current were June 1, 2005 through June 8, 2005. Data that were not factored into the calculations for the current include the observations on June 6, 2005 from 1:00 p.m. to 7:15 p.m. due to network problems and the current recordings outside the twelve hour period because of their insignificant contribution to the total current records. The apparent power data sets consist of data recorded in 15 minute intervals over a 24 hour period. The dates of the apparent power tests were June 4, 2005 through June 8, 2005. During the span of these tests, we collected a total of 366 data observations recording current and 480 data observations recording apparent power.

1. Electrical Current Analysis

During the eight days of current testing, the conventional-MPPT solar PV system produced 2,377.28-A, while the solar PV system with PVPC nearly doubled the output with a total of 4,037.19-A. See Figure 18 for total daily current produced and Figure 19 for total current produced by each solar PV system. The conventional-MPPT system performed marginally better by producing 28-A more than the PVPC system between the hours of 8 a.m. and 9 a.m. and from 7 p.m. to 8 p.m. During the remaining eight hours, 9 a.m. to 6 p.m., the solar PV system with PVPC out produced the conventional-MPPT system by 1,688-A. The added 1,688-A is nearly equal to the total current produced by the conventional-MPPT solar PV system during the entire eight day test.



Source: Data export from Atira's Building Manager

Figure 18 Total Current Produced By Each Solar PV System.

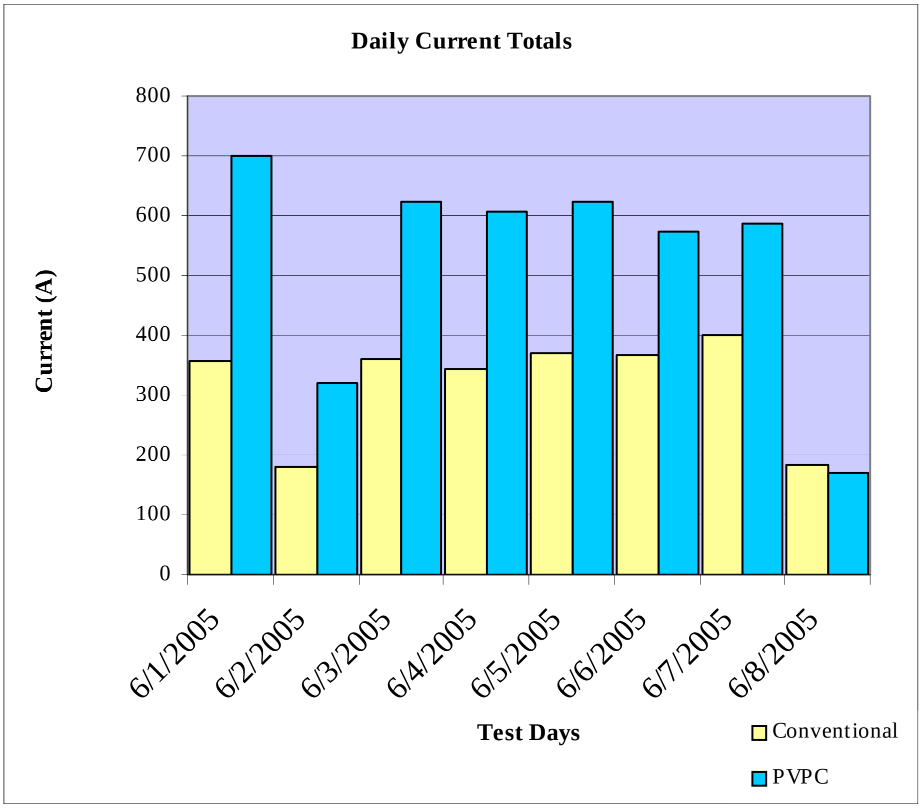
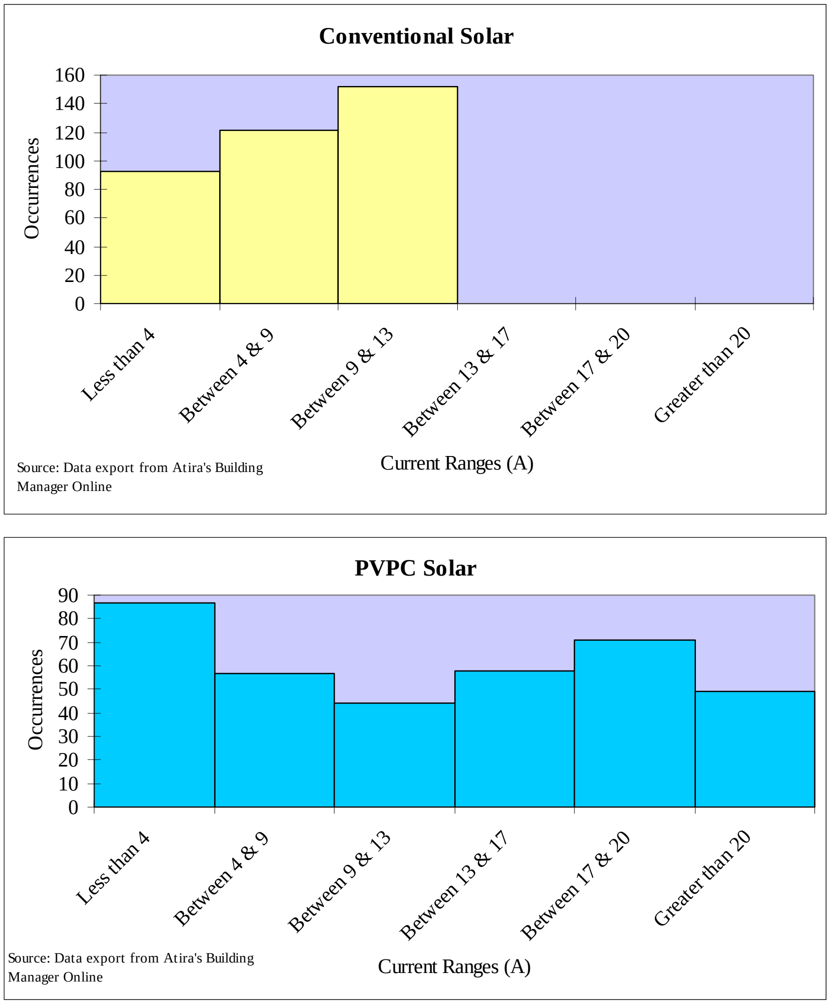


Figure 19 Daily Current Totals For Both Solar PV Systems.

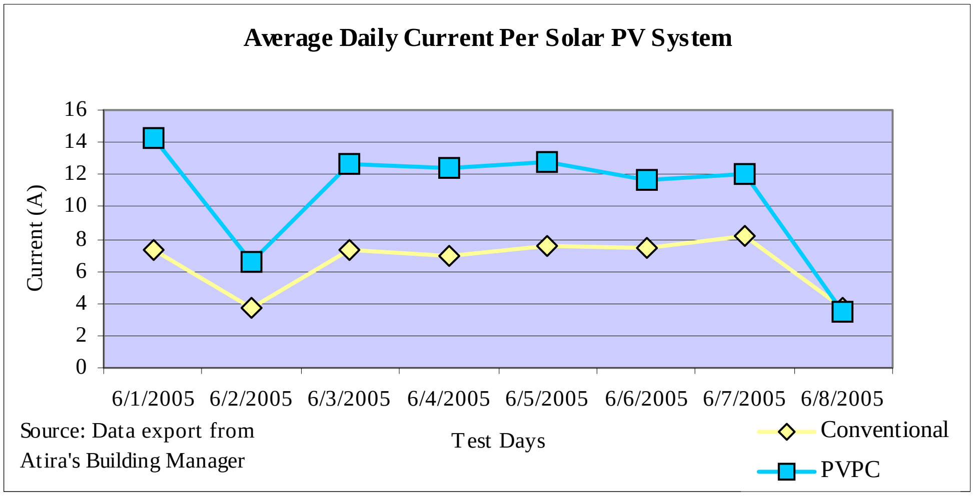
Figure 20 is a histogram that groups current levels by their number of occurrences. It can be seen that the levels of current produced by the conventional-MPPT solar PV system never reached above 13-A. While the solar PV system with PVPC was able to reach levels greater than 13-A and even over 20-A. The line graph in Figure 21 depicts the average daily current. The increases and decreases in the average current shown in this figure were due to changes in terrestrial weather conditions. We experienced clear to cloudy to rainy days during our tests. The weather data for test and evaluation testing are shown in Appendix D. Consequently, weather conditions impact performance of any solar PV system. However, the solar PV system with PVPC continued to produce a higher average current per day.



Source: Data export from Atira's Building Manager Online

Source: Data export from Atira's Building Manager Online

Figure 20 Occurrences of Current Levels for Each Solar PV System.

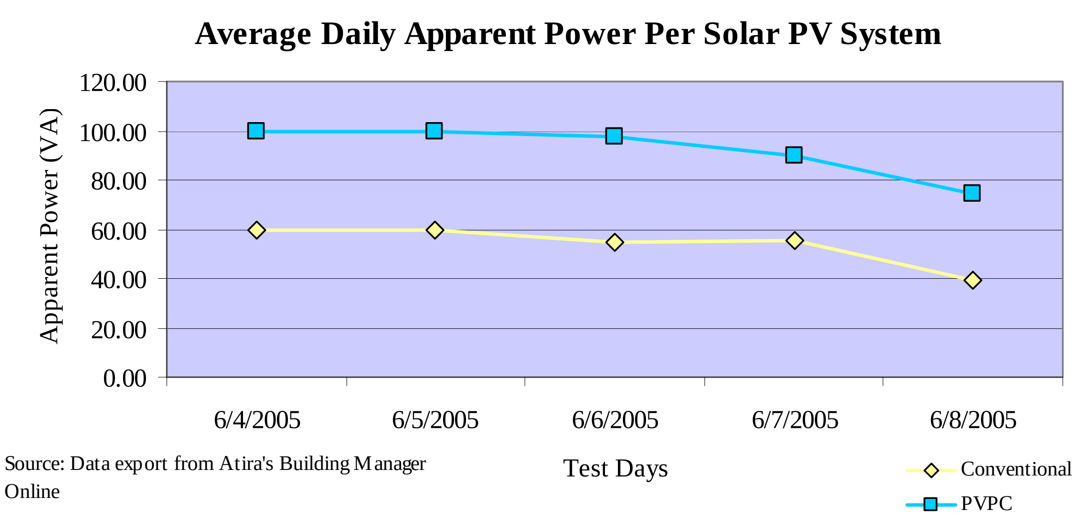


Source: Data export from Atira's Building Manager

Figure 21 Total Average Daily Current for each Solar PV System.

2. Apparent Power Analysis

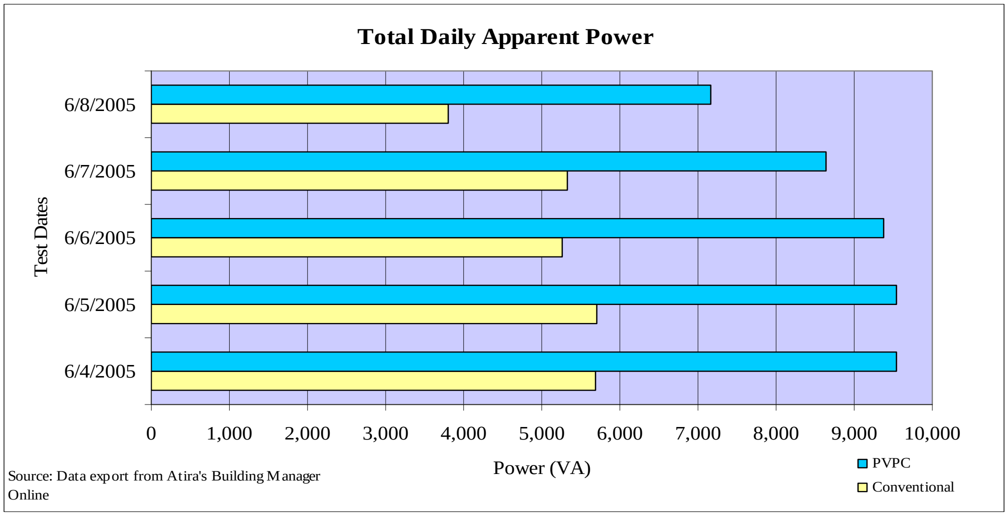
In addition to the electrical current data collection, there were five days of apparent power data collection. In reduction of the data it was observed that the conventional-MPPT solar PV system produced apparent power equal to 21,500-VA. The solar PV system with PVPC produced apparent power equal to 36,308-VA. This difference is an increase in apparent power by the PVPC system of 68.87 percent. See Figure 22 for the average daily apparent power of each system. The decrease in power of both systems is similar to the drop in current mentioned previous. As the terrestrial weather conditions change the performance of solar PV systems is degraded. The PVPC technology does optimize the input to maximize the output, but there are limits to its capabilities when clouds and rain block a large portion of the sunlight reaching the solar panels. This is most noticeable on June 8, 2005 for both current and apparent power. Loss in performance of solar PV systems on cloudy or overcast days can be as low as 30 percent.



Source: Data export from Atira's Building Manager Online

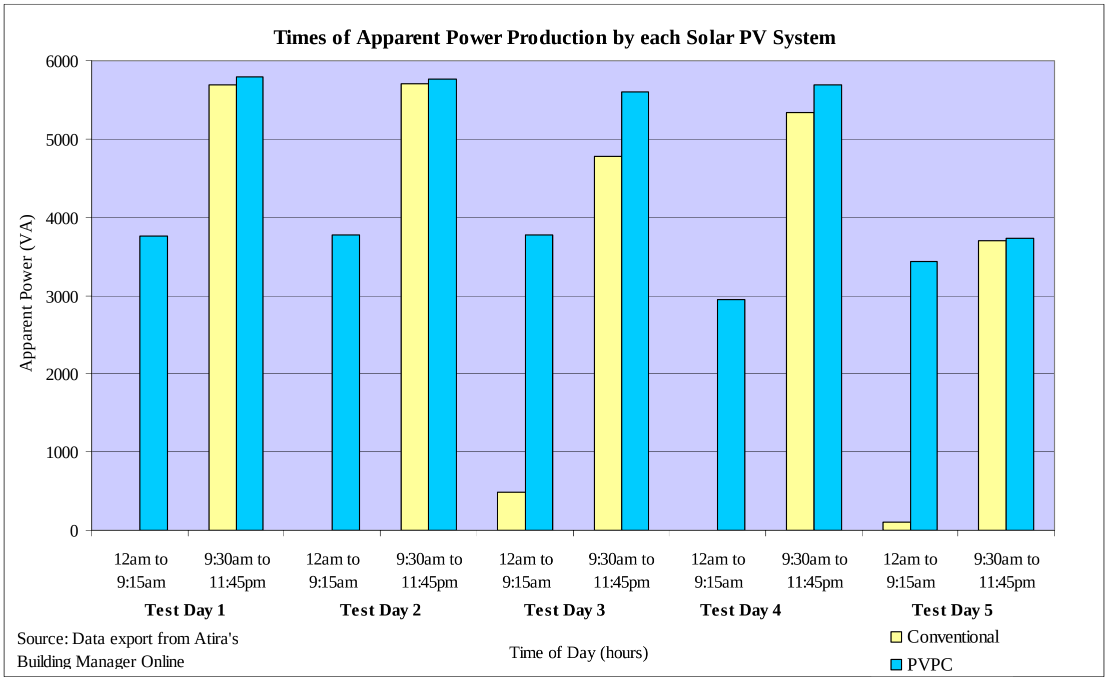
Figure 22 Average Daily Apparent Power per Solar PV System.

The conventional-MPPT solar PV system was unable to perform as well as the PVPC system as evidenced by its inability to produce as much total daily power as depicted in Figure 23. The data illustrates an advantage of the solar PV system integrated with PVPC was its ability to generate enough power to charge the batteries while continuously illuminating the light bulb. Figure 24 shows from midnight to early morning the apparent power delivered by the conventional-MPPT solar PV system dropped to zero three of the five test days, and thus the light bulb was not illuminated. On the fifth day during these same hours 12:00 am to 9:15 am there was some apparent energy delivered, but at a much reduced level from the PVPC system during this time.



Source: Data export from Atira's Building Manager Online

Figure 23 Total Daily Apparent Power of Both Solar PV Systems.



Source: Data export from Atira's Building Manager Online

Figure 24 Times of Apparent Power Delivered by Each Solar PV System.

3. Statistical Analysis

Other related test results indicate that PVPC solar PV systems generate an average increase of 39 percent more power than conventional-MPPT solar PV systems. For a comparable analysis between our test results and the other related test results, we used the same statistical procedures used for the other recent analyses that tested the mean value of a distribution. We used two statistical methods to analyze our results: 1) t-Test: Paired Two Sample for Means, and 2) t-estimate: Mean. These t-tests compare two distributions of interval data to determine the highest improvement in current and apparent power between two means and to compute the upper and lower limits to find the percentage of improvement between the conventional-MPPT and PVPC solar PV systems. To statistically determine if one system is better than the other, we stated the same null and alternative hypotheses as used in the other related PVPC tests. The alternative hypothesis (H_1) and null hypothesis (H_0) are:

$$H_0:\ (S_1 - S_2) = 0$$

$$H_1:\ (S_1 - S_2) > 0$$

The decision parameter to reject or not reject the null hypothesis is the difference between the two means, $S_1 - S_2$. The parameter S_1 represents the mean highest current or apparent power value of the PVPC system. The parameter S_2 represents the mean highest current or apparent power value of the conventional-MPPT solar PV system. To calculate the mean value for current and apparent power for both solar PV systems we found the difference of each mean value for both systems then divided that number by the mean value of the conventional system. Next, we multiplied the result by 100 to get the percent increase or decrease between the conventional-MPPT and PVPC systems. Either of the two equations shown in Figure 25 or Figure 26 can be used to calculate the percent increase or decrease of current and apparent power for each system.

$$\frac{S_1 - S_2}{S_2} \text{ X } 100 = \text{Percent Change from Conventional to PVPC}$$

Figure 25 Percent Change from S_2 to S_1.

$$\frac{S_2}{S_1} = \text{Multiplier for Conventional to Equal PVPC}$$

Figure 26 Multiplier Value for S_2 to equal S_1.

The dissimilarities between these two equations are the results of the final value. In the calculated percent equation, Figure 25, the value is determined from the conventional-MPPT system to the PV system. This value is considered the percent increase. In the second equation, Figure 26, the calculated value is only the multiplier to the conventional system value (S_2) and is not considered the percent increase. In the second equation, the percent value of 100 is already included in the result. Therefore, to calculate the true percent increase from Figure 26, subtract 100 from the result then multiply it by 100.

To compare observations of the two distributions statistically, current and apparent power, we used a t- Test analysis. The results provide statistical evidence necessary to reject the null hypothesis or support the alternative hypothesis and show the percent increase in performance of a solar PV system with PVPC. The results shown in Table 10, Table 11, Table 12, and Table 13 for both the current and apparent power measurements were calculated with a 95 percent confidence interval.

The results for current in Table 10 of the t-Test: Paired Two Sample for Means indicate that the mean for current of the PVPC system exceeds the mean for the conventional-MPPT solar PV system. In addition the t-stat outcome and the p-value provide overwhelming evidence to infer that the alternative hypothesis is true. Therefore, we rejected the null hypothesis and concluded that a solar PV system with the PVPC technology generates more current than a conventional-MPPT system. We calculated a

64.31 percent improvement in current over the conventional-MPPT solar PV system using the results of the t-Test: Mean in Table 11.

Table 10 t-Test: Paired Two Sample for Means for Current Records.

Parameters	Conventional System	PVPC System
Mean	6.997	11.497
Variance	12.760	56.355
Observations	366	366
Pearson Correlation	0.9314	
Hypothesized Mean Difference	10	
Df	365	
t Stat	-63.370	
P(T<=t) one-tail	2.3567E-199	
t Critical one-tail	1.649039018	
P(T<=t) two-tail	4.7135E-199	
t Critical two-tail	1.966484524	

Table 11 t-Estimate: Mean for Current Records.

Parameter	Difference
Mean	4.5003
Standard Deviation	4.3775
Lower Confidence Limit (LCL)	4.05032
Upper Confidence Limit (UCL)	4.95018

The results for apparent power in Table 12 of the t-Test: Paired Two Sample for Means indicate that the mean for apparent power of the PVPC system exceeds the mean for the conventional-MPPT solar PV system. In addition, the t-stat outcome and the p-value provide overwhelming evidence to infer that the alternative hypothesis is true. Therefore, we rejected the null hypothesis and concluded that a solar PV system with the PVPC technology generates more apparent power than a conventional-MPPT system. We calculated a 71.68 percent improvement in apparent power over the conventional-MPPT solar PV system using the results of the t-Test: Mean in Table 13.

Table 12 t-Test: Paired Two Sample for Means for Apparent Power Records.

Parameters	**Conventional System**	**PVPC System**
Mean	53.725	92.233
Variance	2388.700835	632.129
Observations	480	480
Pearson Correlation	0.259053915	
Hypothesized Mean Difference	50	
Df	479	
T Stat	-39.71327377	
P(T<=t) one-tail	6.0515E-154	
T Critical one-tail	1.648040973	
P(T<=t) two-tail	1.2103E-153	
T Critical two-tail	1.964928777	

Table 13 t-Estimate: Mean for Apparent Power Records.

Parameter	Difference
Mean	38.5083
Standard Deviation	48.828
Lower Confidence Limit (LCL)	34.12909657
Upper Confidence Limit (UCL)	42.8875701

C. ANALYSES ASSESSMENT

The statistical test results depicted in Table 10 through Table 13 estimated with a 95 percent confidence interval, that the mean current and apparent power for the PVPC exceeds the mean power for the MPPT or conventional Solar PV system. The increase for current of the PVPC system lies between 4.05-A and 4.95-A as depicted by the LCL and UCL. We calculated that the PVPC solar PV system generates between 57.88 percent and 70.74 percent more current. Additionally, the increase for apparent power of the PVPC system lies between 34.12-VA and 42.88-VA as depicted by the LCL and UCL. Subsequently, we calculated that the PVPC solar PV system generates between 63.53 percent and 79.83 percent more apparent power. These percent increases were calculated by dividing the LCL and UCL by the mean of the conventional solar PV system. We used the results in Table 10 and Table 11 to calculate percent increases in current and Table 12 and Table 13 to calculate percent increases in apparent power.

As previously stated there were other related PVPC tests. These related tests results found that PVPC improved performance of a solar PV system by 39 percent while our own test results indicated a 64.31 percent and 71.68 percent improvement. The difference in the results of our analysis when compared to related test results can be attributed to test design. Previous related tests were designed to measure the percent change of recharging batteries at specific points in time. These related tests were a series of iterations to accurately measure the rate to fully charge a battery. Our tests were designed to accumulate data over a long continuous period. Our tests were not restricted by iterations so the accumulation of data continuously resulted in higher percentages.

THIS PAGE INTENTIONALLY LEFT BLANK

VI. COST ESTIMATE FOR IRAQ SOLAR POWER IMPLEMENTATION

A. SOLAR COST OVERVIEW

The performance improvements of solar PV systems with PVPC have the ability to increase electrical current and apparent power as numerically proven. The question is does this improvement reduce the cost of a solar PV system?

The concept of using solar PV systems to assist in the rebuilding of the Iraqi infrastructure may initially seem impractical due to cost. However, the uses of solar PV systems in specific situations such as the ones discussed in previous case studies indicate their practicality and potential to help improve the electrical infrastructure. This section provides an overview of solar cost as it relates to their use and return on investment in the U.S., and then provides a scenario that details the benefit of implementing solar PV systems in Baghdad. Next, the section provides a cost comparison of conventional versus PVPC solar PV systems, which are specifically configured for Iraq. Finally, the section concludes with the cost of providing solar PV systems to Iraq using the percent increase in performance determined in the comparison test section.

The combination of grid power and solar power with battery storage, referred to as a hybrid system, has become more cost-effective over the last five years than when originally introduced. The cost of these solar PV systems has declined considerably over the past two decades. As a general cost guide the purchase and installation of a hybrid solar PV system is approximately $9 per wattage of the solar PV system capacity. This equates to an average monthly cost of about $0.25 per kWh as compared to an average monthly cost for commercial grid power of about $0.10 per kWh. According to the Energy Information Administration’s Electric Power Monthly newsletter of May 2004, “the residential electricity prices in the U.S. ranged from $0.05 to $0.18 per kilowatt-hour in February 2004”. A small, 75-watt solar PV system can cost $900 or about $12 per watt generation capability. As the power capacity of the solar PV system increases the cost per watt is reduced. “A 2 kW system costs from $16,000 to $20,000, or $8 to $10 per watt. A high end solar PV system, around 5-kW, costs $30,000 to $40,000, or $6 to

$8 per watt."[78] Generally, over the 20 year lifecycle (warranty) of a solar PV system, the average monthly cost will be just slightly less than the average monthly cost of commercial grid power. With the new PVPC technology, the breakeven point may be less than one-half that of normal solar PV systems.

B. SOLAR COST SCENARIO

Since the conclusion of combat operations in OIF, Iraq has been in a condition of rebuilding and reconstruction with slow progress being made in the restoration of reliable electrical power. The electrical demand of 8,000-MW continues to be unattainable due to years of maintenance neglect and continued terrorist attacks on the country's electrical infrastructure. There has been several billion dollars spent to meet the demand; however, Iraq still has an estimated power shortage of 3,600-MW. Hybrid solar PV systems have the potential to subsidize the current Iraqi power shortage. This section provides cost on several implementation alternatives for solar PV power.

The cost to install solar PV systems on every home in Iraq is likely not feasible; however, a tiered approach, such as installing these systems in a major city would be more attainable. Any power generated from a hybrid solar city would help lessen the overall country's power demands. Adding solar power to a major city could benefit the entire country. For example, if a portion of Baghdad installed solar PV systems on 80,000 residences, the power shortage would decrease by 1,178-MW. In other words, the 1,178-MW provided by the solar homes can be used elsewhere in the country as illustrated in Table 14 and Table 15.

Table 14 Amount of Solar Generated by Homes in Baghdad.

City	Portion of Homes	Daily Req (kWh/day)	Total (kWh/day)	Total (MWh/day)
Baghdad	80,000	14.73	1,178,400	1,178

---

[78] Downloaded from http://www.nrel.gov/docs/fy04osti/35297.pdf on April 1, 2005.

Table 15 Effects of Solar Residential Systems in Baghdad versus Overall Country Power Requirements (MWh).

Current Power Demand	8,000
Current Power Available	**4,400**
Shortage	3,600
Power Supplied by Baghdad Solar Homes	1,178
New Shortage Requirement	**2,422**

The following assumptions were used in calculating the amount of power generated by Baghdad:

- On average, 11 hours of power are supplied to homes per day;
- The remaining 13 hours in the day are provided by solar PV systems; and
- The home power requirements calculation equal to 14.73 kWh/day was calculated from Table 16.

This scenario illustrates that diversification of the current power generation for Iraq with solar PV systems would reduce the burden on the commercial grid power infrastructure.

1. Cost of Conventional Solar PV Systems for Iraq

There are two options when purchasing solar PV systems and multiple options when selecting vendors. Solar PV systems can be purchased as a preassembled kit or as components that can be integrated to meet the residential and commercial power needs of Iraq. Table 17 lists four retailers and their components that were configured to provide approximately 45 percent, 11 hours, of the daily Iraqi power. These systems were designed with consideration that the typical Iraqi home of 6 occupants uses 14.73 kWh of power per day. Table 16 is a list of home appliances used to estimate the home power per day. Each of the solar PV systems in Table 17 includes a bank of batteries to power critical loads such as refrigerator, lights, and appliances for 6 hours, in the event of a rolling blackout, natural disaster, or some other reason for power loss.

The cost shown in Table 17 are based on available components of each retailer and depict solar PV systems with approximately 2.0-W to 3.0-W capacity. The prices range from roughly $18,000.00 to $24,000.00. The difference in price is largely due to the quantity of solar PV panels, the inverter power capacity, and batteries. Virtually all cost of a solar PV system is up-front cost, primarily for the expense of solar PV panels.

"The solar module (also called a solar panel) accounts for between 40 to 50 percent of the total cost of an installed solar energy system."[79]

The solar PV system of choice for Iraq is the hybrid PV system. It has a significant advantage over on-grid or off-grid systems because a hybrid PV system can be setup to redistribute excess power back to the commercial power grid. This important characteristic is very appealing of having a hybrid tied solar PV system. The excessive power generated by a solar PV system can be used to supplement or increase the electrical needs of others. It is important to note that the costs in Table 17 do not reflect the inclusion of PVPC or any other cost savings. This is discussed in the next section.

Table 16 Iraqi Household Appliance Power Usage.

Appliance	**Watts (W)**	**Estimated Hours Used per Month (Hr)**	**Quantity per Household**	**Watts per day**
Window Unit Air Conditioner	350	200	1	2,333
CD, Tape, Radio, Receiver System	250	60	1	500
Clock	3	730	2	146
Coffee Maker (Auto Drip)	1165	4	1	155
Fan (Ceiling)	80	150	1	400
Fry Pan	1200	10	1	400
Hair Dryer (Hand Held)	1000	10	1	333
Heater (Portable)	1500	40	1	2,000
Iron	1000	5	1	167
Lighting (Incandescent)	75	100	10	2,500
Lighting (Fluorescent)	40	100	3	400
Microwave Oven	1500	11	1	550
Motor (1 HP)	1000	20	1	667
Power Tools (Circular Saw)	1800	1	1	60
Radio	71	101	1	239
Satellite Dish (with Receiver)	360	183	1	2,196
Television (Color, Solid State)	200	183	1	1,220
Toaster	1400	3	1	140
Vacuum Cleaner	1560	6	1	312
VCR	45	6	1	9
			Total Wh/day	**14,727**

---

[79] Downloaded from http://www.solarbuzz.com/Consumer/FastFacts.htm on March 9, 2005.

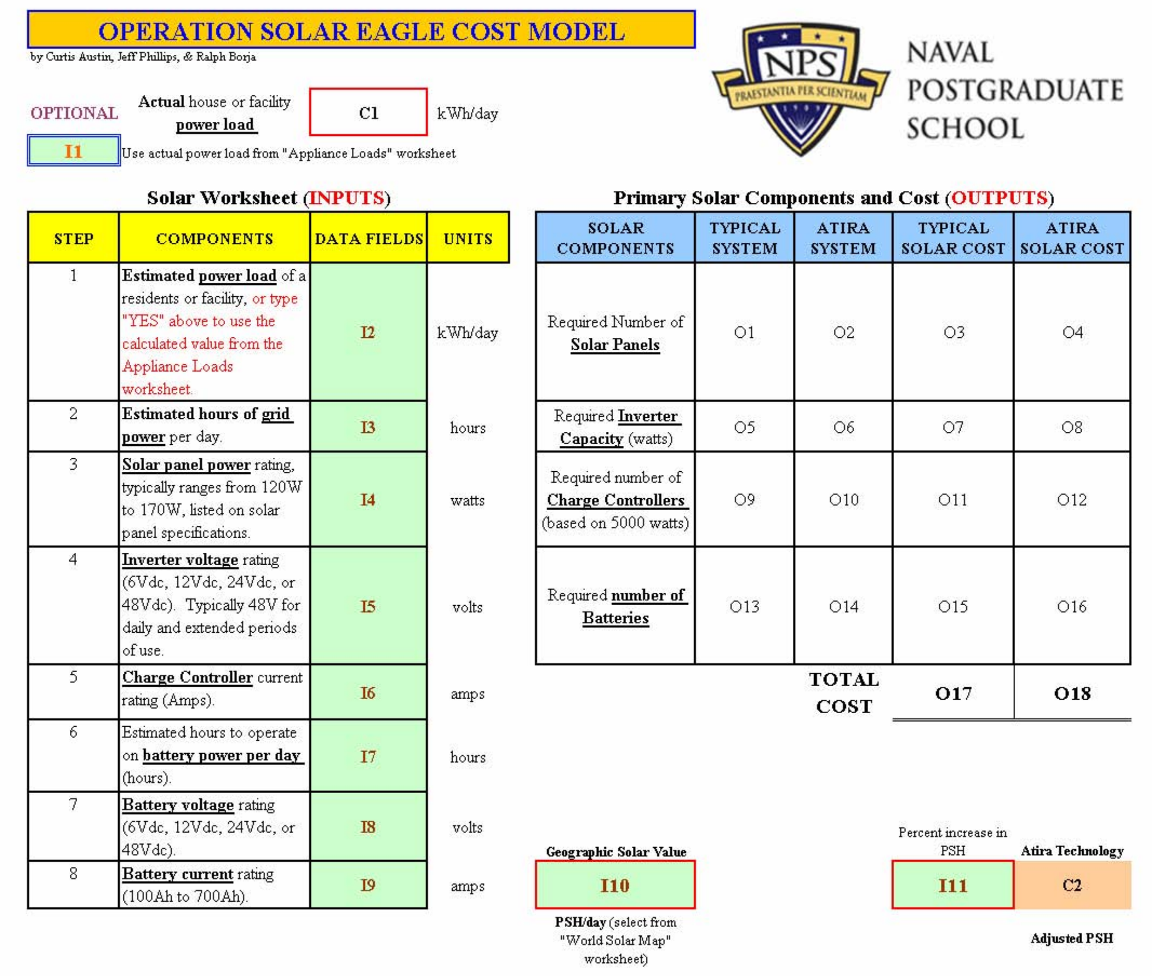
Table 17 Solar Retailer Cost Comparison.

Retailer	Affordable Solar	Solar Depot	BackWoods Solar	Sunwize
Model Number	GGSPS-3000	SG2600-OB	Kit #5	GTS-2338-2.5
System Power (Wp)	3080	2560	2880	2338
Quantity and Type of Solar Panels	28 each Evergreen EC-110, 110 watts	20 each BP BP3160B 160 watts	24 each Kyocera KC120 120 watts	16 each SunWize SW165-L 155 watts
Quantity and Type of Inverter (sine wave power)	1 each Fronius IG 3000 SW3048E	1 each Beacon Power M5	1 each Xantrex SW4048E	1 each FX2548
Inverter Capacity (load watts continuous)	3300 watts	5000 watts	4000 watts	2500 watts
Charge Controller	1 each OutBack Power MX60 MPPT	1 each Solarix Tarom 430	1 each OutBack Power MX60 MPPT	1 each Solar Boost 6024HDL
Battery Type	Surrette S-460 6V, 360Ah	MK8A31 6V, 370Ah	Trojan L-16HC 6V, 420Ah	Rolls Battery B10 6V, 530Ah
Quantity Batteries	16	24	16	16
Battery Configuration	48Vdc, 720Ah parallel, 2 banks of 8	48Vdc, 740Ah parallel, 4 banks of 6	48Vdc, 840Ah parallel, 2 banks of 8	48Vdc, 1060Ah parallel, 2 banks of 8
Battery Run Time without 20 percent loss	10.5 hours	6 hours	10.08 hours	11.30 hours
Total Cost	$17,999.00	$23,634.00	$19,250.00	$19,700.00

2. Operation Solar Eagle Cost Model Defined

We developed the Operation Solar Eagle Cost Model in Table 18 to compare costs and components of solar PV systems with and without PVPC for applications in Iraq. Next, we evaluated costs of solar PV systems as a result of increases in PSH due to measured capabilities of the PVPC.

Table 18 Automated Solar Sizing Cost Commutator.



OPERATION SOLAR EAGLE COST MODEL

by Curtis Austin, Jeff Phillips, & Ralph Borja

NAVAL
POSTGRADUATE
SCHOOL

OPTIONAL	**Actual** house or facility **power load**	C1	kWh/day
I1	Use actual power load from "Appliance Loads" worksheet		

Solar Worksheet (INPUTS)

STEP	COMPONENTS	DATA FIELDS	UNITS
1	**Estimated power load** of a residents or facility, or type "YES" above to use the calculated value from the Appliance Loads worksheet.	I2	kWh/day
2	**Estimated hours of grid power** per day.	I3	hours
3	**Solar panel power** rating, typically ranges from 120W to 170W, listed on solar panel specifications.	I4	watts
4	**Inverter voltage** rating (6Vdc, 12Vdc, 24Vdc, or 48Vdc). Typically 48V for daily and extended periods of use.	I5	volts
5	**Charge Controller** current rating (Amps).	I6	amps
6	Estimated hours to operate on **battery power per day** (hours).	I7	hours
7	**Battery voltage** rating (6Vdc, 12Vdc, 24Vdc, or 48Vdc).	I8	volts
8	**Battery current** rating (100Ah to 700Ah).	I9	amps

Primary Solar Components and Cost (OUTPUTS)

SOLAR COMPONENTS	TYPICAL SYSTEM	ATIRA SYSTEM	TYPICAL SOLAR COST	ATIRA SOLAR COST
Required Number of **Solar Panels**	O1	O2	O3	O4
Required **Inverter Capacity** (watts)	O5	O6	O7	O8
Required number of **Charge Controllers** (based on 5000 watts)	O9	O10	O11	O12
Required **number of Batteries**	O13	O14	O15	O16
		TOTAL COST	**O17**	**O18**

Geographic Solar Value	Percent increase in PSH	Atira Technology
I10	I11	C2
PSH/day (select from "World Solar Map" worksheet)		Adjusted PSH

The cost model is an intuitive Microsoft Excel spreadsheet with adjustable input cells that automatically calculate costs of particular sized solar PV system. We recognized that Iraq could benefit from installing solar PV systems in diverse applications. For instance, residential homes, schools, service providers, and medical facilities all have different requirements for power and configurations of solar PV systems. The cost model allows actual or estimated daily power requirements for these alternatives to be entered to calculate total cost of a conventional and PVPC solar PV system.

The Operation Solar Eagle Cost Model is linked to three other interactive Excel worksheets that contain variables that are factored into the total cost. These worksheets consist of the World Solar Map, Appliance Loads, and Solar Price Index. The World

Solar Map provides a graphical reference to the amount of PSH in different parts of the world, see Appendix B. Its primary purpose is to allow selection of the appropriate PSH value from any location for calculating cost and components of a particular sized solar PV system. The Appliance Loads worksheet allows the user to choose a combination of appliances that a solar PV system might have to power, see Appendix B. This is an optional worksheet that is linked to the Solar Sizing worksheet for calculating cost based on actual appliance loads. The Solar Price Index worksheet should be periodically updated at www.solarbuzz.com/ModulePrices.htm. This worksheet accounts for price fluctuations in the primary solar components: panels, inverter, batteries, and charge controller.

The main interface, Solar Sizing worksheet, of the Operation Solar Eagle Cost Model is divided into two sections: inputs and outputs. The eleven input cells can be changed to evaluate different configurations of solar PV systems. The output cells including both total cost cells will simultaneously update as inputs are made. There are eighteen output cells that represent the different component quantities and costs. These cells are used to compare the two solar PV systems, conventional-MPPT to PVPC. To better describe the model inputs, letters and numbers are used to annotate the different cells. The input cells are indicated by an I and the output cells are indicated by an O. The I labeled cells are the only cells that a user can manipulate.

a. Cost Model Inputs

The following provides additional information on the cost model inputs with a depiction of input cells shown in Table 19. The value used in I2 represents the power requirement for any of the four Iraqi alternatives: 1) residents, schools, service providers, or medical facilities. The values entered in cells I3 through I9 represent specific parameters used to calculate cost and characterize solar PV system configurations that meet the needs of the four alternatives.

Table 19 Cost Model Input Cells.

Solar Worksheet (INPUTS)

STEP	COMPONENTS	DATA FIELDS	UNITS
1	**Estimated power load** of a residents or facility, or type "YES" above to use the calculated value from the Appliance Loads worksheet.	**I2**	kWh/day
2	**Estimated hours of grid power** per day.	**I3**	hours
3	**Solar panel power** rating, typically ranges from 120W to 170W, listed on solar panel specifications.	**I4**	watts
4	**Inverter voltage** rating (6Vdc, 12Vdc, 24Vdc, or 48Vdc). Typically 48V for daily and extended periods of use.	**I5**	volts
5	**Charge Controller** current rating (Amps).	**I6**	amps
6	Estimated hours to operate on **battery power per day** (hours).	**I7**	hours
7	**Battery voltage** rating (6Vdc, 12Vdc, 24Vdc, or 48Vdc).	**I8**	volts
8	**Battery current** rating (100Ah to 700Ah).	**I9**	amps

(1) Input of Load Requirements. The cell I1 is optional. The choice of Yes or No made in this cell causes either the daily power requirements in cell C1 or I2 to be used in the cost calculations. By entering Yes, the model uses the value in C1 derived from the power load in the Appliance Loads worksheet. By entering No, the model uses the manually entered value in I2. The choice of No was selected for our cost calculations. We used the power requirements of similar structures in Monterey, California to estimate the power requirements for Iraq.

(2) Input of Estimated Power Load. The values used in cell I2 represent the electrical loads of the Iraqi alternatives we assessed as being the most practical for solar PV systems. For each of the Iraq power requirements entered into I2 the cost model calculated the required number of components and cost to configure a solar PV system for that particular alternative. Larger electrical loads entered into I2 cause the cost to increase.

(3) Input of Grid and Battery Power. The estimated grid power per day of 11 hours in I3 was based on our research of Iraqi demographics that the current grid power is available between 11 and 15 hours. A lower value was selected because Iraqi power has only averaged 8 hours of grid power per day as determined from our research. An estimation of grid hours greater than the actual grid power in cell I3 will result in an inferior solar PV system. A solar PV system would be calculated by the cost model that would not meet the Iraqi power load requirements. The battery power per day of 6 hours in I7 was chosen as a realistic amount of time needed to meet electrical power requirements during grid power outages. Higher requirements for battery power per day reduce component quantities and provide extra power during grid power failures. Increased capacity of battery power reduces other component quantities and cost, but it increases maintenance, battery cost, and total solar PV system cost.

(4) Input of Other Solar Components. The charge controller value for I6 represents the electrical current output to charge the batteries. The value of 60 was selected because of the expected constant use of the Iraqi solar PV systems and the need to continuously and accurately regulate the daily battery recharges. Lower values used in I6 reduce or restrict the capacity of the solar PV system to fully charge the batteries during the day.

The values used in the other input cells: I4, I5, I8, and I9 were determined using Microsoft Excel Table. We found that these values were the optimal solution to minimize costs. The cell I10 represents the peak sun hours (PSH) of energy received during the day at any geographical location within the world as defined by the solar world map at www.sunwize.com/info_center/insolmap.htm. The value of five was used because this is the PSH for Iraq. The PSH value is very important in the component configuration of a conventional solar PV system, see Table 20. It is used as a factor in the power load requirements to determine the number of solar panels needed.

Table 20 PSH Comparison to Standard and Atira Technology.

Geographic Solar Value	Percent increase in **PSH**	**Atira Technology**
I10	**I11**	**C2**
peak sun hours/day (select from "World Solar Map" worksheet)		**Adjusted PSH**

The value shown in C2 is the new PSH value as a result of the percentage entered into cell I11. As the percentages of desired sunlight or PSH are changed in cell I11, the affect on PSH can be observed in C2. The percentages entered into I11 are factored into the power load requirement to estimate the cost and components of a solar PV system integrated with PVPC. Using the cost model we found that if an Iraqi home with a power load of 14.73 kWh/day had an increase of one additional hour of PSH above the initial PSH of five, then the cost is reduced by $1,000. We then used Microsoft Excel Table to evaluate the cost of solar PV systems ranging from a PSH value of five to thirteen in increments of five percent. We observed that a cost savings can be gained at an increase of 55 percent above the standard five PSH for Iraq, see Table 21. At an increase of 60 percent in PSH there is a considerable decrease in the cost of a solar PV system.

It was also interesting to see that this cost savings is constant, the PV system cost is the same with an increase from 8.00 (5 + 3) to 11.75 (5 + 6.75) PSH. The range of costs of a solar PV system for an Iraqi home is shown in Table 21. This table illustrates that the cost fell into ranges at different percent changes in PSH. In order for PVPC to further reduce our cost, then it would have to improve the PSH by 140 percent to move into the next range.

The two cells, C1 and C2, are only provided in the cost model to display additional information relative to the choices made in I1 and I11. The cell C1 shows the power load made in the Appliance Load worksheet if Yes is entered into the optional cell, I1. The cell C2 displays the number of hours per day calculated from the percent value entered in I11. This can be used as a comparison to the PSH value in I10.

Table 21 Cost Ranges of Solar PV Systems Determined by Increases in PSH.

% PSH Increase	PVPC PSH	Total Cost
55%	7.75	$11,464.80
60%	8.00	$8,296.80
65%	8.25	$8,296.80
70%	8.50	$8,296.80
75%	8.75	$8,296.80
80%	9.00	$8,296.80
90%	9.50	$8,296.80
100%	10.00	$8,296.80
110%	10.50	$8,296.80
120%	11.00	$8,296.80
135%	11.75	$8,296.80
140%	12.00	$5,906.40

b. Cost Model Outputs

The following information provides information on the cost model outputs with a depiction of output cells shown in Table 22.

The output cells O1 through O18 display data for comparison of components and costs of a conventional solar PV system to a solar PV system with PVPC. All even numbered output cells O2, O4, O6, O8, O10, O12, O14, O16, and O18 under the titles Atira, depict the data of a PVPC configured solar PV system. All other output columns, odd numbered cells, indicate the cost and components of a conventional-MPPT solar PV system.

Table 22 Cost Model Output Cells.

Primary Solar Components and Cost (OUTPUTS)

SOLAR COMPONENTS	TYPICAL SYSTEM	ATIRA SYSTEM	TYPCIAL SOLAR COST	ATIRA SOLAR COST
Required Number of **Solar Panels**	**O1**	**O2**	**O3**	**O4**
Required **Inverter Capacity** (watts)	**O5**	**O6**	**O7**	**O8**
Required number of **Charge Controllers** (based on 5000 watts)	**O9**	**O10**	**O11**	**O12**
Required **number of Batteries**	**O13**	**O14**	**O15**	**O16**
		TOTAL COST	**O17**	**O18**

This side-by-side comparison makes it easy to see the difference of a solar PV system integrated with PVPC. Since a PVPC solar PV system requires fewer solar components, there will be decreased maintenance requirements and less equipment failures. A reduction in solar panels consequently lowers the inverter capacity, which in turn lowers the number of batteries. In addition, the total cost of a solar PV system is less because the price of solar components is based on dollars per watt and dollars per amp. The following section uses the cost model to evaluate the costs of solar PV systems implemented in different alternatives in Iraq.

In an effort to validate the model, we distributed the model to commercial solar vendors for review. After reviewing the model, they concurred that it was a tool that supplied reasonable estimates of cost. In addition, the contractor of the PVPC technology confirmed that our estimated cost savings matched their internal estimates as well.

3. Cost of Emerging Technology Solar Power Systems for Iraq

To estimate the cost for solar implementation in Iraq, we calculated the electrical requirements for a typical residence in Iraq and we used a comparison of three community services in Monterey, California to determine similar requirements of like services in Iraq. We selected 1) education, 2) public health, and 3) law enforcement. The first service consisted of the combined Monterey Police and Fire Department. This facility averages 38,400 kWh/year or 107 kWh/day of electrical power use. The next service was an elementary school at Fort Ord in Seaside, California that has an average power use of 72,000 kWh/year or about 200 kWh/day. Finally, the average power of a recreational department at the Naval Postgraduate School was chosen. It has an average power use of 1,021,260 kWh/year, for 2,836 kWh/day.

The research studies of the Iraqi electrical infrastructure indicate that the power demand of Iraq is about one third of the U.S. power requirements. As a comparison to current solar PV systems with the emerging technology of the PVPC solar PV systems, the following power estimates in Table 23 were used. These power estimates represent one third of the average daily power for the three services described above.

Table 23 Iraq Power Estimates.

Implementation Alternatives	**Electrical Power Requirements**
Residential	14.73 kWh/day
Public Service Providers	36 kWh/day
Schools	66 kWh/day
Hospital	945 kWh/day

Other parameters that were predefined to optimize the cost of solar PV systems using the Operation Solar Eagle Cost Model and Microsoft Excel Table 2003 are shown in Table 24.

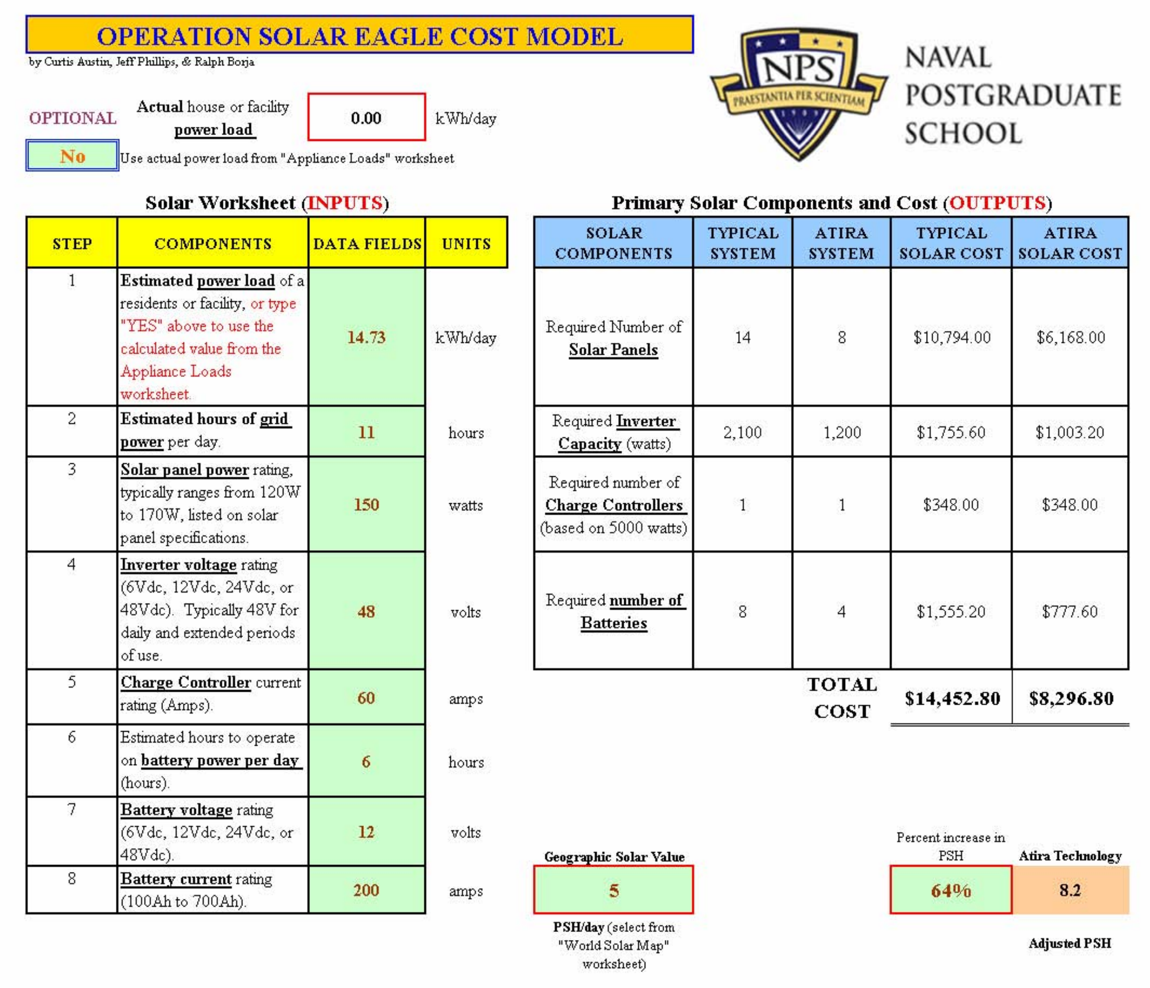
Table 24 Predefined Solar Cost Estimate Parameters.

Parameter	Designation
Available Grid Power	11 hours per day
Essential Battery Backup Power	6 hours per day
Solar Panel Power	150 watts
Inverter Voltage	48 volts
Charge Controller current rating	60 amps
Battery Characteristics	12 volts, 200 amps
3 hour increase of PSH due to PVPC	8 hours, (5 PSH plus 3 PVPC PSH)

a. The Cost of Solar Powering a Residential Home

Using the appliance load worksheet depicted in Table 16, the Operation Solar Eagle Cost Model, and the predefined parameters in Table 24, we were able to accurately predict the cost of a solar PV system to meet the power requirements of a typical Iraqi home. Based on our calculations from the appliance load worksheet, the estimated power requirements for a typical Iraqi home is 14.73 kWh/day. This equates to each home needing a 2,500-W solar PV system. The two cost estimates depicted in Table 25 represent the prices of a conventional-MPPT 2,100-W solar PV system compared to a 1,200-W PVPC solar PV system, $14,452.80 and $8,296.80 respectfully. This cost does not take into account installation cost, taxes, transportation fees, or any cost saving due to large quantity discounts.

Table 25 Residential Iraqi Solar Cost Estimate.



OPERATION SOLAR EAGLE COST MODEL

by Curtis Austin, Jeff Phillips, & Ralph Borja

NAVAL POSTGRADUATE SCHOOL

OPTIONAL **Actual** house or facility **power load** 0.00 kWh/day

No Use actual power load from "Appliance Loads" worksheet

Solar Worksheet (INPUTS)

STEP	COMPONENTS	DATA FIELDS	UNITS
1	**Estimated power load** of a residents or facility, or type "YES" above to use the calculated value from the Appliance Loads worksheet.	14.73	kWh/day
2	**Estimated hours of grid power** per day.	11	hours
3	**Solar panel power** rating, typically ranges from 120W to 170W, listed on solar panel specifications.	150	watts
4	**Inverter voltage** rating (6Vdc, 12Vdc, 24Vdc, or 48Vdc). Typically 48V for daily and extended periods of use.	48	volts
5	**Charge Controller** current rating (Amps).	60	amps
6	Estimated hours to operate on **battery power per day** (hours).	6	hours
7	**Battery voltage** rating (6Vdc, 12Vdc, 24Vdc, or 48Vdc).	12	volts
8	**Battery current** rating (100Ah to 700Ah).	200	amps

Primary Solar Components and Cost (OUTPUTS)

SOLAR COMPONENTS	TYPICAL SYSTEM	ATIRA SYSTEM	TYPICAL SOLAR COST	ATIRA SOLAR COST
Required Number of **Solar Panels**	14	8	$10,794.00	$6,168.00
Required **Inverter Capacity** (watts)	2,100	1,200	$1,755.60	$1,003.20
Required number of **Charge Controllers** (based on 5000 watts)	1	1	$348.00	$348.00
Required **number of Batteries**	8	4	$1,555.20	$777.60
		TOTAL COST	**$14,452.80**	**$8,296.80**

Geographic Solar Value 5 **PSH/day** (select from "World Solar Map" worksheet)

Percent increase in PSH 64%

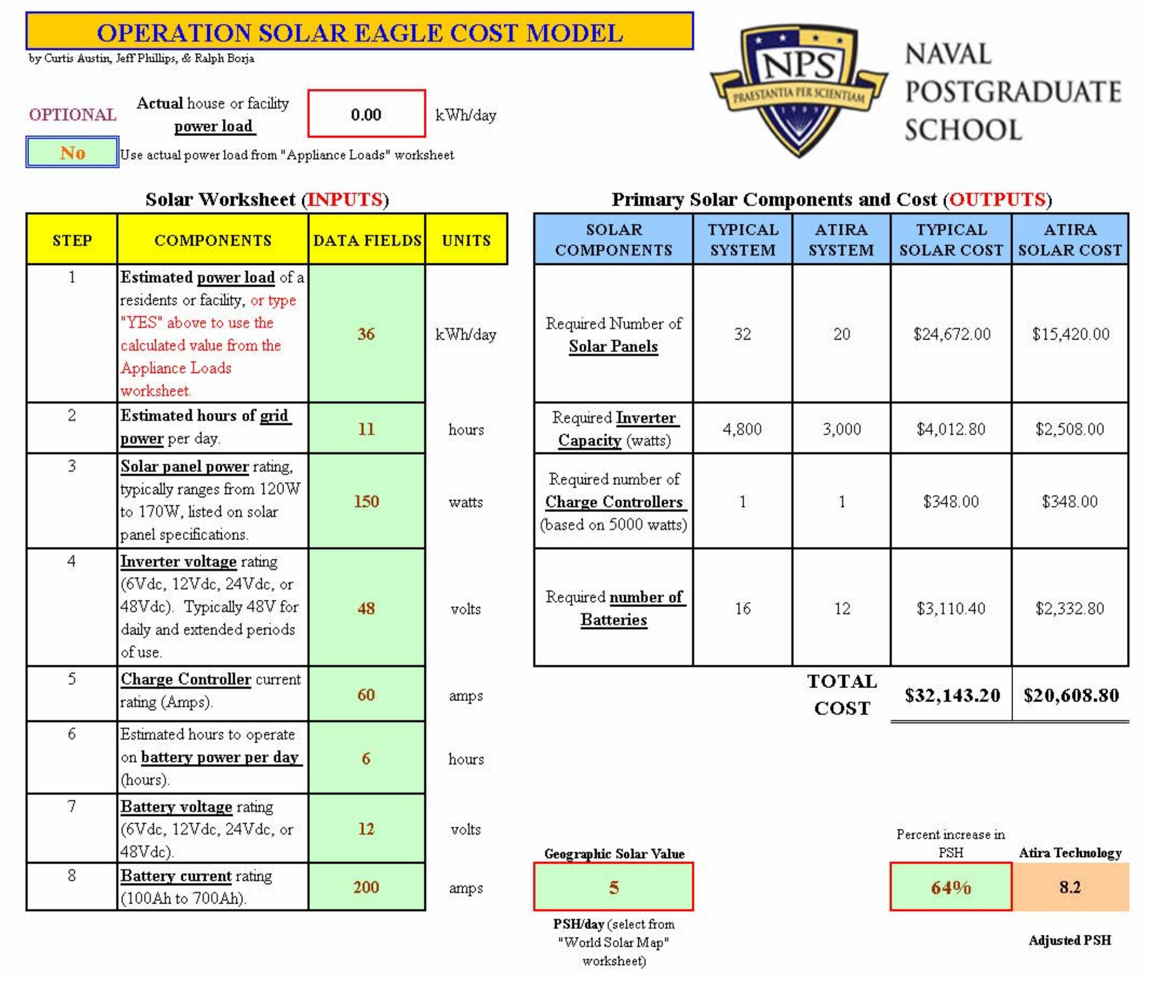
Atira Technology 8.2 **Adjusted PSH**

b. The Cost of Solar Powering a Public Service Provider

Using cost estimates based on similar electrical structures, the Operation Solar Eagle Cost Model, and the predefined parameters in Table 24, we were able to accurately predict the cost of a solar PV system to meet the power requirements of a typical Iraqi Public Service Provider. For comparison purposes, we used the Monterey Police Station and their electrical requirements to predict the electricity requirements for an Iraqi police station. Based on our calculations the estimated power requirement for a typical Iraqi public service provider is 36 kWh/day. The two cost estimates depicted in Table 26 correspond to the prices of a conventional-MPPT 4,800-W solar PV system compared to a 3,000-W PVPC solar PV system, $32,143.20 and $20,608.80 respectfully.

This cost does not take into account installation cost, taxes, transportation fees, or any cost saving due to large quantity discounts.

Table 26 Iraqi Public Service Provider Solar Cost Estimate.



OPERATION SOLAR EAGLE COST MODEL

by Curtis Austin, Jeff Phillips, & Ralph Borja

OPTIONAL — **Actual** house or facility **power load**: 0.00 kWh/day

No — Use actual power load from "Appliance Loads" worksheet

NAVAL POSTGRADUATE SCHOOL

Solar Worksheet (INPUTS)

STEP	COMPONENTS	DATA FIELDS	UNITS
1	**Estimated power load** of a residents or facility, or type "YES" above to use the calculated value from the Appliance Loads worksheet.	36	kWh/day
2	**Estimated hours of grid power** per day.	11	hours
3	**Solar panel power** rating, typically ranges from 120W to 170W, listed on solar panel specifications.	150	watts
4	**Inverter voltage** rating (6Vdc, 12Vdc, 24Vdc, or 48Vdc). Typically 48V for daily and extended periods of use.	48	volts
5	**Charge Controller** current rating (Amps).	60	amps
6	Estimated hours to operate on **battery power per day** (hours).	6	hours
7	**Battery voltage** rating (6Vdc, 12Vdc, 24Vdc, or 48Vdc).	12	volts
8	**Battery current** rating (100Ah to 700Ah).	200	amps

Primary Solar Components and Cost (OUTPUTS)

SOLAR COMPONENTS	TYPICAL SYSTEM	ATIRA SYSTEM	TYPICAL SOLAR COST	ATIRA SOLAR COST
Required Number of **Solar Panels**	32	20	$24,672.00	$15,420.00
Required **Inverter Capacity** (watts)	4,800	3,000	$4,012.80	$2,508.00
Required number of **Charge Controllers** (based on 5000 watts)	1	1	$348.00	$348.00
Required **number of Batteries**	16	12	$3,110.40	$2,332.80
		TOTAL COST	**$32,143.20**	**$20,608.80**

Geographic Solar Value: 5 — **PSH/day** (select from "World Solar Map" worksheet)

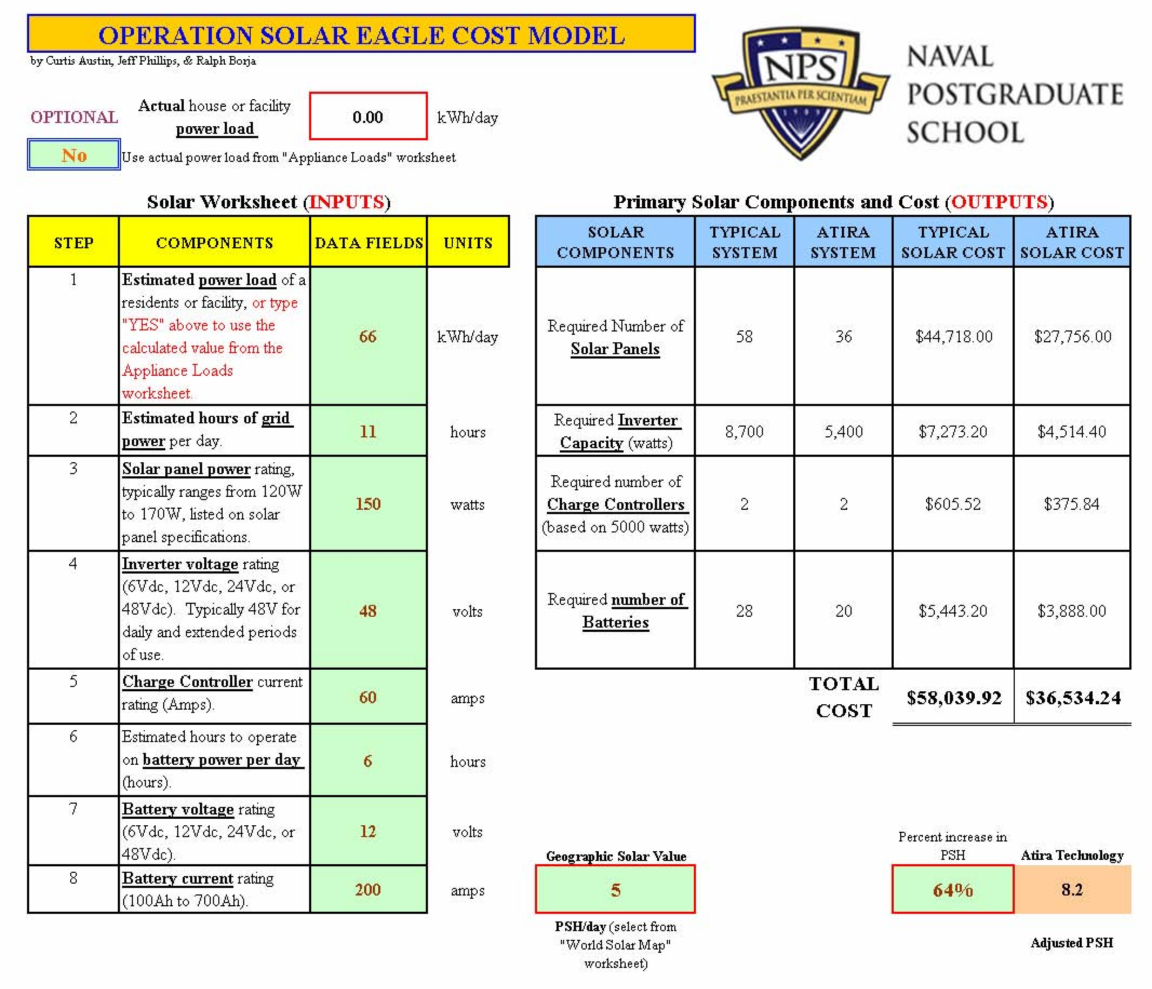
Percent increase in PSH: 64%

Atira Technology: 8.2 — **Adjusted PSH**

c. The Cost of Solar Powering a School

Using cost estimates based on similar electrical structures, the Operation Solar Eagle Cost Model, and the predefined parameters in Table 24, we were able to accurately predict the cost of a solar PV system to meet the power requirements of a typical Iraqi School. For comparison purposes, we used an Elementary School in Marina, California and their electrical requirements to predict the electricity requirements for an Iraqi school. Based on our calculations the estimated power requirement for a typical Iraqi school is 66 kWh/day. The two cost estimates depicted in Table 27 represent the prices of a conventional-MPPT 8,700-W solar PV system compared to a 5,400-W PVPC solar PV system, $58,039.92 and $36,534.24 respectfully. This cost does not take into account installation cost, taxes, transportation fees, or any cost saving due to large quantity discounts.

Table 27 Iraqi School Solar Cost Estimate.



OPERATION SOLAR EAGLE COST MODEL

by Curtis Austin, Jeff Phillips, & Ralph Borja

NAVAL
POSTGRADUATE
SCHOOL

OPTIONAL — **Actual** house or facility **power load**: 0.00 kWh/day

No — Use actual power load from "Appliance Loads" worksheet

Solar Worksheet (INPUTS)

STEP	COMPONENTS	DATA FIELDS	UNITS
1	**Estimated power load** of a residents or facility, or type "YES" above to use the calculated value from the Appliance Loads worksheet.	66	kWh/day
2	**Estimated hours of grid power** per day.	11	hours
3	**Solar panel power** rating, typically ranges from 120W to 170W, listed on solar panel specifications.	150	watts
4	**Inverter voltage** rating (6Vdc, 12Vdc, 24Vdc, or 48Vdc). Typically 48V for daily and extended periods of use.	48	volts
5	**Charge Controller** current rating (Amps).	60	amps
6	Estimated hours to operate on **battery power per day** (hours).	6	hours
7	**Battery voltage** rating (6Vdc, 12Vdc, 24Vdc, or 48Vdc).	12	volts
8	**Battery current** rating (100Ah to 700Ah).	200	amps

Primary Solar Components and Cost (OUTPUTS)

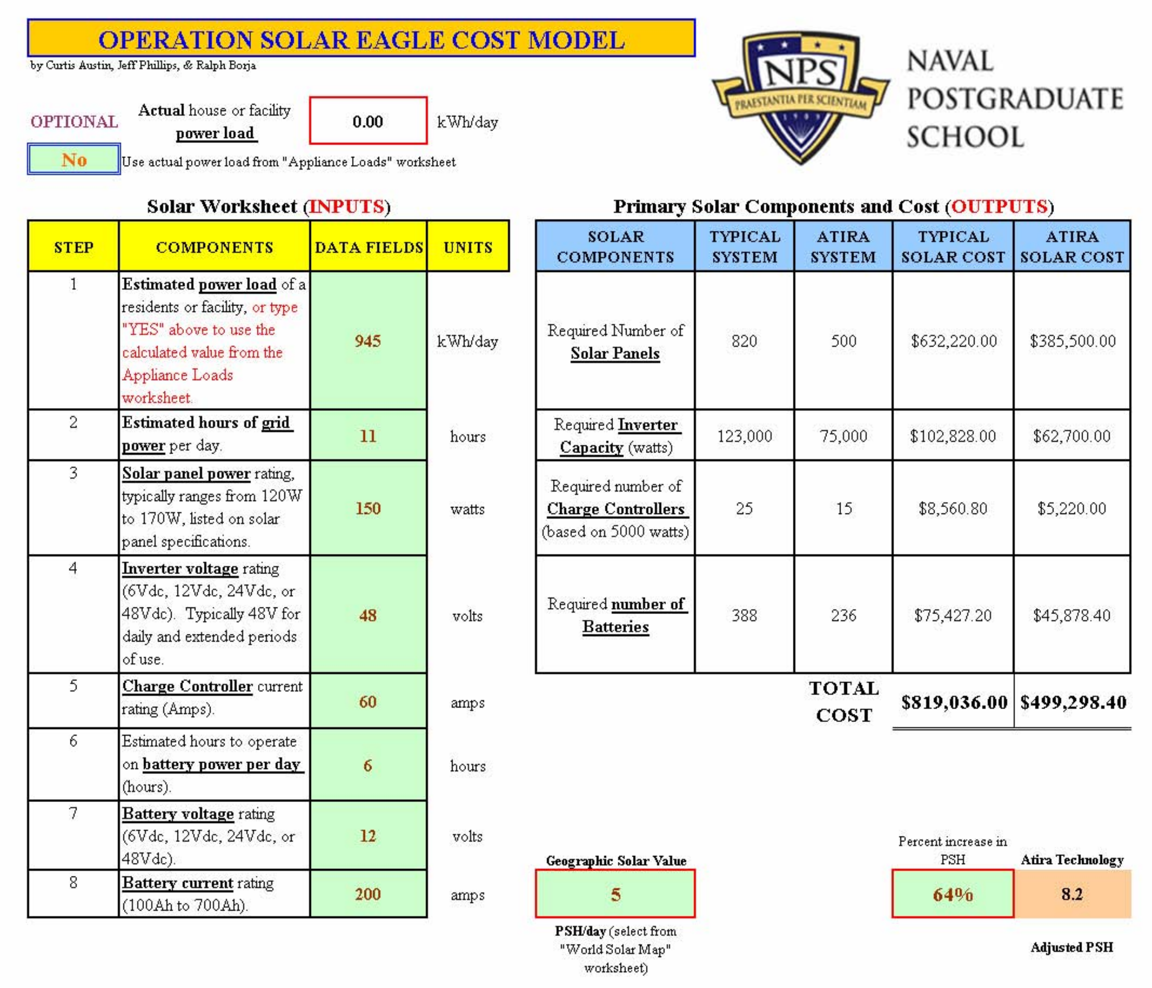
SOLAR COMPONENTS	TYPICAL SYSTEM	ATIRA SYSTEM	TYPICAL SOLAR COST	ATIRA SOLAR COST
Required Number of **Solar Panels**	58	36	$44,718.00	$27,756.00
Required **Inverter Capacity** (watts)	8,700	5,400	$7,273.20	$4,514.40
Required number of **Charge Controllers** (based on 5000 watts)	2	2	$605.52	$375.84
Required **number of Batteries**	28	20	$5,443.20	$3,888.00
		TOTAL COST	$58,039.92	$36,534.24

Geographic Solar Value	Percent increase in PSH	Atira Technology
5	64%	8.2
PSH/day (select from "World Solar Map" worksheet)		Adjusted PSH

d. *The Cost of Solar Powering a Hospital*

Using cost estimates based on similar electrical structures, the Operation Solar Eagle Cost Model, and the predefined parameters in Table 24, we were able to accurately predict the cost of a solar PV system to meet the power requirements of a typical Iraqi hospital. For comparison purposes, we used the facilities at the Naval Postgraduate School in Monterey, California and their electrical requirements to predict the electricity requirements for an Iraqi hospital. Based on our calculations the estimated power requirement for a typical Iraqi hospital is 945 kWh/day. The two cost estimates depicted in Table 28 represent the prices of a 123,000-W conventional-MPPT solar PV system compared to a 75,000-W PVPC solar PV system, $819,036.00 and $499,298.40 respectfully. This cost does not take into account installation cost, taxes, transportation fees, or any cost saving due to large quantity discounts.

Table 28 Iraqi Hospital Solar Cost Estimate.



OPERATION SOLAR EAGLE COST MODEL

by Curtis Austin, Jeff Phillips, & Ralph Borja

NAVAL
POSTGRADUATE
SCHOOL

OPTIONAL — **Actual** house or facility **power load**: 0.00 kWh/day

No — Use actual power load from "Appliance Loads" worksheet

Solar Worksheet (INPUTS)

STEP	COMPONENTS	DATA FIELDS	UNITS
1	**Estimated power load** of a residents or facility, or type "YES" above to use the calculated value from the Appliance Loads worksheet.	945	kWh/day
2	**Estimated hours of grid power** per day.	11	hours
3	**Solar panel power** rating, typically ranges from 120W to 170W, listed on solar panel specifications.	150	watts
4	**Inverter voltage** rating (6Vdc, 12Vdc, 24Vdc, or 48Vdc). Typically 48V for daily and extended periods of use.	48	volts
5	**Charge Controller** current rating (Amps).	60	amps
6	Estimated hours to operate on **battery power per day** (hours).	6	hours
7	**Battery voltage** rating (6Vdc, 12Vdc, 24Vdc, or 48Vdc).	12	volts
8	**Battery current** rating (100Ah to 700Ah).	200	amps

Primary Solar Components and Cost (OUTPUTS)

SOLAR COMPONENTS	TYPICAL SYSTEM	ATIRA SYSTEM	TYPICAL SOLAR COST	ATIRA SOLAR COST
Required Number of **Solar Panels**	820	500	$632,220.00	$385,500.00
Required **Inverter Capacity** (watts)	123,000	75,000	$102,828.00	$62,700.00
Required number of **Charge Controllers** (based on 5000 watts)	25	15	$8,560.80	$5,220.00
Required **number of Batteries**	388	236	$75,427.20	$45,878.40
		TOTAL COST	**$819,036.00**	**$499,298.40**

Geographic Solar Value: 5

PSH/day (select from "World Solar Map" worksheet)

Percent increase in PSH: 64%

Atira Technology: 8.2

Adjusted PSH

C. SOLAR COST SUMMARY

Even though improvements in manufacturing and technology have made solar power less expensive, the idea of providing solar power to every home in Iraq is an expensive proposition (800,000 homes in Baghdad X \$8,296.80 = \$6,637,440,000). This investment appears very large; however, this expenditure will result in approximately 12,000 Megawatts of power a day, completely satisfying Iraq’s need for power, now and for years into the future. Given that an annual investment of one billion dollars is needed for the electrical grid in any event, putting that investment into solar energy will solve many problems. Even providing only ten percent of the homes with solar energy systems will provide 1,200 Megawatts of power and bring Iraq close to meeting its current, critical energy needs. A less expensive alternative than providing solar energy systems for all homes in Baghdad is to provide solar power to the public service providers, schools and hospitals (it is unknown how many of these locations there are in Iraq). However, solar PV systems should certainly be considered for implementation at some level. After examining the four very different alternatives: residences, public service providers, schools, and hospitals, we conclude that solar PV systems, when combined with the new emerging technology of PVPC, could satisfy Iraq’s electrical requirements at an individual system cost of \$8,296.80, \$20,608.80, \$36,534.24, and \$499,298.40 respectively. These estimates provide input for a decision-maker to determine where to spend reconstruction funds that provide the most benefit. Furthermore, depending on the alternative and quantities of solar PV systems to purchase, it is anticipated that the government could negotiate large discounts for large purchases. These potential discounts make solar power an even more feasible solution to consider.

THIS PAGE INTENTIONALLY LEFT BLANK

VII. CONCLUSION AND RECOMMENDATIONS

The following section contains the conclusion and recommendations and is presented for the reader to see the significance of the conducted research. This section answers the research questions as well as indicates future areas of research deemed applicable toward the use of solar PV systems.

A. CONCLUSION

This project concludes that solar PV systems can be a feasible solution at some level of implementation for the rebuilding of the Iraqi infrastructure. The MBA project provides a decision maker with information on an alternative approach to assist in meeting the electrical needs of Iraq. By prioritizing needs and applying resources to meet these needs, the decision maker can alleviate part of the country's power shortages at a reasonable cost with the installation of solar PV systems when combined with PVPC technology.

In a country of 25,374,691 citizens, electrical power is essential to sustaining a wholesome and vital lifestyle. Iraq's current power production is below the necessary level to meet the current 8,000-MW demand and will likely have difficult meeting the anticipated future demand of 15,000-MW, although the solar energy solution in Baghdad alone can account for the entire future demand. Iraqi citizens have been forced to live with programmed electrical blackouts because of an insufficient power grid for many years, but solar PV systems could help minimize or eliminate this problem. The infrastructure rebuilding efforts of the U.S. and other nations have failed to sustain an acceptable level of power to meet the needs of the country. This failure can be contributed to the effectiveness of insurgents' activities as well as trying to correct the problems caused by years of neglect in maintaining the existing grid network.

The use of solar PV systems could not only benefit residential housing, but could also contribute to the revitalization of the communities and industries, as well as improving the overall well-being of the country. The case studies that are presented in this MBA project show how this revitalization is possible. By implementing a hybrid (on-grid/off-grid) PV power solution connected bidirectional to a home or business, it could literally provide power back to the grid for others to use. The power provided back to the grid from the hybrid PV power solution would help decrease the difference between the power producing capabilities and the existing and future power requirements. Table 29 depicts the lessons learned regarding the use of solar PV systems, including problems and benefits, from our examination of the four case studies.

Available commercial solar power equipment coupled with emerging solar technologies, PVPC, provides solutions to help meet Iraq's electrical infrastructure shortcomings. Earlier in the report, we identified that a critical factor in selecting appropriate technology for infrastructure rebuilding is maintainability. It appears that the Iraqi officials are failing to properly operate and maintain the electrical plants that were refurbished beginning in 2003. The U.S. officials think that because the plants were not operated and maintained properly, this has led to multiple power shortages this past winter. On a related note, of the 19 electrical facilities that have been refurbished by U.S. funding, it is believed that none are being properly operated. The use of solar PV systems will eliminate these types of concerns.

In this MBA project, we provide our test results and related test results that clearly show the benefit from the PVPC when used with commercially available solar components. Our test and evaluation assessment provided significant data to evaluate the performance of solar PV systems with and without the PVPC technology. The collected data was analyzed and showed an improvement in solar panel output as compared to a conventional solar PV system without the PVPC technology. The test results clearly demonstrate the effectiveness of this emerging technology and are a key component in our recommendation to use a solar solution to assist in the rebuilding of the Iraqi electrical infrastructure.

Table 29 Lessons Learned from Examination of Solar Case Studies.

Choosing a PV application	No single type of PV application was chosen in order to "gain both technical and economic experience from multiple applications"[80]
Purchasing components in bulk	"PV modules were purchased in substantial quantities in order to progressively reduce the cost of installed PV systems"[81]
Residential PV system benefits	"Provided electrical grid support, eliminated costs and losses in transmission and distribution, no special impact assessments, approvals or permits required"[82]
Convenience	"Real estate comes free with the building – the system is simply installed on building"
"No site development costs – the PV is simply placed on the roof"	"Utility interconnection already exists to serve the building"[83]
Tracking Tools	PV systems were linked into internet websites to show how systems were performing under different conditions and used to alert users of problems.
Educational Benefits	Schools that utilized solar PV systems taught the benefits of PV technology using education modules.
Standardization	Communities that implemented unique designs, installation, components, and usage had significant problems.
Installation Problems	Low quality components were selected and installed.
Inexperienced system designers and installers were employed.	"Under-sized battery cables, thus limiting battery recharge"
"Improper orientation and location of panels"	"Incorrect type of batteries used for application"[84]
User Knowledge	"Lack of end user knowledge on proper orientation and maintenance, and on limitations of the system contributed to problems"[85]
Training	Formal training provided by the utility company to teachers on their solar PV systems was a key action.
Quality Control	Quality control programs conducted a year after the project had been completed uncovered several problems like installation issues, theft, and vandalism. It would have been even more beneficial if quality control actions began earlier in the process.
Liaisons	Liaisons with the community were set up to help monitor and report problems, promote security, and train teachers in the operation and maintenance of the systems installed in schools.
Security	A solar panel array security frame and steel enclosures were installed in African Schools to deal with vandalism. Additionally, schools were expected to hire a night watchman and install fences and burglar bars on classroom windows.

---

[80] Donald W. Aitken, SMUD PV Program Review, December 30, 2000, p. 3.

[81] Ibid, 3.

[82] Ibid, 3.

[83] Ibid, 3.

[84] Michael Ross, et al. Applying solar energy to extend distance education to remote communities in Mexico and Central America. Paper presented at American Solar Energy Society Annual Conference, www.sandia.gov/pv/docs/PDF/Ross%20ASES.pdf (accessed April 25, 2005). p. 4.

[85] Ibid, 4.

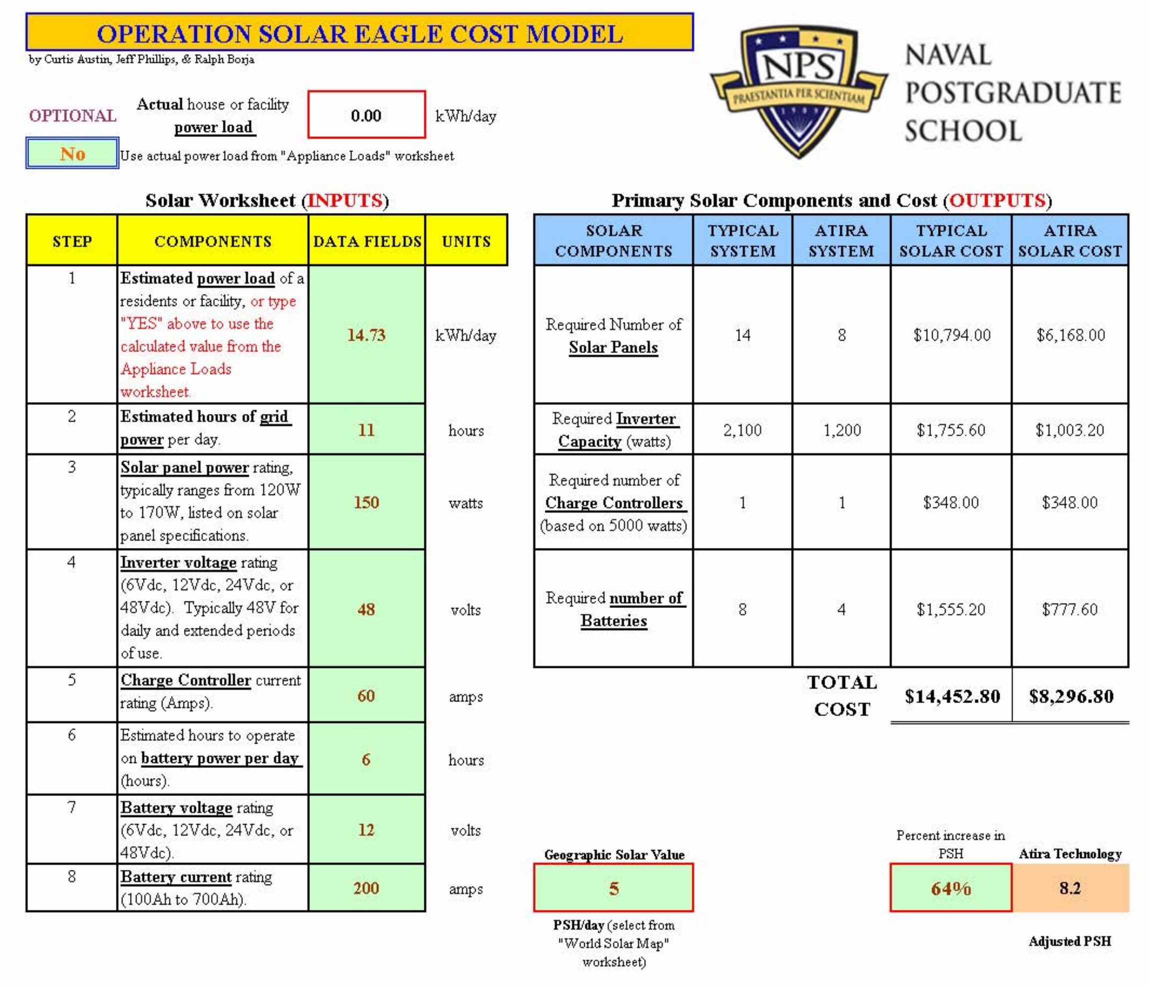
Based on statistical test results, we estimate with a 95 percent confidence interval, that the mean current and apparent power for the PVPC exceeds the mean power for the MPPT or conventional solar PV system. The increase for current of the PVPC system lies between 4.05-A and 4.95-A. We calculated that the PVPC solar PV system generates between 57.88 percent and 70.74 percent more current. Additionally, the increase for apparent power of the PVPC system lies between 34.12-VA and 42.88-VA. Subsequently, we calculated that the PVPC solar PV system generates between 63.53 percent and 79.83 percent more apparent power.

As previously stated there were other related PVPC tests. These related test results found that PVPC improved performance of a solar PV system by 39 percent, while our own test results indicated a 64.31 percent and 71.68 percent improvement. The difference in the results of our analysis when compared to related test results can be attributed to test design. Previous related tests were designed to measure the percent increase or decrease of recharging batteries at specific points in time. These related tests were a series of iterations to accurately measure the rate to fully charge a battery. Our tests were designed to accumulate data over a long continuous period. Our tests were not restricted by iterations so the accumulation of data continuously resulted in higher percentages.

Even though improvements in manufacturing and technology have made solar power less expensive, the idea of providing solar power to every home and business in Iraq is still not a feasible cost alternative. Nonetheless, at some level, solar PV systems could certainly be used to complement the ongoing efforts to strengthen the existing electrical grid, help meet increasing power demands, and counter attacks on existing power plants and distribution lines. Currently, if a terrorist destroys one power plant thousands of people are affected by the loss of power. Conversely, a terrorist that attacks and destroys a solar PV system on one building will have little to no effect on the power in other buildings and could potentially alienate the citizens against the terrorists. The solar PV system is an attractive possible solution because an insurgent attack’s impact is reduced on the population. Insurgents would literally have to destroy thousands of individual PV systems to have a significant affect on a large population.

In this MBA project, we make no effort to try and determine where to implement or on what scale to implement a solar solution in Iraq, however we do examine configuration alternatives and their associated costs. After examining four very different alternatives: residences, public service providers, schools, and hospitals, we conclude that solar PV systems, when combined with the new emerging technology of PVPC, could satisfy Iraq's electrical requirements at an individual system cost of $8,296.80, $20,608.80, $36,534.24, and $499,298.40 respectively. These estimates provide input for a decision-maker to determine where to best spend reconstruction funds that provide the most benefit. The following table was extracted from the Cost Estimate section of this MBA project and shows the Operation Solar Eagle Cost Model results for a typical Iraqi residence.

Table 30 Residential Iraqi Solar Cost Estimate.



OPERATION SOLAR EAGLE COST MODEL

by Curtis Austin, Jeff Phillips, & Ralph Borja

NAVAL
POSTGRADUATE
SCHOOL

OPTIONAL **Actual** house or facility **power load** 0.00 kWh/day

No Use actual power load from "Appliance Loads" worksheet

Solar Worksheet (INPUTS)

STEP	COMPONENTS	DATA FIELDS	UNITS
1	**Estimated power load** of a residents or facility, or type "YES" above to use the calculated value from the Appliance Loads worksheet.	14.73	kWh/day
2	**Estimated hours of grid power** per day.	11	hours
3	**Solar panel power** rating, typically ranges from 120W to 170W, listed on solar panel specifications.	150	watts
4	**Inverter voltage** rating (6Vdc, 12Vdc, 24Vdc, or 48Vdc). Typically 48V for daily and extended periods of use.	48	volts
5	**Charge Controller** current rating (Amps).	60	amps
6	Estimated hours to operate on **battery power per day** (hours).	6	hours
7	**Battery voltage** rating (6Vdc, 12Vdc, 24Vdc, or 48Vdc).	12	volts
8	**Battery current** rating (100Ah to 700Ah).	200	amps

Primary Solar Components and Cost (OUTPUTS)

SOLAR COMPONENTS	TYPICAL SYSTEM	ATIRA SYSTEM	TYPICAL SOLAR COST	ATIRA SOLAR COST
Required Number of **Solar Panels**	14	8	$10,794.00	$6,168.00
Required **Inverter Capacity** (watts)	2,100	1,200	$1,755.60	$1,003.20
Required number of **Charge Controllers** (based on 5000 watts)	1	1	$348.00	$348.00
Required **number of Batteries**	8	4	$1,555.20	$777.60
		TOTAL COST	**$14,452.80**	**$8,296.80**

Geographic Solar Value	Percent increase in PSH	Atira Technology
5	64%	8.2
PSH/day (select from "World Solar Map" worksheet)		Adjusted PSH

Taking into consideration the practical applications of solar PV systems in Iraq and the savings due to PVPC, the U.S. government could negotiate with retailers and manufacturers for lower prices. Depending on the alternative, and quantities of PV systems purchased, it is anticipated that discounts for large purchases are available. These potential discounts should make solar PV power an even more feasible solution to implement in Iraq than predicted in this MBA project.

B. RECOMMENDATIONS

This project identified the current state of the Iraqi infrastructure, details on how a solar technology solution would work, and the cost of using a solar technology solution in Iraq. We now have a better understanding of solar PV systems, past and present uses, the emerging technology of PVPC, cost of implementation, and applicable alternatives. This information can be used as input to making an informed decision on how to best use solar PV power as an electrical source in Iraq. We recommend that solar energy systems utilizing the Atira PVPC technology be used in the reconstruction of the Iraqi electrical grid to some extent. While the cost of powering all homes in Iraq might be prohibitive, the cost of powering all homes in a restricted area such as Baghdad is possible, with the attendant relief on the Iraqi electrical grid. As a minimum, solar energy should be used to power the police stations, schools, and hospitals as these are critical nodes in government efficiency impacting on Iraqi public perception.

There are multiple issues that can be addressed in further research that could strengthen our conclusion. We provide possible topics that we considered, but did not include in the scope of this research project. Potential areas of additional research include the following:

1. *What are the socioeconomic impacts of the large scale use of solar PV systems and other applications such as wind energy or power storage embedded with PVPC? In particular can PVPC make other sources of energy more practical to replace petroleum resources and what effect does this have on the global economy?*

The research associated with this particular question would be particularly beneficial from an economic lens. The global economy is predicated on the use of fossil fuels, so an alternative energy source would likely have significant impacts on the global economy. This research would likely benefit from computer modeling and economic expertise.

2. *What is the long-term cost savings of using PVPC compared to conventional solar PV systems?*

The research associated with this particular question is a very good follow-on to this research project. The NPS could acquire all the necessary solar components to conduct independent testing on the PVPC. Our primary testing produced results from measurements taken at a remote site over a short time span, while the secondary testing produced results from measurements taken from prototype equipment to determine readiness of the PVPC technology. From these results, we were able to make cost estimates that we feel are reasonably representative of actual cost savings. However, additional long-term testing could be used to improve or further validate our estimates.

3. *How would the actual contract be written to account for purchase, installation, storage, security, and maintenance if the decision was made to use solar PV systems in Iraq?*

The research associated with this particular question is a very good follow-up to this research project. At several points in this MBA project, we noted that the U.S. government could negotiate with retailers and manufacturers for lower prices, depending on the alternative and quantities of solar PV systems purchased. Additionally, we realize that other factors such as installation, storage, security, and maintenance would contribute to the final cost. A research project that examines the negotiation and contracting phases of implementing a solar solution for Iraq's electrical infrastructure would be a study that considers other costs not calculated in this project.

4. *If the decision was made to use solar PV systems to assist in the rebuilding of the Iraqi infrastructure, where is the best location to start installing the solar PV equipment?*

A natural follow-on study to this MBA project is to examine the best locations to start implementing the solar solution in Iraq for the greatest results. This study would require a level of country expertise, an understanding of political ramifications, and in-depth knowledge of current and future infrastructure improvement projects that were not available to this research team. This research has obvious benefit, but without access to an increased level of understanding, it would be pure speculation.

5. *How would we use the media and the Public Affairs Office to promote the solar power program, and how would we use them to educate the Iraqi population on the solar PV systems?*

An interesting follow-up study to this MBA project would be the development of a media plan to promote the benefits of the solar solution and to educate the Iraqi citizens on the requirements of solar operation and maintenance. When promoting the benefits of the solar solution, it is intuitive to believe that the media plan would help strengthen the new Iraqi government's credibility and sustainability in the eyes of the citizens. The media plan would likely include an educational aspect that would train Iraqi citizens to properly maintain and operate their systems.

6. *What are the psychological implications for the Iraqi population to have a distributed energy system at their homes and businesses?*

An important aspect of any military operation or reconstruction program is the hearts and minds of the local population. Iraq has suffered from an insurgency, which can only be overcome by the population rising to resist it. If a distributed energy system is in place and owned by the local population, what would the result be if the insurgents begin to take away or attempt to destroy the systems? Would the population's collective reaction be against the insurgency?

APPENDIX A – SOLAR ABSTRACT

This section provides details on solar components, retailers, maintenance, assemblies, and applications.

A. SOLAR COMPONENTS

1. Solar Cells

Solar cells capture the sun's energy and change it to electricity that produces a small electrical current. Metal grids around the solar cells direct the current into wires that lead it to an output for use on electrical applications.

2. Solar Panels

The solar panel is comprised of one or more solar cells that produce electricity or power. The performance of solar PV systems varies with weather conditions due to reduced sunlight exposure on the solar panels, which consequently reduces their output power. Solar panels can be wired in series or in parallel to increase voltage (volts) or amperage (amps) respectively, and they can be wired both in series and in parallel to simultaneously increase volts and amps. Solar panels wired together are called a solar array and connect to batteries and other solar components. The various wiring configurations are used to achieve the desired output levels for a solar PV system. For example, two 12 volt (V), 3.5 amp (A) panels wired in series produce 24 V at 3.5 A, and two 12 V, 3.5 A panels wired in parallel produce 12 V at 7 A. The output power, measured in watts (W), of a solar panel is determined by multiplying the rated volts by the rated amps. For example, a solar panel rated at 17.1 Vdc and 3.5 A equals 60 W, V x A =W.

The four major manufacturers of solar panels include Sharp, Kyocera, BP Solar, and Shell Solar. These four companies represent over 50 percent of solar panel production. The pie chart below, Figure 27, depicts Megawatt slices of solar cells produced by the top ten solar panel manufactures in 2003.

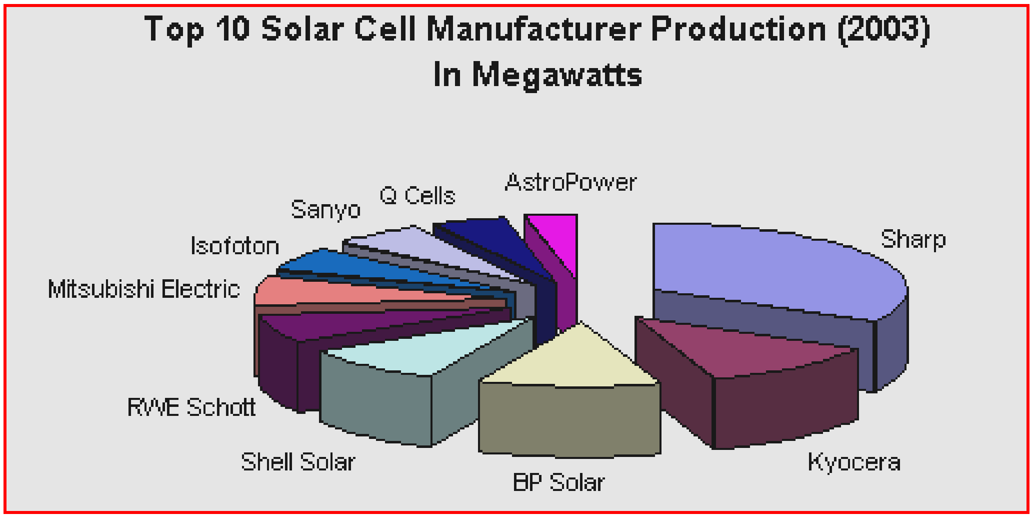


Figure 27 Top 10 2003 Solar Cell Manufacturers.[86]

The important specifications to consider for selecting solar panels are:

- Maximum Power Voltage (Vpm): 23.5 volt
- Maximum Power Current (Ipm): 7.1 amp
- Maximum Power (Pm): 167 Watts
- Minimum Power (Pm): 150.3 Watts
- Module Efficiency: 12.60 percent

Sharp ND-167U1, 167 Watt Solar Panel

3. Inverter

An inverter is a device that changes DC power from solar panels or stored in batteries to the standard 120/240 Vac electricity. Most inverters produce 120 Vac, but can be equipped with a step-up transformer to produce 240 Vac. Solar PV systems generate direct current, which is stored in batteries. The inverter switches the direct current back and forth to produce alternating current that is transformed into an acceptable output waveform. Inverters come in two basic output designs - sine wave and

---

[86] Downloaded from www.solarbuzz.com/StatsGrowth.htm on April 17, 2005.

modified sine wave. Most 120 Vac devices can use the modified sine wave. However, devices such as laser printers can be damaged, motors and power supplies can run warmer and other devices will be less efficient on modified sine wave power. Some things, like fans, amplifiers, and cheap fluorescent lights, give off an audible buzz on modified sine wave power. The inverter is a major electronic component of solar PV systems and come in ratings of 50 to 5500 watts. It monitors power sources and auto selects between grid, solar, and battery power depending on what is available.

The important specifications to consider for selecting an inverter are:

- Continuous output @ 25 degrees C: 33 amps AC
- Output voltage (RMS): 120 VAC
- Frequency 60 Hz
- AC input voltage: 120 Vac
- AC input voltage range: 80-149 Vac
- DC input voltage: 48 Vdc
- DC input voltage range: 44-66 Vdc
- Continuous Power @ 25 degrees C 4000 VA
- 100 mSec Surge Capability: 78 amps AC

Xantrex/Trace SW4048 Series II Inverter

4. Charge Controller

A charge controller prevents battery over charge, out-gassing, and is required for charging batteries. A charge controller monitors the battery's state-of-charge to insure that when the battery needs charge, the proper amount of current is provided. Connecting a solar panel to a battery without a charge controller seriously risks damaging the batteries and creates a potential safety hazard. Charge controllers are rated based on the amount of amperage they can process from a solar panel. If a charger controller is rated at 20 amps (A), it means that you can connect a solar panel output of 20A to the charger controller. A new feature of charge controllers is Maximum Power Point Tracking

(MPPT). This is an electronic circuit that improves efficiency of solar panels by maximizing output power. It allows the charger controller to monitor the panel's output and compares it to the battery bank voltage. Then the charge controller converts the panel voltage to maximum the current for better battery charging. A charge controller with MPPT improves solar PV system performance by about 10 percent.

The important specifications to consider for selecting a charge controller are:

- AC Output Current Rating: 60 amps at 48Vdc
- Nominal Battery Voltage: 48Vdc
- Open Circuit Voltage: 125 Vdc Maximum
- Voltage Regulation Setpoints: 13 - 80 Vdc
- Power Conversion Efficiency
  - 99.1 percent @ 40 amps Output
  - 97.3 percent @ 60 amps Output

OutBack MX60 MPPT Charge Controller

5. Batteries

The batteries store the solar power that has been generated by the panels and discharge the power as needed. A typical battery bank consists of one or more deep-cycle type batteries. The deep cycle batteries are designed to be discharged and then re-charged hundreds or thousands of times. These batteries are rated in Amp Hours (AH), which refers to the amount of current that can be supplied by the batteries over a specific period of hours.

Like solar panels, batteries can be wired in series and/or parallel to increase voltage to the desired level and increase amp hours. The size of the battery bank depends on the storage capacity required, maximum discharge rate, maximum charge rate, and minimum temperature at which the batteries will be used. Batteries can instantly supply large surges of stored electricity as needed to start or run appliances that the solar panels alone could not power. This large power capability can be a fire hazard just like utility company power, so fuses and circuit breakers are essential. Battery size is chosen for both surge power requirements and for reserve power needed. Typically, battery efficiency is 80 percent requiring a battery bank capacity getter than what is actually needed. Batteries periodically need servicing and have the highest potential of faults in a solar PV system. The important specifications to consider for selecting a battery are:

- Capacity: 6 Vdc, 350 Amp Hour
- 350 Amp Hour 20 Hour Rate
- 460 Amp Hour 100 Hour Rate

Surrette S-530 Solar Battery

6. Metering

A solar PV system meter is similar to an automobile gauge and is necessary for assessing operation of solar PV systems. They confirm the battery charging process, show power consumption, battery reserve capacity, and provide historical battery data. A meter is typically located at a convenient spot in the home. A good battery meter is a very useful diagnostic and customer service tool.

7. Wiring

Wiring is used to distribute power to various devices. Selecting the correct size and type of wire enhances performance and reliability of solar PV systems. The size of the wire must be large enough to carry the maximum expected current without causing any voltage losses.

8. Disconnect Box

Connecting solar PV systems to the house and grid require a disconnect box with fuses. Interconnection requirements include a utility accessible box with a visible main breaker disconnect switch, fused between the batteries and other power system components to prevent fires, protect people, and equipment damage in the event of a malfunction. The battery banks and solar PV system also need a common ground tied to the house ground. Having differences in ground potential between the house, the batteries and the system is dangerous, imposing serious electrical hazards.

9. Loads

A load consumes electrical power and consists of home appliances and devices such as televisions, computers, lights, pumps, and air conditioners. The general power loads of some common household appliances are shown in Table 31. The estimated hours are based on an average monthly use of a family of four. "A U.S. home of 2,200 square feet using an assortment of everyday household appliances including an air conditioner consumes an average of 1,899 kWh per month or 56 kWh per day for a total of 20,700 kWh per year."[87]

10. Efficiency Losses

A known limitation with current solar PV systems is inefficiency. In any of the discussed solar PV system configurations, there are losses due to electrical wiring, battery performance, and efficiency of components. The inefficiencies vary from component to component, and from system to system and can be as high as 25 percent.

It is common to perform a load analysis to identify a system that matches the power budget needs. To increase efficiency of a solar PV system, the design accounts for some of the efficiency losses. The basic methodology for designing solar PV systems is shown in Table 32. The values depicted in the table are similar to Iraqi household electrical requirements.

11. Lighting Streets with Solar

Besides solar PV systems, there exist solar street lighting systems. They work identically to solar PV systems using grid and battery power. However, they contain a device or microprocessor that automatically turns the light on at dusk, regulates the hours of light operation, and prevents battery overcharge and discharging. Some of these solar lighting systems are able to operate for at least five consecutive days without sunlight. The batteries have a typical life expectancy of 5 years with system life expectancy of 20 to 25 years. They are available with optional features that include a bulletproof shield to protect panels and lock secured battery enclosures to deter vandalism.

---

[87] Downloaded from www.faqfarm.com/Q/How_much_electricity_does_an_average_2-story_3-bedroom_house_use_per_day_per_month_or_per_year on April 3, 2005.

Table 31 Power Usage by Common Household Appliances.[88]

Appliance	**Watts (W)**	**Estimated Hours Used per Month (Hr)**
Air Conditioner (5,000 to 12,000 BTU)	700 to 1500	200
Auto Engine Heater	600	40
Battery Charger (Car)	150	15
Blender	385	2
CD, Tape, Radio, Receiver System	250	60
Clock	3	730
Clothes Dryer	5000	17
Coffee Maker (Auto Drip)	1165	4
Computer (With Monitor and Printer)	365	75
Convection Oven	1500	8
Curling Iron	1500	5
Dehumidifier (20 Pints, Summer)	450	360
Dishwasher (Wash to Dry Cycle)	200 to 1200	25
Disposal	420	60
Electric Blanket	175	180
Fan (Ceiling)	80	150
Freezer (Automatic Defrost 15 cu. ft.)	440	334
Fry Pan	1200	10
Garage Door Opener	350	3
Hair Dryer (Hand Held)	1000	10
Heat Lamp	250	5
Heat Tape (30ft., Winter)	180	720
Heater (Auto Engine, Winter)	1000	180
Heater (Portable)	1500	40
Heating System (Warm Air Fan)	312	288
Humidifier (Winter)	177	230
Iron	1000	5
Lighting (Incandescent)	75	100
Lighting (Fluorescent)	40	100
Microwave Oven	1500	11
Mixer, Hand	100	10
Power Tools (Circular Saw)	1800	1
Radio	71	101
Range (Oven)	2660	8
Refrigerator/Freezer (17.5cu.ft.)	450	333
Satellite Dish (with Receiver)	360	183
Sump Pump (1/2 HP)	500	20
Television (Color, Solid State)	200	183
Toaster	1400	3
Vacuum Cleaner	1560	6
VCR	45.0	6
Waffle Iron	1200	4
Washer (Automatic)	512	17
Water Heater (Quick Recovery)	4500	89
Water Pump (1/2 HP)	460	41

---

[88] Downloaded from www.cornhusker-power.com/householdappliances.asp on April 3, 2005.

Table 32 Solar Sizing Worksheet.

STEP	PROCESS	SOLAR SPECIFICS
1	Determine the **power load** using Table 1.	17.33 kWh/day
2	Calculate the **actual power load** by multiplying step 1 by 1.2 to compensate for loss from battery charge and discharge. Next multiply result by 0.75 to design for an 18 hour/day system.	17.33 x 1.2 = 20.8 kWh/day 20,800 x 0.75 = **15.6 kWh/day**
3	Determine the **average sun hours per day** (PSH) for the desired area to use solar energy..	5, as shown in Appendix B for Iraq
4	Determine the amount of **solar panel power** required, divide step 2 by step 3.	15,600/5 = **3,120 W**
5	Record the rated **solar panel power** that will be used (ranges from 100 to 300W), listed with panel specifications.	150W
6	Determine the **number of solar panels** needed (connected in parallel) divide step 4 by step 5.	2808/150 = **18.72 ~ 20**
7	Select a continuous sine wave **Inverter** with capacity (W) equal to the solar array power calculated in Step 4 (you can select more than one of equal capacity, then connect in series for total capacity).	Step a **2850W** or greater Inverter. Could select two 1500W inverters or four 750W inverters.
8	Record the **Inverter dc input voltage** (6Vdc, 12Vdc, 24Vdc, or 48Vdc), listed on inverter specifications.	48V
9	Determine the **battery bank capacity** by multiplying the inverter capacity times the number of hours to operate on batteries. Then divide by 0.8 to account for battery loss.	For example: if you selected 8 hours of battery run time (3000 x 8)/.8 = **30,000Wh**
10	Determine the **battery** current hours need for the system. Dividing the battery bank capacity in Step 9 by the Inverter voltage in Step 8.	30000/48 = **625 AH**
11	Determine the **battery capacity** to use for the system. You can use any voltage level of battery (6Vdc, 12Vdc, 24Vdc, or 48Vdc) for any system. Just need to connect them in series and parallel to get the current as calculated in Step 10. For example: Select **<u>6Vdc, 360AH batteries</u>**, then two banks of 8 batteries are required <u>Because</u> 625AH/360AH = 1.736 ~ 2 and 48/6 = 8. Bank 1: 6+6+6+6+6+6+6+6 = <u>48Vdc</u> at <u>360Ah</u> Bank 2: 6+6+6+6+6+6+6+6 = <u>48Vdc</u> at <u>360Ah</u> = 48Vdc at 720Ah Meets battery capacity in Step 9, 48 x 720 = **34,560Wh**	Need **16 batteries**, 6Vdc at 360AH

B. SOLAR MAINTENANCE AND WARRANTY

The maintenance process of a solar PV system is an integral part of the system design. Component selection should be based, in part, on the type and frequency of maintenance that will be performed. Solar PV systems are an arrangement of components that require routine maintenance that can be performed with some basic tools and minimal training. Checking connections and battery fluid levels can be accomplished very easily by the user. Major repairs and periodical maintenance should be performed by a professional. The most likely failures and easiest to repair are the connections, fuses, and switches. Preventive maintenance is the least costly of all maintenance. An important maintenance measure is to keep the solar panels clean. A schedule should be established to perform maintenance checks on the solar PV system at least 4 times a year.

The durability of solar power makes it an attractive alternative power provider. With routine maintenance, solar PV systems will generally last over 20 years. The longest-lived component of a solar PV system is the solar panels. The highest maintenance item is the batteries; especially the flooded lead acid batteries.

Most solar panels are designed to withstand all of the rigors of the environment including arctic cold, desert heat, tropical humidity, winds in excess of 125 mph, and one-inch hail at a constant speed. The high quality solar panels are designed to last at least 30 years and carry a 20 year warranty. The solar panels represent around 45 to 55 percent of the total cost of a solar energy system. Therefore, the solar panel price is the greatest deciding factor in sizing of a system power system.

There are some solar panels featuring thin film silicon that have a reduction in power output just after a few months of operation. However, there are other solar panels made of polycrystalline cells that do not experience this kind of degradation in power.

The most reliable, longest-lived solar PV systems use a glass superstrate on the solar panels. This is a low, iron-tempered glass that is laminated with layers of plastics. This construction is very durable, but is susceptible to breakage. If the glass is shattered or punctured, the solar panel will eventually fail because of corrosion build up on the solar cells. The water leakage inside a solar panel can also damage the electrical connections between any given pair of cells, resulting in reduced or zero power output. There are panels that have that have an aluminum substrate rather than glass. These panels are lightweight, rugged, and shatterproof. Yet, they typically have a warranty less than 20 years.

Batteries can account for around 15 percent of the total cost of a solar PV system. Batteries are typically large, heavy, dangerous (risk of explosions), expensive and short-lived (many need replacing in a mere five years). The batteries used in a solar PV system range from Absorbed Glass Mat (AGM) to lead acid. The high quality sealed batteries can last about 7 years, but lower quality flooded lead acid batteries typically last 3 to 5 years. The warranty for batteries consists of a full warranty for a specified number of years with a pro-rated warranty for the remaining number of years. They can also have a terminal life warranty set to a specific length of use (normally in years) or a maximum number of cycles it can perform before the warranty expires. Battery warranties are determined by the manufacture and range anywhere from 1 to 10 years.

Other components, like the charge controller and inverter, usually have a two year parts and labor warranty with an option to purchase an extended warranty. There are also more expensive inverters and charge controllers that have a warranty up to five years without any extended options. The charge controller and the inverter typically represent around 20 percent of the total cost of a solar PV system. These two items are very reliable and have few failures. If a failure does occur, it is easily evident because house power is not available.

Overall, a solar PV system can be nearly maintenance free between battery replacements. The use of high quality sealed batteries and an appropriately sized charge controller can reduce some of the battery problems. However, batteries typically never last longer than 5 to 7 years. The solar PV systems of today are very reliable and can expect a lifetime of at least 20 years. In addition, the use of a solar power meter will help assess system integrity as well as detecting faults and verifying system performance.

C. SOLAR RETAILERS

Solar retailers offer a variety of equipment that are totally assembled as a system or kit, or provide specific solar components that can be configured as a complete solar PV system. Some retailers provide full service to include design, kitting, and installation. A list of recommended vendors that offer the expertise, components, and complete systems are provided in Table 33. A comprehensive listing of solar retailers and their products can be found at either www.cleanenergy.de/index2.html or at www.solarbuzz.com/CompanyListings/UnitedStates.htm.

Other good sources to locate solar retailers are the local telephone directory, contacting the U.S. Department of Energy (DOE) Energy Efficiency and Renewable Energy (EERE) at (877) 337-3463, or visiting their website at www.eere.energy.gov/solar/yellow_pages.html. Also, contacting the California Energy Commission will provide a list of retailers participating in solar energy programs. To contact the Energy Commission go to their website at www.energy.ca.gov, send an email to renewable@energy.state.ca.us, or call (800) 555-7794.

Table 33 Solar Retailers.

Vendor	Location	Contact Information	Products
Advanced Energy Solutions, Inc	192 Gates Road Pomona, IL 62975	(800) 229-0453 info@advancedenergyonline.com www.advancedenergyonline.com	Kits, panels, batteries, controllers, and inverters
Affordable Solar	517 Central NE #206 Albuquerque, NM 87195	(800) 810-9939 or (505) 244-1154 sales@affordable-solar.com www.affordable-solar.com	Solar panels, controllers, inverters, batteries, systems
Applied Power Corp	1210 Homann Drive SE, Lacey, WA 98503	(360) 438 2110 www.appliedpower.com	Solar panels, controllers, inverters, batteries, systems
Astropower	Solar Park, Newark, Delaware 19716	(302) 366-0400 astropower@aol.com members.aol.com/astropower	Solar cells, modules, panels, inverters, and development
Backwoods Solar Electric Systems	1589 Rapid Lightning Creek Rd Sandpoint, Idaho 83864	(208) 263-4290 info@backwoodssolar.com www.backwoodssolar.com	Complete systems, panels, batteries, controllers, and inverters
BP Solar	630 Solarex Court, Frederick, Maryland 21703	(301) 698-4200 info@bpsolar.com www.bpsolar.com	Photovoltaic modules and cells
Dependable Solar Products, c/o ETA Engineering, Inc.	2010 E. University Dr. Suite #20 Tempe, AZ 85281	(480) 966-1380 877-964-4188 info@dependablesolarproducts.com www.dependablesolarproducts.com	Components and complete systems
Evergreen Solar, Inc	259 Cedar Hill Street Marlboro, MA 01752	(508) 357-2221 www.evergreensolar.com	Complete systems, panels, batteries, controllers, and inverters
Global Solar Energy, Inc.	5575 S. Houghton Rd Tucson, AZ 85747	(520) 546-6313 www.globalsolar.com info@globalsolar.com	Panels for military and consumer
Innovative Power Systems, Inc. (IPS)	1153 16th Ave. SE, Minneapolis, MN 55414	(612)-623-3246 ips-solar.com info@ips-solar.com	Full service retailer, components, complete systems, and installation
Kyocera Corporation	Address: 7812 East Acoma Dr, Scottsdale, AZ 59840	(480) 948-8003	Photovoltaic, cells, modules, and components
SBT Designs	25581 IH-10 West San Antonio, Texas 78257	(210) 698-7109 or 800-895-9808 www.sbtdesigns.com info@sbtdesigns.com	Full service retailer, panels, and components
Sierra Solar power systems	109-N Argall Way, Nevada City, California 95959, USA	1 916-265-8441 or (888) 667-6527 solarjon@oro.net www.sierrasolar.com	Photovoltaic, power systems, and pumps
Solar Depot	1240 Holm Rd. Petaluma, CA 94954	(707) 766-7727 or (800) 822-4041 info@solardepot.com www.solardepot.com	Complete systems, panels, and components
Solar Energy	1057 N. Ellis Rd #6, Jacksonville, Florida 32254	(904) 786-6600 mnewman@solarenergy.com www.solarenergy.com	Photovoltaic cells, panels, inverters, and batteries
SunWize	701 Del Norte, Unit 360 Oxnard, CA 93030	(805) 278-1553 sunwize@besicorp.com sunwizeca@skypipeline.com www.sunwize.com	Complete systems, panels, and installation

D. SOLAR ASSEMBLIES

Solar PV systems offer renewable energy solutions for every situation. The necessary components to integrate solar power into the homes and businesses consist of solar panels, mounting structures, controller, inverter, batteries, enclosure, wiring, meter, and a breaker box. These components can come as a complete assembly designed to provide safe and reliable power. The battery comes in a strong, lightweight, corrosion resistant enclosure for protection of harsh and severe weather conditions. Likewise, the other components come in a similar housing that is environmentally protected and can be secured to prevent theft. The configuration of these components into a complete solar PV system will provide a dependable power source with hours of battery backup. An assembly of a solar PV system is shown in Figure 28.

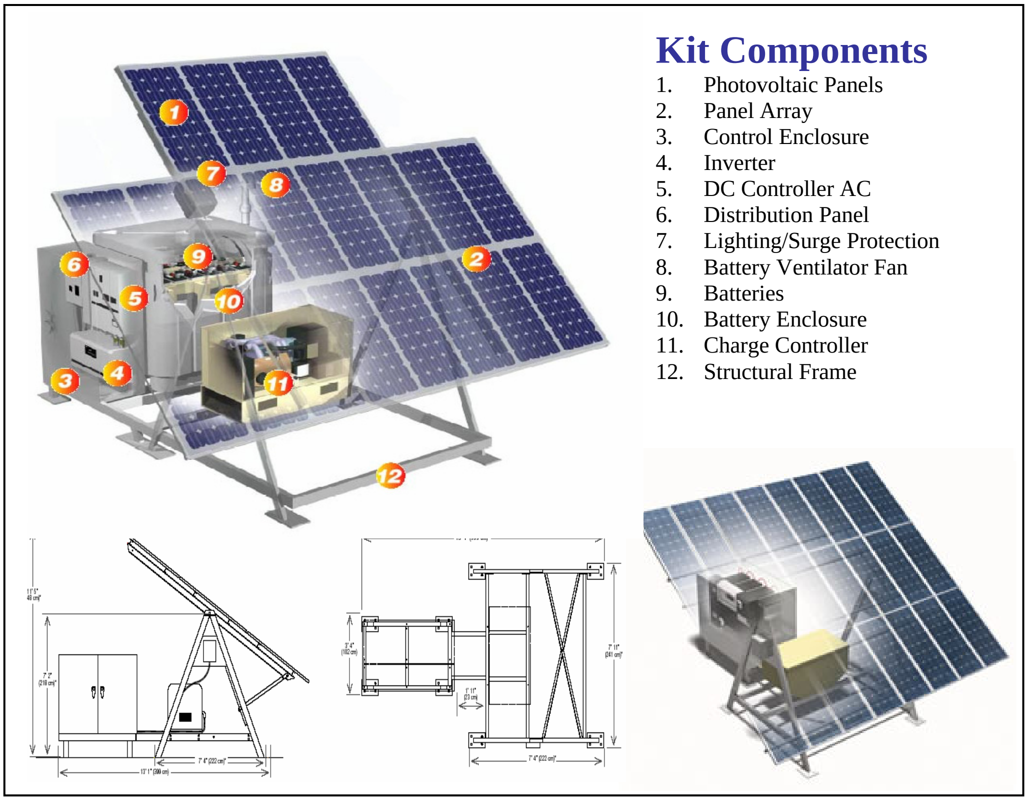


Figure 28 Basic Solar PV System.[89]

---

[89] Downloaded from www.utilityfree.com/solar/powerstation.html on April 12, 2005.

In addition to the solar PV systems that provide valuable power for residents and businesses are the energy efficient solar lighting systems as shown in Figure 29. These systems connected or not to grid utility power could provide lighting for designated streets and residential neighborhoods. These solar light systems could be a key factor in reducing pilfering and mischief during scheduled blackouts and grid power sabotage. Other uses include lighting for parking lots, security, city departments, and storage facilities.

Figure 29 Solar Light System.

E. COMMUNITY APPLICATIONS

There are several scenarios where solar technology could be used to improve communities. This section provides a brief description of such scenarios.

Solar PV systems can be used to meet water needs in some communities by using solar powered pumps. Communities with non-potable water supplies can be serviced with solar purification systems. They can be used in small irrigation applications and other water communities that can identify a need.

Health centers and clinics can use solar PV systems for lighting and refrigeration. Many clinics rely on lighting from other sources (i.e., lantern), which pose a risk to patients. Solar power will allow clinics to serve patients at night and to extend hours for vaccination programs and primary care services. Currently in Iraq, the emergency services must receive 24 hours of electrical power, providing them solar power would assist in redistribution of electricity to others.

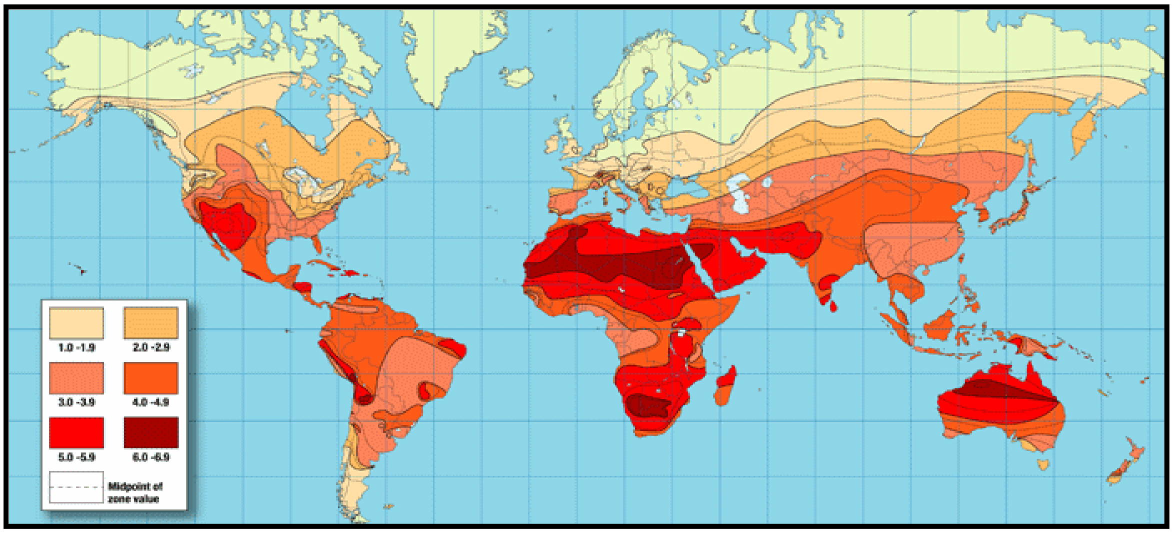
As mentioned earlier in the study, the Iraqi people are concerned about their school programs and how the electrical infrastructure problems are adversely affecting the entire educational system. Using solar PV systems in rural or urban schools could extend teaching hours and allow students to have lights for night studies. The quality of education will be enhanced with the more regular availability of power. Additional, power in schools would make it possible to run demonstrations and science experiments. Even the solar PV system itself presents an interesting and educational introduction to the basic principles of science, power, and electricity.

Community centers with adequate lighting for continuous daily and night activities from solar PV systems will allow entertainment for the community, meetings to be held, and events and places for children events to occur.

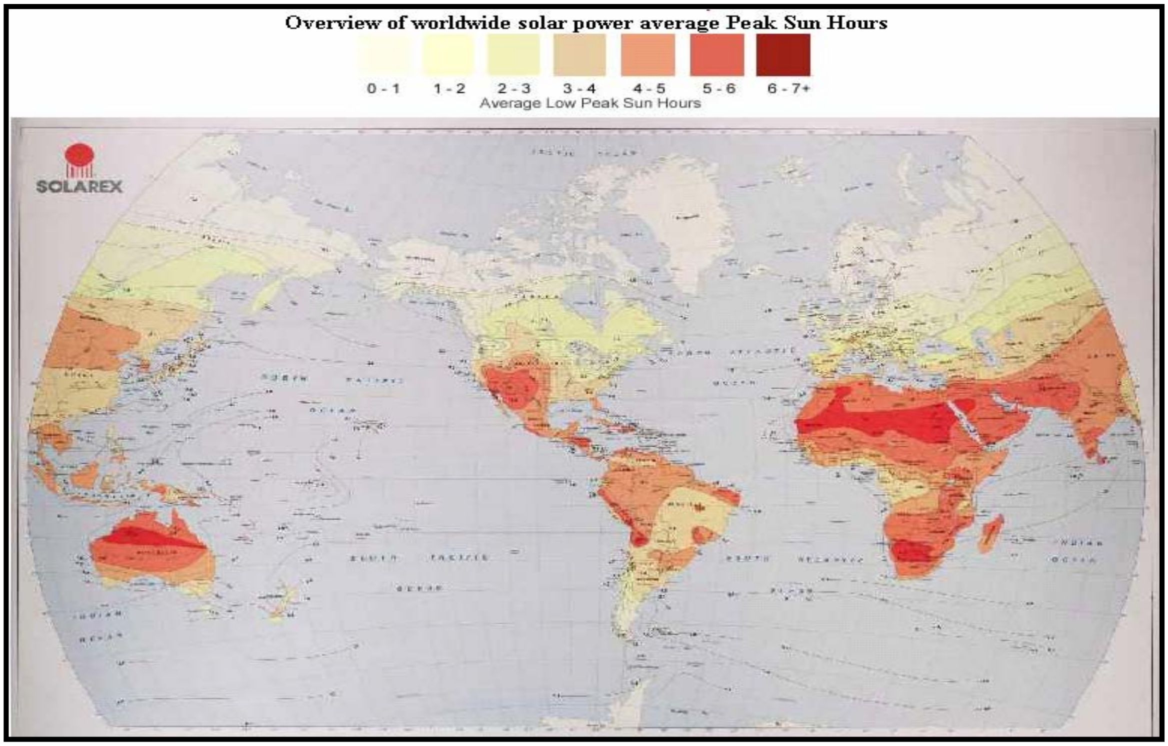
The use of solar power in police and fire stations strengthens the forces to fight against the opposition. Solar PV systems provide continuous electrical power to operate radios, surveillance equipment, computers, and other electronic devices. These services would remain operational at all times helping to establish a unified force that is equipped to conduct their mission 24 hours 7 days a week.

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX B – OPERATION SOLAR EAGLE WORKSHEETS



http://www.sunwize.com/info_center/insolmap.htm



http://www.solar4power.com/solar-power-global-maps.html

World Solar Maps for Selecting Peak Sun Hours (PSH)

Power Usage by Common Household Appliances

Appliance	Watts (W)	Estimated Hours Used per Month (Hr)	QUANTITIES USED	Total Watts/day
Air Conditioner (5,000 to 12,000 BTU)	900	200	0	0
Window Unit Air Conditioner	350	200	0	0
Auto Engine Heater	600	40	0	0
Battery Charger (Car)	150	15	0	0
Blender	385	2	0	0
CD, Tape, Radio, Receiver System	250	60	0	0
Clock	3	730	0	0
Clothes Dryer	5000	17	0	0
Coffee Maker (Auto Drip)	1165	4	0	0
Computer (With Monitor and Printer)	365	75	0	0
Convection Oven	1500	8	0	0
Curling Iron	1500	5	0	0
Dehumidifier (20 Pints, Summer)	450	360	0	0
Dishwasher (Wash to Dry Cycle)	550	25	0	0
Disposal	420	60	0	0
Electric Blanket	175	180	0	0
Fan (Ceiling)	80	150	0	0
Freezer (Automatic Defrost 15 cu. ft.)	440	334	0	0
Fry Pan	1200	10	0	0
Garage Door Opener	350	3	0	0
Hair Dryer (Hand Held)	1000	10	0	0
Heat Lamp	250	5	0	0
Heat Tape (30ft., Winter)	180	720	0	0
Heater (Auto Engine, Winter)	1000	180	0	0
Heater (Portable)	1500	40	0	0
Heating System (Warm Air Fan)	312	288	0	0
Humidifier (Winter)	177	230	0	0
Iron	1000	5	0	0
Lighting (Incandescent)	75	100	0	0
Lighting (Fluorescent)	40	100	0	0
Lighting (Compact Fluorescent)	18	100	0	0
Microwave Oven	1500	11	0	0
Mixer, Hand	100	10	0	0
Motor (1 HP)	1000	20	0	0
Power Tools (Circular Saw)	1800	1	0	0
Radio	71	101	0	0
Range (Oven)	2660	8	0	0
Refrigerator/Freezer (17.5cu.ft.)	450	333	0	0
Satellite Dish (with Receiver)	360	183	0	0
Sump Pump (1/2 HP)	500	20	0	0
Television (Color, Solid State)	200	183	0	0
Toaster	1400	3	0	0
Vacuum Cleaner	1560	6	0	0
VCR	45	6	0	0
Waffle Iron	1200	4	0	0
Washer (Automatic)	512	17	0	0
Water Heater (Quick Recovery)	4500	89	0	0
Water Pump (1/2 HP)	460	41	0	0
			Total Wh/day	**0**

http://www.cornhusker-power.com/householdappliances.asp

Appliance Loads Worksheet for Calculating Daily Power Requirements

Solar Componet Price Index

as of **May-05**

Panels ($/Watt)	Inverters ($/Watt)	Charge Controller ($/Amp)	Batteries ($/Watt)
5.140	**0.836**	**5.800**	**1.620**

http://www.solarbuzz.com/ModulePrices.htm

5.120	**0.836**	**5.800**	**1.610**	5-Apr

Hyperlink to examples of Component Specifications

Sharp 167 Watt Solar Panels

Xantrex/Trace SW4048 Series II Inverter

OutBack Power MX60 MPPT Charge Controller

Surrette S-460 Batteries

Solar Price Index Worksheet

THIS PAGE INTENTIONALLY LEFT BLANK

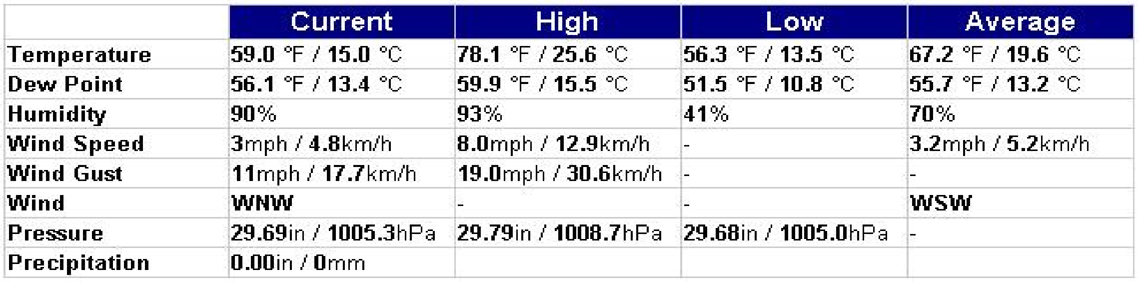
APPENDIX C – WEATHER DATA FOR TESTING OF PVPC

The weather data provided depicts the daily weather conditions during the performance comparison testing of solar PV systems with and without PVPC technology. The reported conditions are for Novato, California from June 1, 2005 to June 8, 2005. The data is synthesized for each day as shown in the figures and provided as a Microsoft Excel file for each day in 30 minute intervals.

Source: The Weather Underground, Inc.
www.wunderground.com/weatherstation/WXDailyHistory.asp?ID=KCANOVAT2&month=6&day=7&year=2005

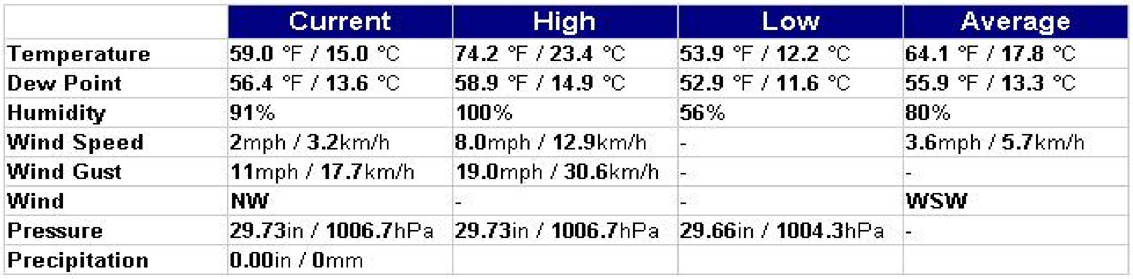
Novato, CA
Latitude: N 38 degrees 5 minutes 59 seconds (38.100 degrees)
Longitude: W 122 degree 35 minutes 59 seconds (-122.600 degrees)
Elevation: 20 ft

June 1, 2005



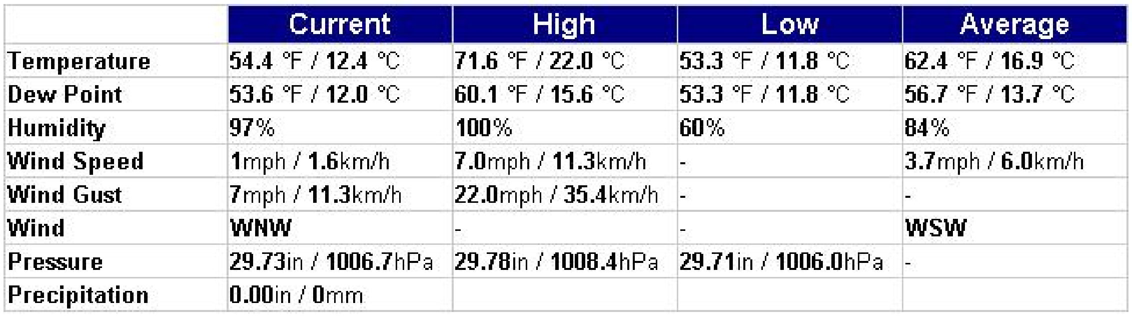
	Current	High	Low	Average
Temperature	59.0 °F / 15.0 °C	78.1 °F / 25.6 °C	56.3 °F / 13.5 °C	67.2 °F / 19.6 °C
Dew Point	56.1 °F / 13.4 °C	59.9 °F / 15.5 °C	51.5 °F / 10.8 °C	55.7 °F / 13.2 °C
Humidity	90%	93%	41%	70%
Wind Speed	3mph / 4.8km/h	8.0mph / 12.9km/h	-	3.2mph / 5.2km/h
Wind Gust	11mph / 17.7km/h	19.0mph / 30.6km/h	-	-
Wind	WNW	-	-	WSW
Pressure	29.69in / 1005.3hPa	29.79in / 1008.7hPa	29.68in / 1005.0hPa	-
Precipitation	0.00in / 0mm			

June 2, 2005



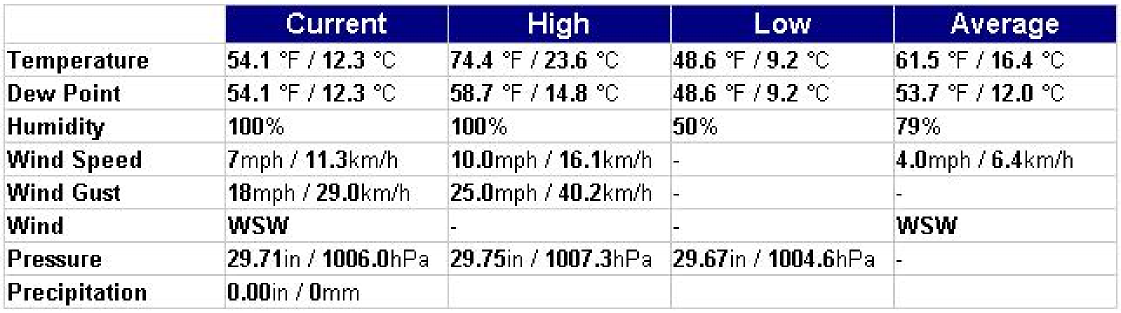
	Current	High	Low	Average
Temperature	59.0 °F / 15.0 °C	74.2 °F / 23.4 °C	53.9 °F / 12.2 °C	64.1 °F / 17.8 °C
Dew Point	56.4 °F / 13.6 °C	58.9 °F / 14.9 °C	52.9 °F / 11.6 °C	55.9 °F / 13.3 °C
Humidity	91%	100%	56%	80%
Wind Speed	2mph / 3.2km/h	8.0mph / 12.9km/h	-	3.6mph / 5.7km/h
Wind Gust	11mph / 17.7km/h	19.0mph / 30.6km/h	-	-
Wind	NW	-	-	WSW
Pressure	29.73in / 1006.7hPa	29.73in / 1006.7hPa	29.66in / 1004.3hPa	-
Precipitation	0.00in / 0mm			

June 3, 2005



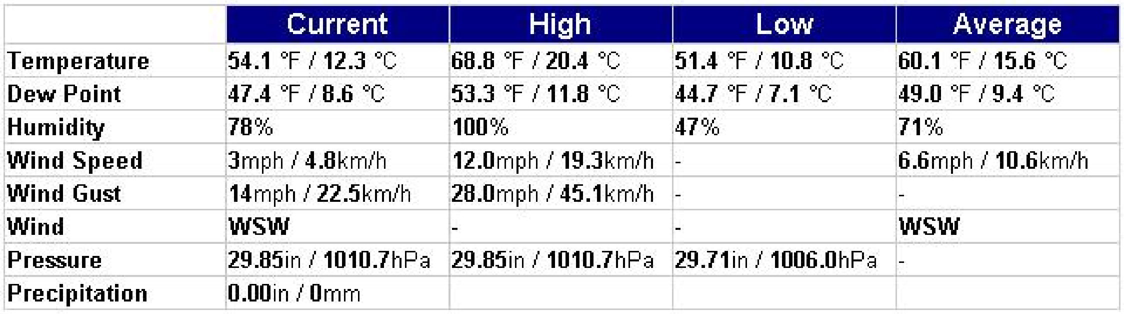
	Current	High	Low	Average
Temperature	54.4 °F / 12.4 °C	71.6 °F / 22.0 °C	53.3 °F / 11.8 °C	62.4 °F / 16.9 °C
Dew Point	53.6 °F / 12.0 °C	60.1 °F / 15.6 °C	53.3 °F / 11.8 °C	56.7 °F / 13.7 °C
Humidity	97%	100%	60%	84%
Wind Speed	1mph / 1.6km/h	7.0mph / 11.3km/h	-	3.7mph / 6.0km/h
Wind Gust	7mph / 11.3km/h	22.0mph / 35.4km/h	-	-
Wind	WNW	-	-	WSW
Pressure	29.73in / 1006.7hPa	29.78in / 1008.4hPa	29.71in / 1006.0hPa	-
Precipitation	0.00in / 0mm			

June 4, 2005



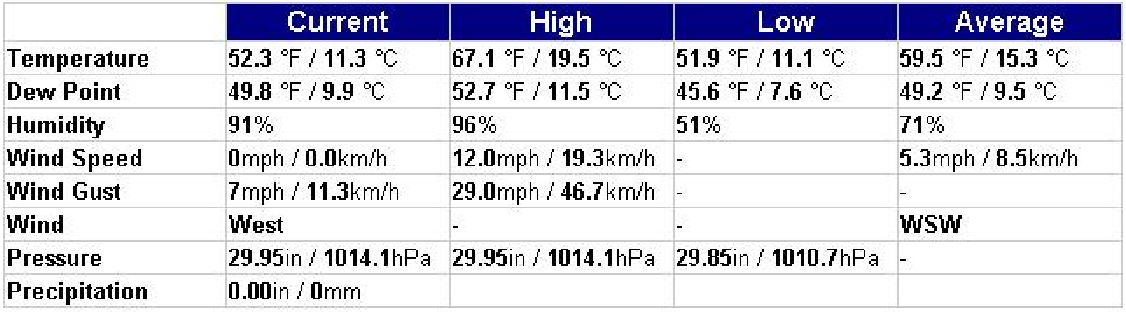
	Current	High	Low	Average
Temperature	54.1 °F / 12.3 °C	74.4 °F / 23.6 °C	48.6 °F / 9.2 °C	61.5 °F / 16.4 °C
Dew Point	54.1 °F / 12.3 °C	58.7 °F / 14.8 °C	48.6 °F / 9.2 °C	53.7 °F / 12.0 °C
Humidity	100%	100%	50%	79%
Wind Speed	7mph / 11.3km/h	10.0mph / 16.1km/h	-	4.0mph / 6.4km/h
Wind Gust	18mph / 29.0km/h	25.0mph / 40.2km/h	-	-
Wind	WSW	-	-	WSW
Pressure	29.71in / 1006.0hPa	29.75in / 1007.3hPa	29.67in / 1004.6hPa	-
Precipitation	0.00in / 0mm			

June 5, 2005



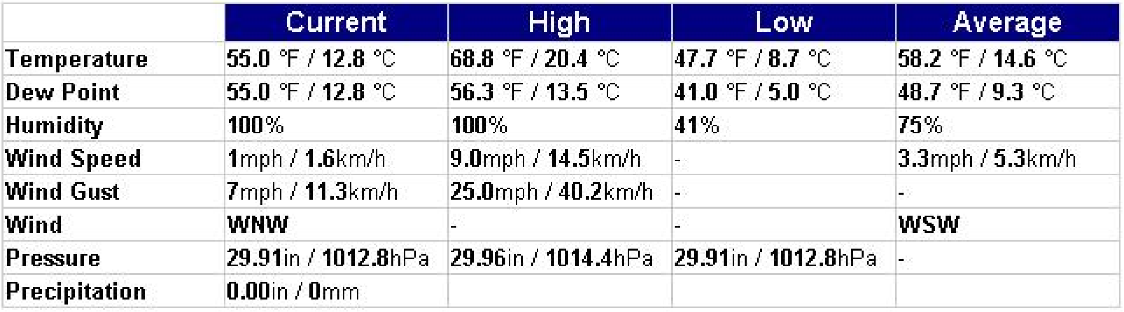
	Current	High	Low	Average
Temperature	54.1 °F / 12.3 °C	68.8 °F / 20.4 °C	51.4 °F / 10.8 °C	60.1 °F / 15.6 °C
Dew Point	47.4 °F / 8.6 °C	53.3 °F / 11.8 °C	44.7 °F / 7.1 °C	49.0 °F / 9.4 °C
Humidity	78%	100%	47%	71%
Wind Speed	3mph / 4.8km/h	12.0mph / 19.3km/h	-	6.6mph / 10.6km/h
Wind Gust	14mph / 22.5km/h	28.0mph / 45.1km/h	-	-
Wind	WSW	-	-	WSW
Pressure	29.85in / 1010.7hPa	29.85in / 1010.7hPa	29.71in / 1006.0hPa	-
Precipitation	0.00in / 0mm			

June 6, 2005



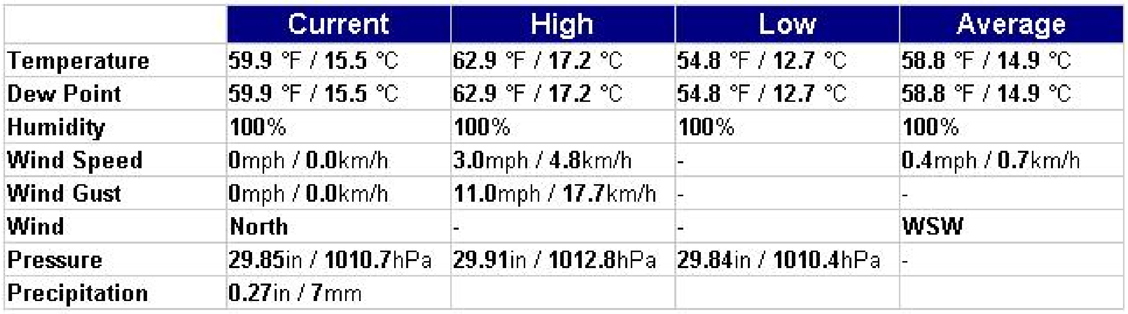
	Current	High	Low	Average
Temperature	52.3 °F / 11.3 °C	67.1 °F / 19.5 °C	51.9 °F / 11.1 °C	59.5 °F / 15.3 °C
Dew Point	49.8 °F / 9.9 °C	52.7 °F / 11.5 °C	45.6 °F / 7.6 °C	49.2 °F / 9.5 °C
Humidity	91%	96%	51%	71%
Wind Speed	0mph / 0.0km/h	12.0mph / 19.3km/h	-	5.3mph / 8.5km/h
Wind Gust	7mph / 11.3km/h	29.0mph / 46.7km/h	-	-
Wind	West	-	-	WSW
Pressure	29.95in / 1014.1hPa	29.95in / 1014.1hPa	29.85in / 1010.7hPa	-
Precipitation	0.00in / 0mm			

June 7, 2005



	Current	High	Low	Average
Temperature	55.0 °F / 12.8 °C	68.8 °F / 20.4 °C	47.7 °F / 8.7 °C	58.2 °F / 14.6 °C
Dew Point	55.0 °F / 12.8 °C	56.3 °F / 13.5 °C	41.0 °F / 5.0 °C	48.7 °F / 9.3 °C
Humidity	100%	100%	41%	75%
Wind Speed	1mph / 1.6km/h	9.0mph / 14.5km/h	-	3.3mph / 5.3km/h
Wind Gust	7mph / 11.3km/h	25.0mph / 40.2km/h	-	-
Wind	WNW	-	-	WSW
Pressure	29.91in / 1012.8hPa	29.96in / 1014.4hPa	29.91in / 1012.8hPa	-
Precipitation	0.00in / 0mm			

June 8, 2005



	Current	High	Low	Average
Temperature	59.9 °F / 15.5 °C	62.9 °F / 17.2 °C	54.8 °F / 12.7 °C	58.8 °F / 14.9 °C
Dew Point	59.9 °F / 15.5 °C	62.9 °F / 17.2 °C	54.8 °F / 12.7 °C	58.8 °F / 14.9 °C
Humidity	100%	100%	100%	100%
Wind Speed	0mph / 0.0km/h	3.0mph / 4.8km/h	-	0.4mph / 0.7km/h
Wind Gust	0mph / 0.0km/h	11.0mph / 17.7km/h	-	-
Wind	North	-	-	WSW
Pressure	29.85in / 1010.7hPa	29.91in / 1012.8hPa	29.84in / 1010.4hPa	-
Precipitation	0.27in / 7mm			

June 1, 2005

Time	TemperatureF	DewpointF	PressureIn	WindDirection	WindDirectionDegrees	WindSpeedMPH	WindSpeedGustMPH	Humidity	HourlyPrecipIn
6/1/2005 0:00	61.2	53.9	29.77	WSW	247	2	12	77	0
6/1/2005 0:30	61.6	53.6	29.77	WSW	247	2	10	75	0
6/1/2005 1:00	62	53.2	29.77	WSW	247	3	12	73	0
6/1/2005 1:30	61	53	29.77	West	270	1	8	75	0
6/1/2005 2:00	60.1	53.2	29.77	West	270	1	7	78	0
6/1/2005 2:30	60.2	52.6	29.77	WSW	247	2	8	76	0
6/1/2005 3:00	60.7	52	29.77	WSW	247	4	12	73	0
6/1/2005 3:30	59.3	52.4	29.77	West	270	1	10	78	0
6/1/2005 4:00	58.4	51.9	29.78	NW	315	1	10	79	0
6/1/2005 4:30	57.5	52.7	29.77	WNW	292	2	11	84	0
6/1/2005 5:00	57.2	52.1	29.78	NW	315	1	10	83	0
6/1/2005 5:30	57.3	51.5	29.78	NW	315	2	12	81	0
6/1/2005 6:00	56.3	52.5	29.78	West	270	1	7	87	0
6/1/2005 6:30	56.5	52.4	29.78	West	270	2	10	86	0
6/1/2005 7:00	58.1	52.6	29.78	West	270	1	8	82	0
6/1/2005 7:30	61.6	51.7	29.78	WSW	247	2	8	70	0
6/1/2005 8:00	67.3	53.8	29.79	WSW	247	1	7	62	0
6/1/2005 8:30	72	54.4	29.79	SW	225	0	5	54	0
6/1/2005 9:00	72.7	54.6	29.79	WSW	247	1	6	53	0
6/1/2005 9:30	76.1	53.8	29.79	WSW	247	1	6	46	0
6/1/2005 10:00	76.8	53.8	29.78	WSW	247	1	7	45	0
6/1/2005 10:30	78.1	52.5	29.78	WSW	247	1	7	41	0
6/1/2005 11:00	76	58.7	29.77	WSW	247	2	13	55	0
6/1/2005 11:30	76.1	59.3	29.77	WSW	247	4	12	56	0
6/1/2005 12:00	76.3	59.9	29.77	WSW	247	5	16	57	0

June 1, 2005 continued

6/1/2005 12:30	76	59.7	29.76	WSW	247	6	13	57	0
6/1/2005 13:00	75.8	58.5	29.76	WSW	247	6	14	55	0
6/1/2005 13:30	76.1	56.7	29.75	WSW	247	6	16	51	0
6/1/2005 14:00	75.8	55.8	29.74	WSW	247	6	16	50	0
6/1/2005 14:30	74.7	58.5	29.74	WSW	247	7	19	57	0
6/1/2005 15:00	74.2	58.5	29.74	WSW	247	7	17	58	0
6/1/2005 15:30	73.3	59	29.73	WSW	247	8	19	61	0
6/1/2005 16:00	74	58.8	29.73	WSW	247	5	16	59	0
6/1/2005 16:30	72.8	59	29.72	WSW	247	6	19	62	0
6/1/2005 17:00	72.5	58.7	29.71	WSW	247	6	17	62	0
6/1/2005 17:30	71.5	58.2	29.69	WSW	247	5	17	63	0
6/1/2005 18:00	68.4	58.6	29.69	WSW	247	6	19	71	0
6/1/2005 18:30	66.3	58.1	29.69	West	270	5	18	75	0
6/1/2005 19:00	66.9	57.2	29.68	WSW	247	4	17	71	0
6/1/2005 19:30	66	57.8	29.69	WSW	247	5	13	75	0
6/1/2005 20:00	64	58.1	29.68	WSW	247	4	12	81	0
6/1/2005 20:30	62.3	58.1	29.68	WSW	247	3	11	86	0
6/1/2005 21:00	60.1	56.8	29.69	West	270	3	12	89	0
6/1/2005 21:30	59	57	29.69	West	270	3	13	93	0
6/1/2005 22:00	60.1	56.2	29.7	West	270	3	12	87	0
6/1/2005 22:30	59.5	55.9	29.7	West	270	3	11	88	0
6/1/2005 23:00	59.5	55.6	29.7	WNW	292	2	10	87	0
6/1/2005 23:30	59	56.1	29.69	WNW	292	3	11	90	0

June 2, 2005

6/2/2005 0:00	58.6	56.3	29.69	NW	315	2	14	92	0
6/2/2005 0:30	58.6	56.3	29.69	WNW	292	2	11	92	0
6/2/2005 1:00	57.8	57.5	29.69	WNW	292	1	8	99	0
6/2/2005 1:30	57	57	29.69	WNW	292	1	7	100	0
6/2/2005 2:00	57.3	55.9	29.69	West	270	2	11	95	0
6/2/2005 2:30	56.7	56.7	29.69	West	270	2	10	100	0
6/2/2005 3:00	56.5	56.5	29.7	West	270	2	11	100	0
6/2/2005 3:30	56	56	29.69	West	270	2	10	100	0
6/2/2005 4:00	55.6	55.6	29.68	West	270	1	8	100	0
6/2/2005 4:30	55.3	55.3	29.69	West	270	1	7	100	0
6/2/2005 5:00	54.5	54.5	29.69	WNW	292	2	10	100	0
6/2/2005 5:30	53.9	53.9	29.7	West	270	1	10	100	0
6/2/2005 6:00	53.9	53.9	29.7	West	270	2	8	100	0
6/2/2005 6:30	54.2	54.2	29.7	West	270	1	8	100	0
6/2/2005 7:00	56.3	56.3	29.7	West	270	1	11	100	0
6/2/2005 7:30	60.2	54	29.7	WSW	247	1	8	80	0
6/2/2005 8:00	63.7	52.9	29.7	WSW	247	2	7	68	0
6/2/2005 8:30	66.9	53.9	29.71	WSW	247	1	7	63	0
6/2/2005 9:00	68.6	54.2	29.71	WSW	247	2	10	60	0
6/2/2005 9:30	69.3	54.8	29.71	WSW	247	3	10	60	0
6/2/2005 10:00	70.8	56.7	29.71	WSW	247	3	11	61	0
6/2/2005 10:30	71.6	56	29.71	WSW	247	4	12	58	0
6/2/2005 11:00	70.9	57.7	29.71	WSW	247	5	16	63	0
6/2/2005 11:30	71.1	56.5	29.71	WSW	247	6	14	60	0
6/2/2005 12:00	72	55.4	29.71	WSW	247	6	16	56	0

June 2, 2005 continued

6/2/2005 12:30	71.3	55.8	29.71	WSW	247	6	16	58	0
6/2/2005 13:00	71.5	55	29.71	WSW	247	7	16	56	0
6/2/2005 13:30	71.8	56.7	29.71	WSW	247	6	17	59	0
6/2/2005 14:00	73.2	58.5	29.7	WSW	247	4	16	60	0
6/2/2005 14:30	74.2	58.9	29.69	WSW	247	4	12	59	0
6/2/2005 15:00	72.8	58.1	29.69	WSW	247	6	16	60	0
6/2/2005 15:30	72.1	58.4	29.69	WSW	247	6	17	62	0
6/2/2005 16:00	70.9	58.1	29.68	WSW	247	6	14	64	0
6/2/2005 16:30	70.4	58.5	29.67	WSW	247	6	18	66	0
6/2/2005 17:00	69.8	57.9	29.67	WSW	247	6	16	66	0
6/2/2005 17:30	68.3	57.3	29.67	West	270	6	17	68	0
6/2/2005 18:00	66.3	57.8	29.66	WSW	247	6	17	74	0
6/2/2005 18:30	65.3	56.8	29.66	WSW	247	8	19	74	0
6/2/2005 19:00	64	57	29.66	WSW	247	6	17	78	0
6/2/2005 19:30	62.1	56.5	29.68	WSW	247	6	17	82	0
6/2/2005 20:00	60.5	56.9	29.67	WSW	247	6	17	88	0
6/2/2005 20:30	59.3	57	29.68	WSW	247	5	18	92	0
6/2/2005 21:00	58.3	56.3	29.69	WSW	247	4	16	93	0
6/2/2005 21:30	57.3	56.5	29.7	West	270	2	11	97	0
6/2/2005 22:00	57.2	56.6	29.72	West	270	2	11	98	0
6/2/2005 22:30	58.6	56.6	29.72	West	270	2	10	93	0
6/2/2005 23:00	59	56.4	29.72	WNW	292	3	12	91	0
6/2/2005 23:30	59	56.4	29.73	NW	315	2	11	91	0

June 3, 2005

6/3/2005 0:00	58.7	57	29.73	WNW	292	3	11	94	0
6/3/2005 0:30	58.3	56	29.73	WNW	292	3	16	92	0
6/3/2005 1:00	57.8	55.8	29.73	WNW	292	3	11	93	0
6/3/2005 1:30	57.2	55.5	29.73	West	270	3	12	94	0
6/3/2005 2:00	56.5	55.9	29.72	WNW	292	3	11	98	0
6/3/2005 2:30	55.7	55.7	29.72	West	270	3	10	100	0
6/3/2005 3:00	55.1	55.1	29.72	WNW	292	3	11	100	0
6/3/2005 3:30	54.8	54.8	29.72	WNW	292	3	12	100	0
6/3/2005 4:00	55.7	55.7	29.72	West	270	3	12	100	0
6/3/2005 4:30	54.7	54.7	29.72	West	270	1	7	100	0
6/3/2005 5:00	53.3	53.3	29.74	West	270	1	7	100	0
6/3/2005 5:30	53.6	53.6	29.74	WNW	292	1	8	100	0
6/3/2005 6:00	54.2	54.2	29.74	WNW	292	2	10	100	0
6/3/2005 6:30	54.4	54.4	29.74	West	270	1	10	100	0
6/3/2005 7:00	56.3	56.3	29.75	WNW	292	1	6	100	0
6/3/2005 7:30	58.3	55.7	29.76	WSW	247	2	7	91	0
6/3/2005 8:00	62.6	54.9	29.77	WSW	247	1	8	76	0
6/3/2005 8:30	68.4	56.6	29.77	WSW	247	1	7	66	0
6/3/2005 9:00	70.8	56.2	29.77	WSW	247	1	7	60	0
6/3/2005 9:30	69.8	57.9	29.77	WSW	247	2	11	66	0
6/3/2005 10:00	69.8	58.3	29.78	WSW	247	4	12	67	0
6/3/2005 10:30	70.9	58.1	29.77	WSW	247	4	11	64	0
6/3/2005 11:00	70.3	58.4	29.77	WSW	247	5	14	66	0
6/3/2005 11:30	69.1	57.7	29.78	WSW	247	7	16	67	0
6/3/2005 12:00	69.9	58.9	29.77	WSW	247	6	14	68	0

June 3, 2005 continued

6/3/2005 12:30	69.6	59	29.77	WSW	247	7	17	69	0
6/3/2005 13:00	70.3	60.1	29.77	WSW	247	6	16	70	0
6/3/2005 13:30	70.8	59.7	29.76	WSW	247	6	17	68	0
6/3/2005 14:00	71.6	59.6	29.76	WSW	247	6	16	66	0
6/3/2005 14:30	70.1	59	29.75	WSW	247	6	16	68	0
6/3/2005 15:00	70.8	59.3	29.75	WSW	247	6	19	67	0
6/3/2005 15:30	70.1	58.6	29.74	WSW	247	6	16	67	0
6/3/2005 16:00	69.3	57.9	29.74	WSW	247	6	18	67	0
6/3/2005 16:30	68.4	58.6	29.73	WSW	247	7	22	71	0
6/3/2005 17:00	69.9	58.4	29.72	WSW	247	5	16	67	0
6/3/2005 17:30	68.6	57.2	29.72	WSW	247	5	16	67	0
6/3/2005 18:00	66.1	56.8	29.71	WSW	247	6	17	72	0
6/3/2005 18:30	62.7	56.1	29.71	WSW	247	7	19	79	0
6/3/2005 19:00	60.9	56.7	29.71	WSW	247	6	19	86	0
6/3/2005 19:30	59.3	57	29.71	WSW	247	7	18	92	0
6/3/2005 20:00	57.6	57	29.71	WSW	247	5	16	98	0
6/3/2005 20:30	57.6	56.5	29.71	WSW	247	5	13	96	0
6/3/2005 21:00	57.5	56.4	29.71	WSW	247	4	12	96	0
6/3/2005 21:30	56.3	55.7	29.73	WSW	247	2	10	98	0
6/3/2005 22:00	55.7	54.6	29.73	WSW	247	2	11	96	0
6/3/2005 22:30	55.3	54.2	29.73	WSW	247	1	8	96	0
6/3/2005 23:00	54.4	54.1	29.73	West	270	0	6	99	0
6/3/2005 23:30	54.4	53.6	29.73	WNW	292	1	7	97	0

June 4, 2005

6/4/2005 0:00	53.9	53.3	29.73	WSW	247	0	5	98	0
6/4/2005 0:30	53.8	53.5	29.73	WNW	292	0	7	99	0
6/4/2005 1:00	54.1	53	29.72	West	270	2	10	96	0
6/4/2005 1:30	53.2	53.2	29.72	West	270	1	8	100	0
6/4/2005 2:00	52.6	52.6	29.72	WSW	247	1	6	100	0
6/4/2005 2:30	51.9	51.9	29.72	West	270	1	7	100	0
6/4/2005 3:00	51.3	51.3	29.72	WNW	292	1	12	100	0
6/4/2005 3:30	51.6	51.6	29.72	West	270	1	7	100	0
6/4/2005 4:00	51.1	51.1	29.71	West	270	1	7	100	0
6/4/2005 4:30	50.5	50.5	29.71	West	270	1	7	100	0
6/4/2005 5:00	50.4	50.4	29.72	West	270	1	6	100	0
6/4/2005 5:30	50.4	50.4	29.72	WNW	292	0	6	100	0
6/4/2005 6:00	49.2	49.2	29.73	West	270	0	2	100	0
6/4/2005 6:30	48.6	48.6	29.73	North	-999	0	0	100	0
6/4/2005 7:00	51.7	51.7	29.74	West	270	0	5	100	0
6/4/2005 7:30	56.2	56.2	29.74	West	270	1	6	100	0
6/4/2005 8:00	61.2	55	29.75	SW	225	0	3	80	0
6/4/2005 8:30	67.8	55.2	29.75	North	-999	0	0	64	0
6/4/2005 9:00	69.6	54.2	29.75	WSW	247	0	5	58	0
6/4/2005 9:30	73.2	54.5	29.75	WSW	247	0	3	52	0
6/4/2005 10:00	74.4	54.5	29.74	WSW	247	0	8	50	0
6/4/2005 10:30	70.9	55.4	29.74	WSW	247	3	11	58	0
6/4/2005 11:00	72.5	55.4	29.74	WSW	247	4	11	55	0
6/4/2005 11:30	73.5	55.3	29.74	WSW	247	5	12	53	0
6/4/2005 12:00	72.8	56.7	29.74	WSW	247	6	16	57	0

June 4, 2005 continued

6/4/2005 12:30	73.2	58	29.73	WSW	247	5	13	59	0
6/4/2005 13:00	73.9	58.7	29.73	WSW	247	6	14	59	0
6/4/2005 13:30	72.8	57.2	29.73	WSW	247	7	18	58	0
6/4/2005 14:00	72.1	57.4	29.72	WSW	247	7	17	60	0
6/4/2005 14:30	71.8	57.2	29.72	WSW	247	5	14	60	0
6/4/2005 15:00	71.8	57.2	29.71	WSW	247	6	14	60	0
6/4/2005 15:30	69.3	55.7	29.7	WSW	247	8	22	62	0
6/4/2005 16:00	68.3	56.5	29.69	WSW	247	8	24	66	0
6/4/2005 16:30	67.9	56.5	29.68	WSW	247	8	22	67	0
6/4/2005 17:00	66.9	55.2	29.68	WSW	247	10	21	66	0
6/4/2005 17:30	65.6	55.5	29.68	WSW	247	9	25	70	0
6/4/2005 18:00	65.5	54.7	29.67	WSW	247	9	20	68	0
6/4/2005 18:30	65.5	52.1	29.67	WSW	247	8	19	62	0
6/4/2005 19:00	64.2	53	29.67	WSW	247	8	21	67	0
6/4/2005 19:30	61.5	53.5	29.67	WSW	247	8	19	75	0
6/4/2005 20:00	59.2	53	29.68	WSW	247	5	19	80	0
6/4/2005 20:30	57.3	52.5	29.68	WSW	247	7	21	84	0
6/4/2005 21:00	56.6	52.8	29.68	WSW	247	6	16	87	0
6/4/2005 21:30	55.9	51.8	29.69	WSW	247	5	14	86	0
6/4/2005 22:00	55.1	52.5	29.7	WSW	247	5	14	91	0
6/4/2005 22:30	54.7	53.6	29.7	WSW	247	8	25	96	0
6/4/2005 23:00	54.4	53	29.71	WSW	247	7	21	95	0
6/4/2005 23:30	54.1	54.1	29.71	WSW	247	7	18	100	0

June 5, 2005

6/5/2005 0:00	53.3	53.3	29.71	WSW	247	6	16	100	0
6/5/2005 0:30	53.2	53.2	29.71	WSW	247	4	16	100	0
6/5/2005 1:00	53.1	53.1	29.71	WSW	247	6	19	100	0
6/5/2005 1:30	52.6	52.6	29.71	WSW	247	5	17	100	0
6/5/2005 2:00	52.6	52.3	29.71	WSW	247	7	20	99	0
6/5/2005 2:30	52.8	51.4	29.72	WSW	247	7	17	95	0
6/5/2005 3:00	52.6	50.6	29.72	WSW	247	6	17	93	0
6/5/2005 3:30	52.6	49.4	29.72	WSW	247	6	18	89	0
6/5/2005 4:00	52	49.5	29.72	WSW	247	7	19	91	0
6/5/2005 4:30	51.4	49.2	29.73	WSW	247	5	17	92	0
6/5/2005 5:00	51.6	47.9	29.74	WSW	247	4	16	87	0
6/5/2005 5:30	51.9	46.6	29.75	WSW	247	5	18	82	0
6/5/2005 6:00	51.6	47.5	29.76	WSW	247	4	14	86	0
6/5/2005 6:30	52	47	29.77	WSW	247	4	17	83	0
6/5/2005 7:00	53.9	46.2	29.79	WSW	247	5	13	75	0
6/5/2005 7:30	56	46.7	29.79	WSW	247	6	17	71	0
6/5/2005 8:00	59	46.4	29.79	WSW	247	5	14	63	0
6/5/2005 8:30	60.4	45.1	29.81	WSW	247	5	16	57	0
6/5/2005 9:00	63.1	44.7	29.82	WSW	247	5	14	51	0
6/5/2005 9:30	65	44.8	29.82	WSW	247	4	14	48	0
6/5/2005 10:00	67.1	46.2	29.83	WSW	247	3	13	47	0
6/5/2005 10:30	66.1	48	29.83	WSW	247	4	14	52	0
6/5/2005 11:00	66.3	48.1	29.83	WSW	247	5	13	52	0
6/5/2005 11:30	67.6	49.9	29.83	WSW	247	6	14	53	0
6/5/2005 12:00	68.6	48.1	29.84	WSW	247	6	16	48	0

June 5, 2005 continued

6/5/2005 12:30	68.6	50.8	29.84	WSW	247	5	14	53	0
6/5/2005 13:00	68.8	49.4	29.84	WSW	247	6	21	50	0
6/5/2005 13:30	66.9	48.7	29.84	WSW	247	8	21	52	0
6/5/2005 14:00	67.3	49.1	29.83	WSW	247	8	18	52	0
6/5/2005 14:30	67.6	48.8	29.83	WSW	247	8	21	51	0
6/5/2005 15:00	67.1	49.4	29.83	SW	225	8	20	53	0
6/5/2005 15:30	66.1	48	29.83	WSW	247	9	24	52	0
6/5/2005 16:00	64.3	48.7	29.83	WSW	247	11	26	57	0
6/5/2005 16:30	64.2	48.6	29.83	WSW	247	9	24	57	0
6/5/2005 17:00	64	48	29.82	WSW	247	9	28	56	0
6/5/2005 17:30	62.7	48.6	29.82	WSW	247	10	21	60	0
6/5/2005 18:00	61.2	49.3	29.82	WSW	247	12	27	65	0
6/5/2005 18:30	60.4	50.6	29.81	WSW	247	12	26	70	0
6/5/2005 19:00	60.2	50.8	29.81	WSW	247	11	22	71	0
6/5/2005 19:30	58.9	51.3	29.81	WSW	247	8	20	76	0
6/5/2005 20:00	56.9	51.1	29.81	WSW	247	9	21	81	0
6/5/2005 20:30	55.9	49.5	29.82	WSW	247	8	17	79	0
6/5/2005 21:00	55.3	48.9	29.82	WSW	247	8	21	79	0
6/5/2005 21:30	55.3	47.5	29.83	WSW	247	8	19	75	0
6/5/2005 22:00	54.5	48.8	29.84	WSW	247	7	18	81	0
6/5/2005 22:30	54.1	49.1	29.85	WSW	247	5	18	83	0
6/5/2005 23:00	53.9	47.9	29.85	WSW	247	5	17	80	0
6/5/2005 23:30	54.1	47.4	29.85	WSW	247	3	14	78	0

June 6, 2005

6/6/2005 0:00	53.2	48.2	29.85	WSW	247	4	12	83	0
6/6/2005 0:30	53.2	47.8	29.85	WSW	247	5	14	82	0
6/6/2005 1:00	53.3	47.6	29.85	WSW	247	4	14	81	0
6/6/2005 1:30	52.9	48.2	29.85	WSW	247	5	14	84	0
6/6/2005 2:00	52.9	47.9	29.85	WSW	247	5	14	83	0
6/6/2005 2:30	53.2	47.8	29.85	WSW	247	5	17	82	0
6/6/2005 3:00	53.3	46.6	29.86	WSW	247	5	17	78	0
6/6/2005 3:30	52.6	46.3	29.86	WSW	247	1	10	79	0
6/6/2005 4:00	53.2	46.5	29.87	WSW	247	3	13	78	0
6/6/2005 4:30	52.6	46.9	29.87	WSW	247	5	14	81	0
6/6/2005 5:00	52.2	45.9	29.88	WSW	247	3	12	79	0
6/6/2005 5:30	51.9	46.3	29.88	WSW	247	1	13	81	0
6/6/2005 6:00	52	46	29.9	WSW	247	3	14	80	0
6/6/2005 6:30	51.9	45.9	29.9	WSW	247	2	12	80	0
6/6/2005 7:00	53.9	46.2	29.91	WSW	247	1	7	75	0
6/6/2005 7:30	57.6	46.3	29.91	WSW	247	1	10	66	0
6/6/2005 8:00	59.2	45.8	29.92	WSW	247	3	12	61	0
6/6/2005 8:30	61	46.6	29.93	WSW	247	3	13	59	0
6/6/2005 9:00	63.5	47	29.92	WSW	247	3	13	55	0
6/6/2005 9:30	64.5	48	29.93	WSW	247	4	13	55	0
6/6/2005 10:00	65	47.4	29.92	WSW	247	5	13	53	0
6/6/2005 10:30	66.1	47.4	29.92	WSW	247	5	18	51	0
6/6/2005 11:00	67.1	48.9	29.92	SW	225	5	20	52	0
6/6/2005 11:30	66.3	49.2	29.93	WSW	247	7	20	54	0
6/6/2005 12:00	66.6	50.4	29.93	WSW	247	6	18	56	0

June 6, 2005 continued

6/6/2005 12:30	65.5	50.8	29.93	WSW	247	6	18	59	0
6/6/2005 13:00	65.5	50.3	29.93	WSW	247	7	21	58	0
6/6/2005 13:30	66.1	48.5	29.93	WSW	247	8	22	53	0
6/6/2005 14:00	66.4	48.7	29.93	WSW	247	8	22	53	0
6/6/2005 14:30	65.5	47.4	29.93	WSW	247	8	21	52	0
6/6/2005 15:00	63.9	48.4	29.93	WSW	247	11	29	57	0
6/6/2005 15:30	63.7	49.1	29.93	WSW	247	10	28	59	0
6/6/2005 16:00	64.2	46.7	29.92	WSW	247	10	26	53	0
6/6/2005 16:30	63.5	45.6	29.92	WSW	247	12	25	52	0
6/6/2005 17:00	62.6	46.2	29.91	WSW	247	11	27	55	0
6/6/2005 17:30	60.7	46.7	29.9	WSW	247	11	25	60	0
6/6/2005 18:00	60.5	49.5	29.91	WSW	247	9	26	67	0
6/6/2005 18:30	60.1	49.5	29.9	WSW	247	10	25	68	0
6/6/2005 19:00	59.5	50.1	29.91	WSW	247	8	21	71	0
6/6/2005 19:30	58	51.2	29.91	WSW	247	8	21	78	0
6/6/2005 20:00	56	52.5	29.91	WSW	247	6	17	88	0
6/6/2005 20:30	54.7	52.7	29.92	WSW	247	6	17	93	0
6/6/2005 21:00	53.9	52.5	29.93	WSW	247	2	8	95	0
6/6/2005 21:30	53.8	51.5	29.93	WSW	247	3	11	92	0
6/6/2005 22:00	53.3	50.7	29.94	WSW	247	2	10	91	0
6/6/2005 22:30	53.2	52.1	29.95	WSW	247	3	14	96	0
6/6/2005 23:00	52.8	50.8	29.95	WSW	247	2	12	93	0
6/6/2005 23:30	52.3	49.8	29.95	West	270	0	7	91	0

June 7, 2005

6/7/2005 0:00	51.6	49.1	29.96	West	270	0	7	91	0
6/7/2005 0:30	52.3	49.2	29.96	WSW	247	2	10	89	0
6/7/2005 1:00	52.3	48.5	29.96	WSW	247	3	12	87	0
6/7/2005 1:30	50.7	49.6	29.96	West	270	1	8	96	0
6/7/2005 2:00	51.1	49.1	29.96	West	270	1	10	93	0
6/7/2005 2:30	50.2	48.8	29.95	WSW	247	1	7	95	0
6/7/2005 3:00	49.5	49.5	29.94	West	270	0	5	100	0
6/7/2005 3:30	47.7	47.7	29.94	West	270	0	5	100	0
6/7/2005 4:00	48.3	48.3	29.94	WSW	247	0	5	100	0
6/7/2005 4:30	48.9	48.9	29.94	West	270	1	11	100	0
6/7/2005 5:00	48.5	48.5	29.94	West	270	1	7	100	0
6/7/2005 5:30	47.9	47.9	29.94	WNW	292	1	7	100	0
6/7/2005 6:00	47.9	47.9	29.94	WNW	292	0	5	100	0
6/7/2005 6:30	48.5	48.5	29.95	NW	315	0	5	100	0
6/7/2005 7:00	50.7	49.6	29.95	WNW	292	0	3	96	0
6/7/2005 7:30	54.7	49	29.95	NW	315	0	3	81	0
6/7/2005 8:00	58	46.3	29.95	WSW	247	1	5	65	0
6/7/2005 8:30	62.1	47.1	29.95	WSW	247	1	7	58	0
6/7/2005 9:00	63.2	43.7	29.95	WSW	247	2	10	49	0
6/7/2005 9:30	65.3	41	29.94	WSW	247	2	10	41	0
6/7/2005 10:00	66	42.2	29.94	WSW	247	3	13	42	0
6/7/2005 10:30	68.1	43.5	29.94	WSW	247	3	11	41	0
6/7/2005 11:00	68.3	44.3	29.94	WSW	247	2	10	42	0
6/7/2005 11:30	68.8	47.7	29.94	WSW	247	4	13	47	0
6/7/2005 12:00	68.1	48.2	29.94	WSW	247	4	14	49	0

June 7, 2005 continued

6/7/2005 12:30	67.9	46.3	29.94	WSW	247	5	17	46	0
6/7/2005 13:00	67.3	50.1	29.94	WSW	247	5	13	54	0
6/7/2005 13:30	67.3	52	29.95	WSW	247	6	16	58	0
6/7/2005 14:00	67.3	51.5	29.94	WSW	247	5	17	57	0
6/7/2005 14:30	65.5	50.3	29.94	WSW	247	6	25	58	0
6/7/2005 15:00	66.4	50.2	29.94	WSW	247	6	17	56	0
6/7/2005 15:30	66.4	50.2	29.93	WSW	247	6	22	56	0
6/7/2005 16:00	65.5	47.4	29.93	WSW	247	8	19	52	0
6/7/2005 16:30	65.2	46.6	29.93	WSW	247	7	20	51	0
6/7/2005 17:00	64.3	47.3	29.92	WSW	247	6	20	54	0
6/7/2005 17:30	63.5	49.4	29.92	WSW	247	7	21	60	0
6/7/2005 18:00	61.2	48.5	29.93	WSW	247	9	22	63	0
6/7/2005 18:30	60.9	46.9	29.92	WSW	247	8	20	60	0
6/7/2005 19:00	58.7	47.8	29.91	WSW	247	7	16	67	0
6/7/2005 19:30	58.3	49.7	29.91	WSW	247	7	20	73	0
6/7/2005 20:00	56.7	53.2	29.91	WSW	247	5	18	88	0
6/7/2005 20:30	56.6	55.2	29.91	WSW	247	7	19	95	0
6/7/2005 21:00	56.3	53.4	29.92	WSW	247	2	12	90	0
6/7/2005 21:30	56.3	56.3	29.92	WSW	247	5	16	100	0
6/7/2005 22:00	56.2	56.2	29.92	WSW	247	4	12	100	0
6/7/2005 22:30	56	56	29.92	West	270	2	10	100	0
6/7/2005 23:00	55.3	55.3	29.92	WNW	292	1	8	100	0
6/7/2005 23:30	55	55	29.91	WNW	292	1	7	100	0

June 8, 2005

6/8/2005 0:00	54.8	54.8	29.91	West	270	0	6	100	0
6/8/2005 0:30	55.3	55.3	29.9	WSW	247	0	5	100	0
6/8/2005 1:00	56.5	56.5	29.89	WNW	292	0	11	100	0
6/8/2005 1:30	56	56	29.88	WNW	292	0	8	100	0
6/8/2005 2:00	56.9	56.9	29.88	WSW	247	0	3	100	0
6/8/2005 2:30	57.5	57.5	29.87	West	270	0	1	100	0
6/8/2005 3:00	57.8	57.8	29.86	West	270	0	2	100	0
6/8/2005 3:30	57.8	57.8	29.85	WSW	247	0	5	100	0
6/8/2005 4:00	57.5	57.5	29.85	WSW	247	1	7	100	0
6/8/2005 4:30	58.1	58.1	29.85	WSW	247	0	7	100	0
6/8/2005 5:00	58.1	58.1	29.85	WSW	247	0	6	100	0
6/8/2005 5:30	58.6	58.6	29.85	WSW	247	0	5	100	0.01
6/8/2005 6:00	58.6	58.6	29.85	WSW	247	0	3	100	0.03
6/8/2005 6:30	59	59	29.85	WSW	247	0	6	100	0.03
6/8/2005 7:00	59.5	59.5	29.85	WSW	247	0	5	100	0.02
6/8/2005 7:30	59.9	59.9	29.86	WSW	247	0	6	100	0.02
6/8/2005 8:00	60.1	60.1	29.87	WSW	247	1	7	100	0.02
6/8/2005 8:30	60.1	60.1	29.87	WSW	247	0	7	100	0.01
6/8/2005 9:00	61.2	61.2	29.87	WSW	247	0	6	100	0
6/8/2005 9:30	62.1	62.1	29.87	WSW	247	1	11	100	0.01
6/8/2005 10:00	62.1	62.1	29.88	WSW	247	1	7	100	0.02
6/8/2005 10:30	60.9	60.9	29.88	WSW	247	1	10	100	0.02
6/8/2005 11:00	61.3	61.3	29.88	WSW	247	1	8	100	0.02
6/8/2005 11:30	62.9	62.9	29.88	WSW	247	1	10	100	0.01
6/8/2005 12:00	62.3	62.3	29.88	WSW	247	0	8	100	0

June 8, 2005 continued

6/8/2005 12:30	62.7	62.7	29.89	WSW	247	1	11	100	0
6/8/2005 13:00	62.7	62.7	29.89	WSW	247	1	10	100	0
6/8/2005 13:30	62.3	62.3	29.89	WSW	247	1	10	100	0.01
6/8/2005 14:00	62.4	62.4	29.88	WSW	247	2	10	100	0.02
6/8/2005 14:30	61.5	61.5	29.88	WSW	247	3	10	100	0.01
6/8/2005 15:00	62.1	62.1	29.88	WSW	247	1	10	100	0
6/8/2005 15:30	62.1	62.1	29.87	WSW	247	1	8	100	0.01
6/8/2005 16:00	61.8	61.8	29.87	WSW	247	1	8	100	0.01
6/8/2005 16:30	61.6	61.6	29.87	WSW	247	0	7	100	0
6/8/2005 17:00	61	61	29.86	WSW	247	1	8	100	0.01
6/8/2005 17:30	61.2	61.2	29.86	WSW	247	1	6	100	0.03
6/8/2005 18:00	61.5	61.5	29.85	WSW	247	1	8	100	0.02
6/8/2005 18:30	61.2	61.2	29.85	WSW	247	0	7	100	0.01
6/8/2005 19:00	60.9	60.9	29.85	WSW	247	0	5	100	0.01
6/8/2005 19:30	60.5	60.5	29.84	WSW	247	0	8	100	0.01
6/8/2005 20:00	60.4	60.4	29.84	WSW	247	0	8	100	0.01
6/8/2005 20:30	59.8	59.8	29.84	WSW	247	0	6	100	0.01
6/8/2005 21:00	59.8	59.8	29.85	North	-999	0	0	100	0.01
6/8/2005 21:30	59.8	59.8	29.85	North	-999	0	0	100	0.02
6/8/2005 22:00	59.8	59.8	29.85	North	-999	0	0	100	0.05
6/8/2005 22:30	59.6	59.6	29.85	North	-999	0	0	100	0.04
6/8/2005 23:00	59.8	59.8	29.85	North	-999	0	0	100	0.02
6/8/2005 23:30	59.9	59.9	29.85	North	-999	0	0	100	0.06

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX D – DATA USED FOR EVALUATION OF PVPC

All test data used for the performance comparison testing of solar PV systems with and without PVPC technology are provided in this appendix. The appendix is divided into two sections. The first group of data are the Current Power observations from June 1, 2005 to June 8, 2005. The second group of data are the Apparent Power observations from June 4, 2005 to June 8, 2005.

Electrical Current Observations

Time (U.S./Pacific)	**Conventional Current (Amps)**	**PVPC Current (Amps)**
6/1/2005 8:00	0.055	0.629
6/1/2005 8:15	1.026	1.38
6/1/2005 8:30	2.576	2.405
6/1/2005 8:45	3.791	5.971
6/1/2005 9:00	4.799	7.228
6/1/2005 9:15	5.952	9.084
6/1/2005 9:30	6.911	10.629
6/1/2005 9:45	7.698	11.88
6/1/2005 10:00	8.217	12.924
6/1/2005 10:15	8.565	14.035
6/1/2005 10:30	8.773	15.024
6/1/2005 10:45	8.803	16.105
6/1/2005 11:00	9.56	18.687
6/1/2005 11:15	10.385	19.158
6/1/2005 11:30	10.226	20.275
6/1/2005 11:45	10.134	21.19
6/1/2005 12:00	9.86	21.819
6/1/2005 12:15	10.012	22.57
6/1/2005 12:30	9.658	23.083
6/1/2005 12:45	9.597	23.504
6/1/2005 13:00	9.567	24.127
6/1/2005 13:15	9.481	24.292
6/1/2005 13:30	9.475	22.503
6/1/2005 13:45	9.237	22.485
6/1/2005 14:00	9.457	22.387
6/1/2005 14:15	9.597	22.179
6/1/2005 14:30	9.628	22.002
6/1/2005 14:45	9.414	21.752
6/1/2005 15:00	9.664	21.477
6/1/2005 15:15	9.713	20.623
6/1/2005 15:30	9.652	20.372
6/1/2005 15:45	9.487	19.805
6/1/2005 16:00	9.255	18.932
6/1/2005 16:15	9.402	18.333
6/1/2005 16:30	9.365	16.856
6/1/2005 16:45	9.151	16.3
6/1/2005 17:00	8.864	15.36
6/1/2005 17:15	8.669	14.176
6/1/2005 17:30	8.388	12.943
6/1/2005 17:45	7.753	11.709
6/1/2005 18:00	7.149	10.195
6/1/2005 18:15	6.209	8.651
6/1/2005 18:30	5.208	6.88
6/1/2005 18:45	2.473	5.586
6/1/2005 19:00	2.869	2.106
6/1/2005 19:15	0.305	0.049
6/1/2005 19:30	0.061	0.061
6/1/2005 19:45	0.055	0.055
6/1/2005 20:00	0.061	0.055

Time (U.S./Pacific)	Conventional Current (Amps)	PVPC Current (Amps)
6/2/2005 8:00	1.032	0.061
6/2/2005 8:15	1.783	0.58
6/2/2005 8:30	2.747	2.057
6/2/2005 8:45	3.736	3.706
6/2/2005 9:00	4.676	5.812
6/2/2005 9:15	5.531	7.479
6/2/2005 9:30	6.789	8.993
6/2/2005 9:45	7.643	10.263
6/2/2005 10:00	8.205	11.557
6/2/2005 10:15	8.541	12.802
6/2/2005 10:30	8.626	13.767
6/2/2005 10:45	9.035	16.288
6/2/2005 11:00	10.037	17.912
6/2/2005 11:15	11.05	19.359
6/2/2005 11:30	10.916	20.122
6/2/2005 11:45	10.629	21.074
6/2/2005 12:00	10.482	21.978
6/2/2005 12:15	10.256	20.672
6/2/2005 12:30	10.147	21.117
6/2/2005 12:45	10.153	21.361
6/2/2005 13:00	9.64	21.16
6/2/2005 13:15	9.621	21.27
6/2/2005 13:30	9.878	21.581
6/2/2005 13:45	10.055	21.136
6/2/2005 14:00	9.603	21.258
6/2/2005 14:15	9.219	20.891
6/2/2005 14:30	9.151	20.714
6/2/2005 14:45	9.084	20.366
6/2/2005 15:00	8.95	19.799
6/2/2005 15:15	8.712	19.335
6/2/2005 15:30	9.194	19.029
6/2/2005 15:45	9.2	17.485
6/2/2005 16:00	9.237	17.698
6/2/2005 16:15	9.103	16.935
6/2/2005 16:30	9.121	15.916
6/2/2005 16:45	9.048	14.396
6/2/2005 17:00	8.907	14.335
6/2/2005 17:15	8.779	13.211
6/2/2005 17:30	8.413	11.02
6/2/2005 17:45	7.784	11.032
6/2/2005 18:00	7.057	9.475
6/2/2005 18:15	6.117	8.144
6/2/2005 18:30	5.085	6.612
6/2/2005 18:45	2.491	4.939
6/2/2005 19:00	2.906	2.259
6/2/2005 19:15	0.598	0.055
6/2/2005 19:30	0.055	0.061
6/2/2005 19:45	0.067	0.055
6/2/2005 20:00	0.055	0.055

Time (U.S./Pacific)	**Conventional Current (Amps)**	**PVPC Current (Amps)**
6/3/2005 8:00	1.099	0.061
6/3/2005 8:15	1.825	0.488
6/3/2005 8:30	2.814	2.039
6/3/2005 8:45	3.797	3.669
6/3/2005 9:00	4.658	5.83
6/3/2005 9:15	5.562	7.32
6/3/2005 9:30	6.716	8.706
6/3/2005 9:45	7.54	9.951
6/3/2005 10:00	8.114	10.922
6/3/2005 10:15	8.559	12.375
6/3/2005 10:30	8.767	13.193
6/3/2005 10:45	8.999	14.353
6/3/2005 11:00	9.823	14.176
6/3/2005 11:15	10.672	15.788
6/3/2005 11:30	10.781	16.447
6/3/2005 11:45	10.867	16.331
6/3/2005 12:00	10.562	17.326
6/3/2005 12:15	10.684	17.778
6/3/2005 12:30	10.855	22.021
6/3/2005 12:45	10.8	22.656
6/3/2005 13:00	10.275	23.248
6/3/2005 13:15	9.707	21.056
6/3/2005 13:30	9.701	20.879
6/3/2005 13:45	9.426	20.806
6/3/2005 14:00	9.322	20.556
6/3/2005 14:15	9.341	20.012
6/3/2005 14:30	9.164	19.737
6/3/2005 14:45	9.09	19.377
6/3/2005 15:00	8.98	18.834
6/3/2005 15:15	8.883	18.407
6/3/2005 15:30	8.98	17.967
6/3/2005 15:45	8.694	17.204
6/3/2005 16:00	8.767	16.557
6/3/2005 16:15	8.968	16.239
6/3/2005 16:30	9.017	15.501
6/3/2005 16:45	8.742	14.518
6/3/2005 17:00	8.62	13.742
6/3/2005 17:15	8.181	12.65
6/3/2005 17:30	7.711	11.581
6/3/2005 17:45	7.198	10.403
6/3/2005 18:00	6.557	9.188
6/3/2005 18:15	5.916	8.089
6/3/2005 18:30	5.055	6.538
6/3/2005 18:45	2.833	4.976
6/3/2005 19:00	2.802	3.138
6/3/2005 19:15	0.519	0.055
6/3/2005 19:30	0.061	0.049
6/3/2005 19:45	0.061	0.049
6/3/2005 20:00	0.061	0.055

Time (U.S./Pacific)	Conventional Current (Amps)	PVPC Current (Amps)
6/4/2005 8:00	1.16	0.067
6/4/2005 8:15	1.923	0.635
6/4/2005 8:30	2.802	2.07
6/4/2005 8:45	3.773	3.712
6/4/2005 9:00	4.67	6.044
6/4/2005 9:15	5.525	7.418
6/4/2005 9:30	6.514	8.968
6/4/2005 9:45	7.277	10.354
6/4/2005 10:00	7.814	11.404
6/4/2005 10:15	8.187	12.711
6/4/2005 10:30	8.529	13.895
6/4/2005 10:45	8.608	14.676
6/4/2005 11:00	9.64	15.672
6/4/2005 11:15	10.33	16.288
6/4/2005 11:30	9.896	17.051
6/4/2005 11:45	9.658	17.589
6/4/2005 12:00	9.2	17.943
6/4/2005 12:15	9.176	18.4
6/4/2005 12:30	9.011	18.266
6/4/2005 12:45	8.901	19.109
6/4/2005 13:00	8.871	19.493
6/4/2005 13:15	9.353	19.725
6/4/2005 13:30	9.359	19.878
6/4/2005 13:45	9.316	19.976
6/4/2005 14:00	9.267	19.963
6/4/2005 14:15	8.663	19.31
6/4/2005 14:30	8.547	19.212
6/4/2005 14:45	8.327	18.81
6/4/2005 15:00	8.675	18.535
6/4/2005 15:15	8.584	18.297
6/4/2005 15:30	8.834	17.961
6/4/2005 15:45	9.115	17.418
6/4/2005 16:00	9.237	16.911
6/4/2005 16:15	9.432	16.178
6/4/2005 16:30	9.432	15.556
6/4/2005 16:45	9.286	14.365
6/4/2005 17:00	9.145	13.895
6/4/2005 17:15	8.828	12.808
6/4/2005 17:30	8.425	10.904
6/4/2005 17:45	7.943	10.598
6/4/2005 18:00	7.192	9.255
6/4/2005 18:15	6.325	7.882
6/4/2005 18:30	5.22	6.435
6/4/2005 18:45	3.419	4.805
6/4/2005 19:00	2.955	3.4
6/4/2005 19:15	1.032	0.147
6/4/2005 19:30	0.061	0.055
6/4/2005 19:45	0.061	0.055
6/4/2005 20:00	0.055	0.055

Time (U.S./Pacific)	Conventional Current (Amps)	PVPC Current (Amps)
6/5/2005 8:00	1.068	0.055
6/5/2005 8:15	1.886	0.861
6/5/2005 8:30	2.863	2.265
6/5/2005 8:45	3.858	3.858
6/5/2005 9:00	4.945	6.306
6/5/2005 9:15	5.867	7.875
6/5/2005 9:30	6.966	9.457
6/5/2005 9:45	7.814	11.032
6/5/2005 10:00	8.535	12.411
6/5/2005 10:15	8.895	13.608
6/5/2005 10:30	9.243	14.719
6/5/2005 10:45	9.621	15.733
6/5/2005 11:00	10.537	16.807
6/5/2005 11:15	11.471	17.381
6/5/2005 11:30	11.575	18.297
6/5/2005 11:45	11.789	18.639
6/5/2005 12:00	11.233	19.481
6/5/2005 12:15	11.325	19.328
6/5/2005 12:30	11.02	20.293
6/5/2005 12:45	10.946	20.531
6/5/2005 13:00	10.757	20.794
6/5/2005 13:15	10.696	20.904
6/5/2005 13:30	10.812	21.038
6/5/2005 13:45	10.922	21.16
6/5/2005 14:00	10.696	21.038
6/5/2005 14:15	10.348	20.745
6/5/2005 14:30	10.324	20.739
6/5/2005 14:45	10.177	20.067
6/5/2005 15:00	10.031	19.799
6/5/2005 15:15	9.89	19.267
6/5/2005 15:30	9.939	18.468
6/5/2005 15:45	9.896	17.839
6/5/2005 16:00	10.11	17.283
6/5/2005 16:15	10.134	16.441
6/5/2005 16:30	10.293	15.971
6/5/2005 16:45	10.171	15.201
6/5/2005 17:00	9.847	14.103
6/5/2005 17:15	9.487	13.114
6/5/2005 17:30	9.048	12.082
6/5/2005 17:45	8.407	10.952
6/5/2005 18:00	7.546	9.719
6/5/2005 18:15	6.484	7.937
6/5/2005 18:30	5.513	6.722
6/5/2005 18:45	3.974	5.092
6/5/2005 19:00	3.364	3.687
6/5/2005 19:15	1.355	0.379
6/5/2005 19:30	0.067	0.049
6/5/2005 19:45	0.073	0.055
6/5/2005 20:00	0.055	0.049

Time (U.S./Pacific)	Conventional Current (Amps)	PVPC Current (Amps)
6/6/2005 8:00	1.148	0.055
6/6/2005 8:15	2.448	1.343
6/6/2005 8:30	2.491	1.874
6/6/2005 8:45	3.883	4.176
6/6/2005 9:00	5.098	6.575
6/6/2005 9:15	4.878	6.264
6/6/2005 9:30	6.99	9.603
6/6/2005 9:45	7.863	10.928
6/6/2005 10:00	8.492	12.265
6/6/2005 10:15	9.176	13.767
6/6/2005 10:30	9.469	14.634
6/6/2005 10:45	9.982	15.94
6/6/2005 11:00	11.05	16.624
6/6/2005 11:15	12.283	17.186
6/6/2005 11:30	12.332	18.028
6/6/2005 11:45	11.783	18.126
6/6/2005 12:00	12.009	18.742
6/6/2005 12:15	12.234	18.932
6/6/2005 12:30	12.112	19.945
6/6/2005 12:45	11.911	19.988
6/6/2005 19:30	0.049	0.098
6/6/2005 19:45	0.067	0.088
6/6/2005 20:00	0.055	0.078

Time (U.S./Pacific)	Conventional Current (Amps)	PVPC Current (Amps)
6/7/2005 8:00	1.341	0.055
6/7/2005 8:15	2.374	0.317
6/7/2005 8:30	3.465	1.722
6/7/2005 8:45	4.637	3.425
6/7/2005 9:00	5.993	5.665
6/7/2005 9:15	7.136	7.631
6/7/2005 9:30	8.081	9.2
6/7/2005 9:45	9.48	10.446
6/7/2005 10:00	10.315	11.355
6/7/2005 10:15	10.791	13.114
6/7/2005 10:30	10.967	14.096
6/7/2005 10:45	9.621	14.042
6/7/2005 11:00	10.696	16.129
6/7/2005 11:15	11.49	16.6
6/7/2005 11:30	11.068	17.271
6/7/2005 11:45	10.91	17.68
6/7/2005 12:00	10.842	18.284
6/7/2005 12:15	10.659	18.608
6/7/2005 12:30	10.83	18.333
6/7/2005 12:45	10.531	19.194
6/7/2005 13:00	10.537	19.463
6/7/2005 13:15	10.507	19.438
6/7/2005 13:30	10.409	19.438
6/7/2005 13:45	10.69	18.602
6/7/2005 14:00	10.464	19.042
6/7/2005 14:15	10.543	19.035
6/7/2005 14:30	10.287	18.657
6/7/2005 14:45	10.348	18.339
6/7/2005 15:00	10.153	17.869
6/7/2005 15:15	10.208	17.344
6/7/2005 15:30	10.159	16.96
6/7/2005 15:45	10.391	16.465
6/7/2005 16:00	10.33	16.245
6/7/2005 16:15	10.055	15.311
6/7/2005 16:30	10	14.707
6/7/2005 16:45	9.75	12.998
6/7/2005 17:00	9.585	13.205
6/7/2005 17:15	9.121	12.253
6/7/2005 17:30	8.608	10.83
6/7/2005 17:45	8.126	10.098
6/7/2005 18:00	7.363	8.968
6/7/2005 18:15	6.85	8.327
6/7/2005 18:30	5.556	5.69
6/7/2005 18:45	5.006	5.543
6/7/2005 19:00	1.245	0.079
6/7/2005 19:15	0.806	0.049
6/7/2005 19:30	0.128	0.049
6/7/2005 19:45	0.061	0.067
6/7/2005 20:00	0.061	0.055

Time (U.S./Pacific)	Conventional Current (Amps)	PVPC Current (Amps)
6/8/2005 8:00	1.282	0.055
6/8/2005 8:15	1.123	0.061
6/8/2005 8:30	0.556	0.061
6/8/2005 8:45	0.775	0.061
6/8/2005 9:00	2.643	0.733
6/8/2005 9:15	2.845	1.184
6/8/2005 9:30	6.575	5.592
6/8/2005 9:45	3.755	2.253
6/8/2005 10:00	4.695	3.516
6/8/2005 10:15	5.543	4.042
6/8/2005 10:30	6.386	4.621
6/8/2005 10:45	8.437	7.534
6/8/2005 11:00	3.388	2.198
6/8/2005 11:15	5.617	4.567
6/8/2005 11:30	8.962	8.407
6/8/2005 11:45	5.91	4.829
6/8/2005 12:00	8.26	7.79
6/8/2005 12:15	8.254	7.668
6/8/2005 12:30	6.623	7.723
6/8/2005 12:45	6.769	8.291
6/8/2005 13:00	6.457	3.132
6/8/2005 13:15	6.862	9.225
6/8/2005 13:30	5.758	7.198
6/8/2005 13:45	4.371	4.921
6/8/2005 14:00	3.985	4.42
6/8/2005 14:15	5.919	6.569
6/8/2005 14:30	4.41	5.037
6/8/2005 14:45	3.355	3.712
6/8/2005 15:00	6.369	8.059
6/8/2005 15:15	6.466	8.132
6/8/2005 15:30	5.162	6.142
6/8/2005 15:45	2.769	3.04
6/8/2005 16:00	3.976	4.53
6/8/2005 16:15	2.188	2.234
6/8/2005 16:30	2.589	2.747
6/8/2005 16:45	2.72	2.955
6/8/2005 17:00	2.066	1.941
6/8/2005 17:15	1.68	1.508
6/8/2005 17:30	1.421	1.093
6/8/2005 17:45	0.962	0.427
6/8/2005 18:00	0.63	0.049
6/8/2005 18:15	1.949	1.722
6/8/2005 18:30	0.718	0.165
6/8/2005 18:45	0.952	0.275
6/8/2005 19:00	0.972	0.385
6/8/2005 19:15	0.596	0.049
6/8/2005 19:30	0.044	0.055
6/8/2005 19:45	0.044	0.055
6/8/2005 20:00	0.049	0.055

Apparent Power Observations

Time (U.S./Pacific)	Apparent Power (MPPT) (kVA)	Apparent Power (PVPC) (kVA)		Time (U.S./Pacific)	Apparent Power (MPPT) (kVA)	Apparent Power (PVPC) (kVA)
6/4/2005 0:00	0	0.1		6/4/2005 8:15	0	0.1
6/4/2005 0:15	0	0.1		6/4/2005 8:30	0	0.1
6/4/2005 0:30	0	0.096		6/4/2005 8:45	0	0.1
6/4/2005 0:45	0	0.096		6/4/2005 9:00	0	0.1
6/4/2005 1:00	0	0.096		6/4/2005 9:15	0	0.1
6/4/2005 1:15	0	0.096		6/4/2005 9:30	0.096	0.1
6/4/2005 1:30	0	0.1		6/4/2005 9:45	0.096	0.096
6/4/2005 1:45	0	0.096		6/4/2005 10:00	0.1	0.1
6/4/2005 2:00	0	0.096		6/4/2005 10:15	0.096	0.1
6/4/2005 2:15	0	0.1		6/4/2005 10:30	0.1	0.1
6/4/2005 2:30	0	0.1		6/4/2005 10:45	0.1	0.1
6/4/2005 2:45	0	0.096		6/4/2005 11:00	0.1	0.1
6/4/2005 3:00	0	0.1		6/4/2005 11:15	0.1	0.1
6/4/2005 3:15	0	0.1		6/4/2005 11:30	0.096	0.1
6/4/2005 3:30	0	0.096		6/4/2005 11:45	0.096	0.096
6/4/2005 3:45	0	0.096		6/4/2005 12:00	0.096	0.1
6/4/2005 4:00	0	0.096		6/4/2005 12:15	0.096	0.1
6/4/2005 4:15	0	0.096		6/4/2005 12:30	0.1	0.1
6/4/2005 4:30	0	0.1		6/4/2005 12:45	0.1	0.1
6/4/2005 4:45	0	0.1		6/4/2005 13:00	0.1	0.1
6/4/2005 5:00	0	0.1		6/4/2005 13:15	0.1	0.1
6/4/2005 5:15	0	0.1		6/4/2005 13:30	0.096	0.1
6/4/2005 5:30	0	0.1		6/4/2005 13:45	0.1	0.1
6/4/2005 5:45	0	0.1		6/4/2005 14:00	0.096	0.1
6/4/2005 6:00	0	0.1		6/4/2005 14:15	0.1	0.1
6/4/2005 6:15	0	0.1		6/4/2005 14:30	0.096	0.1
6/4/2005 6:30	0	0.1		6/4/2005 14:45	0.1	0.1
6/4/2005 6:45	0	0.1		6/4/2005 15:00	0.1	0.1
6/4/2005 7:00	0	0.1		6/4/2005 15:15	0.096	0.1
6/4/2005 7:15	0	0.1		6/4/2005 15:30	0.1	0.1
6/4/2005 7:30	0	0.1		6/4/2005 15:45	0.1	0.1
6/4/2005 7:45	0	0.1		6/4/2005 16:00	0.1	0.1
6/4/2005 8:00	0	0.1		6/4/2005 16:15	0.1	0.1

Time (U.S./Pacific)	Apparent Power (MPPT) (kVA)	Apparent Power (PVPC) (kVA)
6/4/2005 16:30	0.1	0.1
6/4/2005 16:45	0.096	0.1
6/4/2005 17:00	0.1	0.1
6/4/2005 17:15	0.1	0.1
6/4/2005 17:30	0.1	0.1
6/4/2005 17:45	0.1	0.1
6/4/2005 18:00	0.1	0.1
6/4/2005 18:15	0.096	0.1
6/4/2005 18:30	0.096	0.1
6/4/2005 18:45	0.1	0.1
6/4/2005 19:00	0.1	0.1
6/4/2005 19:15	0.1	0.1
6/4/2005 19:30	0.096	0.1
6/4/2005 19:45	0.1	0.1
6/4/2005 20:00	0.096	0.1
6/4/2005 20:15	0.1	0.1
6/4/2005 20:30	0.096	0.1
6/4/2005 20:45	0.1	0.1
6/4/2005 21:00	0.096	0.1
6/4/2005 21:15	0.096	0.1
6/4/2005 21:30	0.1	0.1
6/4/2005 21:45	0.1	0.1
6/4/2005 22:00	0.096	0.1
6/4/2005 22:15	0.096	0.1
6/4/2005 22:30	0.096	0.1
6/4/2005 22:45	0.096	0.1
6/4/2005 23:00	0.096	0.1
6/4/2005 23:15	0.1	0.1
6/4/2005 23:30	0.096	0.1
6/4/2005 23:45	0.096	0.1

Time (U.S./Pacific)	Apparent Power (MPPT) (kVA)	Apparent Power (PVPC) (kVA)	Time (U.S./Pacific)	Apparent Power (MPPT) (kVA)	Apparent Power (PVPC) (kVA)
6/5/2005 0:00	0	0.1	6/5/2005 8:15	0	0.1
6/5/2005 0:15	0	0.1	6/5/2005 8:30	0	0.1
6/5/2005 0:30	0	0.1	6/5/2005 8:45	0	0.1
6/5/2005 0:45	0	0.1	6/5/2005 9:00	0	0.1
6/5/2005 1:00	0	0.1	6/5/2005 9:15	0	0.1
6/5/2005 1:15	0	0.1	6/5/2005 9:30	0.1	0.1
6/5/2005 1:30	0	0.096	6/5/2005 9:45	0.1	0.1
6/5/2005 1:45	0	0.1	6/5/2005 10:00	0.1	0.1
6/5/2005 2:00	0	0.1	6/5/2005 10:15	0.1	0.1
6/5/2005 2:15	0	0.1	6/5/2005 10:30	0.1	0.1
6/5/2005 2:30	0	0.096	6/5/2005 10:45	0.096	0.1
6/5/2005 2:45	0	0.1	6/5/2005 11:00	0.096	0.1
6/5/2005 3:00	0	0.096	6/5/2005 11:15	0.096	0.1
6/5/2005 3:15	0	0.1	6/5/2005 11:30	0.096	0.1
6/5/2005 3:30	0	0.1	6/5/2005 11:45	0.096	0.096
6/5/2005 3:45	0	0.1	6/5/2005 12:00	0.1	0.096
6/5/2005 4:00	0	0.1	6/5/2005 12:15	0.1	0.1
6/5/2005 4:15	0	0.1	6/5/2005 12:30	0.096	0.1
6/5/2005 4:30	0	0.1	6/5/2005 12:45	0.1	0.1
6/5/2005 4:45	0	0.1	6/5/2005 13:00	0.1	0.1
6/5/2005 5:00	0	0.096	6/5/2005 13:15	0.1	0.1
6/5/2005 5:15	0	0.096	6/5/2005 13:30	0.1	0.1
6/5/2005 5:30	0	0.1	6/5/2005 13:45	0.096	0.1
6/5/2005 5:45	0	0.1	6/5/2005 14:00	0.1	0.1
6/5/2005 6:00	0	0.1	6/5/2005 14:15	0.1	0.1
6/5/2005 6:15	0	0.1	6/5/2005 14:30	0.1	0.1
6/5/2005 6:30	0	0.1	6/5/2005 14:45	0.1	0.1
6/5/2005 6:45	0	0.1	6/5/2005 15:00	0.096	0.1
6/5/2005 7:00	0	0.1	6/5/2005 15:15	0.096	0.1
6/5/2005 7:15	0	0.1	6/5/2005 15:30	0.1	0.1
6/5/2005 7:30	0	0.1	6/5/2005 15:45	0.1	0.1
6/5/2005 7:45	0	0.1	6/5/2005 16:00	0.1	0.1
6/5/2005 8:00	0	0.1	6/5/2005 16:15	0.1	0.1

Time (U.S./Pacific)	**Apparent Power (MPPT) (kVA)**	**Apparent Power (PVPC) (kVA)**
6/5/2005 16:30	0.1	0.1
6/5/2005 16:45	0.1	0.1
6/5/2005 17:00	0.1	0.1
6/5/2005 17:15	0.1	0.1
6/5/2005 17:30	0.1	0.1
6/5/2005 17:45	0.096	0.1
6/5/2005 18:00	0.1	0.1
6/5/2005 18:15	0.096	0.1
6/5/2005 18:30	0.1	0.1
6/5/2005 18:45	0.096	0.1
6/5/2005 19:00	0.1	0.1
6/5/2005 19:15	0.1	0.1
6/5/2005 19:30	0.096	0.096
6/5/2005 19:45	0.1	0.096
6/5/2005 20:00	0.096	0.1
6/5/2005 20:15	0.096	0.1
6/5/2005 20:30	0.096	0.1
6/5/2005 20:45	0.1	0.096
6/5/2005 21:00	0.096	0.096
6/5/2005 21:15	0.096	0.096
6/5/2005 21:30	0.096	0.096
6/5/2005 21:45	0.096	0.096
6/5/2005 22:00	0.096	0.1
6/5/2005 22:15	0.1	0.1
6/5/2005 22:30	0.1	0.1
6/5/2005 22:45	0.096	0.1
6/5/2005 23:00	0.096	0.1
6/5/2005 23:15	0.1	0.1
6/5/2005 23:30	0.096	0.1
6/5/2005 23:45	0.1	0.096

Time (U.S./Pacific)	Apparent Power (MPPT) (kVA)	Apparent Power (PVPC) (kVA)
6/6/2005 0:00	0.1	0.1
6/6/2005 0:15	0.096	0.1
6/6/2005 0:30	0.096	0.1
6/6/2005 0:45	0.096	0.1
6/6/2005 1:00	0.096	0.1
6/6/2005 1:15	0	0.1
6/6/2005 1:30	0	0.096
6/6/2005 1:45	0	0.1
6/6/2005 2:00	0	0.1
6/6/2005 2:15	0	0.1
6/6/2005 2:30	0	0.1
6/6/2005 2:45	0	0.096
6/6/2005 3:00	0	0.1
6/6/2005 3:15	0	0.1
6/6/2005 3:30	0	0.1
6/6/2005 3:45	0	0.1
6/6/2005 4:00	0	0.1
6/6/2005 4:15	0	0.1
6/6/2005 4:30	0	0.096
6/6/2005 4:45	0	0.1
6/6/2005 5:00	0	0.096
6/6/2005 5:15	0	0.1
6/6/2005 5:30	0	0.1
6/6/2005 5:45	0	0.1
6/6/2005 6:00	0	0.1
6/6/2005 6:15	0	0.1
6/6/2005 6:30	0	0.096
6/6/2005 6:45	0	0.096
6/6/2005 7:00	0	0.096
6/6/2005 7:15	0	0.1
6/6/2005 7:30	0	0.1
6/6/2005 7:45	0	0.1
6/6/2005 8:00	0	0.1
6/6/2005 8:15	0	0.1
6/6/2005 8:30	0	0.1
6/6/2005 8:45	0	0.1
6/6/2005 9:00	0	0.1
6/6/2005 9:15	0	0.1
6/6/2005 9:30	0.096	0.096
6/6/2005 9:45	0.1	0.1
6/6/2005 10:00	0.096	0.1
6/6/2005 10:15	0.1	0.1
6/6/2005 10:30	0.096	0.1
6/6/2005 10:45	0.096	0.1
6/6/2005 11:00	0.1	0.1
6/6/2005 11:15	0.096	0.1
6/6/2005 11:30	0.096	0.1
6/6/2005 11:45	0.096	0.1
6/6/2005 12:00	0.1	0.1
6/6/2005 12:15	0.096	0.1
6/6/2005 12:30	0.096	0.096
6/6/2005 12:45	0.1	0.1
6/6/2005 13:00	0.1	0.1
6/6/2005 13:15	0.096	0.096
6/6/2005 13:30	0.096	0.1
6/6/2005 13:45	0.096	0.1
6/6/2005 14:00	0.096	0.1
6/6/2005 14:15	0.1	0.1
6/6/2005 14:30	0.1	0.1
6/6/2005 14:45	0.1	0.1
6/6/2005 15:00	0.096	0.1
6/6/2005 15:15	0.096	0.1
6/6/2005 15:30	0.096	0.1
6/6/2005 15:45	0.1	0.1
6/6/2005 16:00	0.1	0.1
6/6/2005 16:15	0.096	0.1

Time (U.S./Pacific)	Apparent Power (MPPT) (kVA)	Apparent Power (PVPC) (kVA)
6/6/2005 16:30	0.1	0.1
6/6/2005 16:45	0.096	0.1
6/6/2005 17:00	0.096	0.1
6/6/2005 17:15	0.1	0.1
6/6/2005 17:30	0.096	0.096
6/6/2005 17:45	0.1	0.096
6/6/2005 18:00	0.1	0.096
6/6/2005 18:15	0.1	0.096
6/6/2005 18:30	0.1	0.096
6/6/2005 18:45	0.096	0.096
6/6/2005 19:00	0.096	0.096
6/6/2005 19:15	0.096	0.092
6/6/2005 19:30	0.096	0.096
6/6/2005 19:45	0.096	0.096
6/6/2005 20:00	0.096	0.096
6/6/2005 20:15	0.096	0.096
6/6/2005 20:30	0.096	0.096
6/6/2005 20:45	0.096	0.096
6/6/2005 21:00	0.096	0.096
6/6/2005 21:15	0.096	0.096
6/6/2005 21:30	0.096	0.096
6/6/2005 21:45	0	0.096
6/6/2005 22:00	0	0
6/6/2005 22:15	0	0.096
6/6/2005 22:30	0	0.096
6/6/2005 22:45	0	0.1
6/6/2005 23:00	0	0.1
6/6/2005 23:15	0	0.096
6/6/2005 23:30	0	0.1
6/6/2005 23:45	0	0.1

Time (U.S./Pacific)	Apparent Power (MPPT) (kVA)	Apparent Power (PVPC) (kVA)
6/7/2005 0:00	0	0.1
6/7/2005 0:15	0	0.1
6/7/2005 0:30	0	0.1
6/7/2005 0:45	0	0.096
6/7/2005 1:00	0	0.096
6/7/2005 1:15	0	0.1
6/7/2005 1:30	0	0.1
6/7/2005 1:45	0	0.1
6/7/2005 2:00	0	0.1
6/7/2005 2:15	0	0.096
6/7/2005 2:30	0	0.096
6/7/2005 2:45	0	0.096
6/7/2005 3:00	0	0.096
6/7/2005 3:15	0	0.096
6/7/2005 3:30	0	0.096
6/7/2005 3:45	0	0.1
6/7/2005 4:00	0	0.1
6/7/2005 4:15	0	0.1
6/7/2005 4:30	0	0.1
6/7/2005 4:45	0	0.096
6/7/2005 5:00	0	0.1
6/7/2005 5:15	0	0.1
6/7/2005 5:30	0	0.096
6/7/2005 5:45	0	0.1
6/7/2005 6:00	0	0.1
6/7/2005 6:15	0	0.096
6/7/2005 6:30	0	0.1
6/7/2005 6:45	0	0.096
6/7/2005 7:00	0	0
6/7/2005 7:15	0	0
6/7/2005 7:30	0	0
6/7/2005 7:45	0	0
6/7/2005 8:00	0	0
6/7/2005 8:15	0	0
6/7/2005 8:30	0	0
6/7/2005 8:45	0	0
6/7/2005 9:00	0	0
6/7/2005 9:15	0	0.1
6/7/2005 9:30	0	0.1
6/7/2005 9:45	0.1	0.1
6/7/2005 10:00	0.1	0.1
6/7/2005 10:15	0.096	0.1
6/7/2005 10:30	0.1	0.1
6/7/2005 10:45	0.1	0.1
6/7/2005 11:00	0.1	0.1
6/7/2005 11:15	0.1	0.1
6/7/2005 11:30	0.1	0.1
6/7/2005 11:45	0.096	0.1
6/7/2005 12:00	0.1	0.1
6/7/2005 12:15	0.1	0.1
6/7/2005 12:30	0.1	0.1
6/7/2005 12:45	0.096	0.1
6/7/2005 13:00	0.1	0.1
6/7/2005 13:15	0.1	0.1
6/7/2005 13:30	0.1	0.1
6/7/2005 13:45	0.096	0.1
6/7/2005 14:00	0.1	0.1
6/7/2005 14:15	0.1	0.1
6/7/2005 14:30	0.1	0.1
6/7/2005 14:45	0.1	0.1
6/7/2005 15:00	0.1	0.1
6/7/2005 15:15	0.1	0.1
6/7/2005 15:30	0.096	0.1
6/7/2005 15:45	0.1	0.1
6/7/2005 16:00	0.1	0.1
6/7/2005 16:15	0.1	0.1

Time (U.S./Pacific)	**Apparent Power (MPPT) (kVA)**	**Apparent Power (PVPC) (kVA)**
6/7/2005 16:30	0.1	0.1
6/7/2005 16:45	0.1	0.1
6/7/2005 17:00	0.1	0.1
6/7/2005 17:15	0.1	0.1
6/7/2005 17:30	0.1	0.1
6/7/2005 17:45	0.1	0.1
6/7/2005 18:00	0.1	0.1
6/7/2005 18:15	0.1	0.1
6/7/2005 18:30	0.096	0.1
6/7/2005 18:45	0.096	0.1
6/7/2005 19:00	0.1	0.1
6/7/2005 19:15	0.096	0.1
6/7/2005 19:30	0.096	0.096
6/7/2005 19:45	0.096	0.1
6/7/2005 20:00	0.096	0.1
6/7/2005 20:15	0.096	0.1
6/7/2005 20:30	0.096	0.1
6/7/2005 20:45	0.096	0.1
6/7/2005 21:00	0.1	0.1
6/7/2005 21:15	0.1	0.1
6/7/2005 21:30	0.1	0.1
6/7/2005 21:45	0.1	0.1
6/7/2005 22:00	0.1	0.1
6/7/2005 22:15	0.1	0.1
6/7/2005 22:30	0.096	0.1
6/7/2005 22:45	0.096	0.1
6/7/2005 23:00	0.096	0.1
6/7/2005 23:15	0	0.096
6/7/2005 23:30	0	0.1
6/7/2005 23:45	0	0.1

Time (U.S./Pacific)	Apparent Power (MPPT) (kVA)	Apparent Power (PVPC) (kVA)
6/8/2005 0:00	0.096	0.1
6/8/2005 0:15	0	0.096
6/8/2005 0:30	0	0.1
6/8/2005 0:45	0	0.1
6/8/2005 1:00	0	0.096
6/8/2005 1:15	0	0.1
6/8/2005 1:30	0	0.1
6/8/2005 1:45	0	0.1
6/8/2005 2:00	0	0.1
6/8/2005 2:15	0	0.096
6/8/2005 2:30	0	0.096
6/8/2005 2:45	0	0.096
6/8/2005 3:00	0	0.096
6/8/2005 3:15	0	0.1
6/8/2005 3:30	0	0.096
6/8/2005 3:45	0	0.1
6/8/2005 4:00	0	0.096
6/8/2005 4:15	0	0.096
6/8/2005 4:30	0	0.1
6/8/2005 4:45	0	0.1
6/8/2005 5:00	0	0.1
6/8/2005 5:15	0	0.096
6/8/2005 5:30	0	0.096
6/8/2005 5:45	0	0.096
6/8/2005 6:00	0	0.096
6/8/2005 6:15	0	0.1
6/8/2005 6:30	0	0.1
6/8/2005 6:45	0	0.1
6/8/2005 7:00	0	0.096
6/8/2005 7:15	0	0.1
6/8/2005 7:30	0	0.1
6/8/2005 7:45	0	0.1
6/8/2005 8:00	0	0.096
6/8/2005 8:15	0	0.096
6/8/2005 8:30	0	0.1
6/8/2005 8:45	0	0
6/8/2005 9:00	0	0
6/8/2005 9:15	0	0
6/8/2005 9:30	0	0
6/8/2005 9:45	0	0
6/8/2005 10:00	0	0
6/8/2005 10:15	0.096	0
6/8/2005 10:30	0.096	0
6/8/2005 10:45	0.096	0.1
6/8/2005 11:00	0.096	0.096
6/8/2005 11:15	0.096	0.096
6/8/2005 11:30	0.1	0.1
6/8/2005 11:45	0.096	0.096
6/8/2005 12:00	0.096	0.096
6/8/2005 12:15	0.1	0.1
6/8/2005 12:30	0.096	0.1
6/8/2005 12:45	0.096	0.096
6/8/2005 13:00	0.096	0.096
6/8/2005 13:15	0.1	0.1
6/8/2005 13:30	0.1	0.096
6/8/2005 13:45	0.1	0.096
6/8/2005 14:00	0.1	0.096
6/8/2005 14:15	0.096	0.096
6/8/2005 14:30	0.096	0.1
6/8/2005 14:45	0.1	0.096
6/8/2005 15:00	0.1	0.1
6/8/2005 15:15	0.1	0.1
6/8/2005 15:30	0.096	0.1
6/8/2005 15:45	0.1	0.1
6/8/2005 16:00	0.096	0.096
6/8/2005 16:15	0.096	0.096

Time (U.S./Pacific)	Apparent Power (MPPT) (kVA)	Apparent Power (PVPC) (kVA)
6/8/2005 16:30	0.096	0.1
6/8/2005 16:45	0.096	0.1
6/8/2005 17:00	0.1	0.1
6/8/2005 17:15	0.096	0.1
6/8/2005 17:30	0.096	0.096
6/8/2005 17:45	0.096	0.1
6/8/2005 18:00	0.096	0.096
6/8/2005 18:15	0.096	0.1
6/8/2005 18:30	0.1	0.1
6/8/2005 18:45	0.1	0.1
6/8/2005 19:00	0.096	0.1
6/8/2005 19:15	0.1	0.1
6/8/2005 19:30	0.096	0
6/8/2005 19:45	0	0
6/8/2005 20:00	0	0
6/8/2005 20:15	0	0
6/8/2005 20:30	0	0
6/8/2005 20:45	0	0
6/8/2005 21:00	0	0
6/8/2005 21:15	0	0
6/8/2005 21:30	0	0
6/8/2005 21:45	0	0
6/8/2005 22:00	0	0
6/8/2005 22:15	0	0
6/8/2005 22:30	0	0
6/8/2005 22:45	0	0
6/8/2005 23:00	0	0
6/8/2005 23:15	0	0.096
6/8/2005 23:30	0	0.1
6/8/2005 23:45	0	0.096

LIST OF REFERENCES

Aitken, Donald W. Ph.D., Warren Schirtzinger, and Steven Strong. 2000. *SMUD PV PROGRAM REVIEW*. i-143, www.donaldaitkenassociates.com/smudpvprogram (accessed April 17, 2005).

Al-Hasan, A. Y, Ghoneim, A. A, Abdullah, and A. H. 2004. Optimizing electrical load pattern in Kuwait using grid connected photovoltaic systems. Energy Conversion and Management [H. W. Wilson - AST] 45, (4) (Mar): 483. (accessed April 17, 2005).

Ansley, Steven R. and Phillips, Lewis H., "The Photovoltaic Power Converter: A Technology Readiness Assessment" (MBA Professional Report, Naval Postgraduate School, 2005), Chapters 3-4.

Arif, H. E., and Onder, O. Z. Turkeys renewable energy sources: Part 1. historical development. Energy Sources 26, (10) (August): 961-969 (accessed March 15, 2005).

Basu, Moni. 2003. Iraqi's tune in satellite TV; With Saddam gone, sales of dishes soar. The Atlanta Journal-Constitution, May 27, sec. News; 14A. (accessed April 12, 2005).

Bennington, G. E., and K. K. Rebibo. 1976. SPURR\—system for projecting utilization of renewable resources. Paper presented at WSC '76: Proceedings of the 76 Bicentennial conference on Winter simulation, Gaithersburg, MD (accessed April 25, 2005).

Bull, Stanley R., and Lynn Billman. 1999. Renewable energy: Ready to meet its promise? The Washington Quarterly 23, (1): 229-244, http://muse.jhu.edu/journals/washington_quarterly/v023/23.1bull.html (accessed April 25, 2005).

Butalla, Laura. 2004. The hottest trends in smart labels & packaging. Converting Magazine, 22, (6) (Jun): 46 (accessed March 17, 2005).

Carless, Jennifer. 1993. Renewable energy : A concise guide to green alternatives. New York: Walker. (accessed April 17, 2005).

Chow, T. T., A. L. S. Chan, K. F. Fong, W. C. Lo, and C. L. Song. 2005. Energy performance of a solar hybrid collector system in a multistory apartment building. Proceedings of the I MECH E Part A. Journal of Power and Energy, 219, (1) (January): 1-11 (accessed April 25, 2005).

CIA World Factbook. 2005. Iraq country study. Central Intelligence Agency. http://www.cia.gov/cia/publications/factbook/geos/iz.html (accessed April 1, 2005).

Constable, Pamela. 2004. In Iraqi homes, a constant battle just to stay cool; Energy rationing prompts rudimentary alternatives. The Washington Post, July 28, sec. A; A01. (accessed April 12, 2005).

Cosgrove-Davies, Mac, and Anil Cabraal. 1994. Best practices for PV solar home system projects. Paper presented at Proceedings of the 24th IEEE Photovoltaic Specialists Conference. Part 2 (of 2), Dec 5-9 1994, http://dx.doi.org/10.1109/WCPEC.1994.521697 (accessed April 26, 2005).

Dornheim, Michael A. 2003. Get me through the night batteries are now challenging fuel cells to assist long-endurance solar-powered aircraft. Aviation Week & Space Technology 159, (11) (Sep 15): 66 (accessed March 15, 2005).

Ehnberg, S. G. J., and M. H. J. Bollen. 2005. Reliability of a small power system using solar power and hydro. Electric Power Systems Research, 74, (1) (APR): 119-127 (accessed April 27, 2005).

Electrical & Computer Engineering Department (ECE). 2005. Solar performance in various weather conditions. http://www.ece.umr.edu/links/power/Energy_(accessed April 18, 2005).

Glanz, James. 2005. Insurgents wage precise attacks on Baghdad fuel. The New York Times, February 21, sec. A; column 1. (accessed April 13, 2005).

Gross, M. 2005. Harvesting solar energy at the right dose. Chemistry World, 2, (3) (MAR): 14-14 (accessed April 27, 2005).

Hawkins, Steven R. and Gordon Wells. 2005. U.S. military engineers in Iraq. Army, February.

House of Representatives, Committee on Energy and Commerce. RFID technology: What the future holds for commerce, security, and the consumer, serial no. 108-108, July 14, 2004, 108-2 hearing, (accessed April 26, 2005).

Hupping, Carol. 1974. Producing your own power; how to make nature's energy sources work for you. An organic gardening and farming book. Emmaus: PA, Rodale Press, Book Division (accessed April 25, 2005).

Information Technology; Medical Center Adopts Scannable Identification Chip for Emergency Department. 2005. Medical Devices & Surgical Technology Week (Apr 17): 279 (accessed March 17, 2005).

International Energy Agency. 2004. TRENDS IN PHOTOVOLTAIC APPLICATIONS survey report of selected IEA countries between 1992 and 2003. IEA-PVPS T1-13:2004, http://www.oja-services.nl/iea-pvps/isr/index.htm (accessed 25 April 2005).

International Energy Agency. 2003. 16 case studies on the deployment of photovoltaic technologies in developing countries. IEA-PVPS T9-07:2003, http://www.oja-\services.nl/iea-pvps/topics/i_dc.htm (accessed 25 April 2005).

Junne, Gerd, and Willemijn Verkoren. 2005. Postconflict Development; Meeting New Challenges. Boulder: Lynne Rienner.

Ketjoy, Nipon, Wattanapong Rakwichian, Chatchai Sirisumpunwong, Apichot Sansom, Prapita Thanarak, Aekkalak Rojanaporn, and Loh Heng Chew. 2003. Study of mini-grid concept for unelectrified village in Thailand. Paper presented at Proceeding of the 2003 Energy and Environment, Oct 11-14 2003, (accessed April 26, 2005).

Kilmer, L.C. 1995. Design of a more accurate, higher fidelity, dual-source air mass zero solar simulator. TR-94(4524)-1, http://handle.dtic.mil/100.2/ADA291364 (accessed April 26, 2005).

Kocian, Thomas C. 1981. Solar power stations for remote sites: An economic analysis. (accessed April 16, 2005).

Li, Dexin, and Pai H. Chou. 2004. Maximizing efficiency of solar-powered systems by load matching. Paper presented at ISLPED '04: Proceedings of the 2004 international symposium on Low power electronics and design, Newport Beach, California, USA, http://doi.acm.org/10.1145/1013235.1013280 (accessed April 25, 2005).

Lof, George O. G. 1973. Solar energy: An infinite source of clean energy. The Annals of the American Academy of Political and Social Science, 410, (The Energy Crisis: Reality or Myth) (Nov.): 52-64, http://links.jstor.org/sici?sici=0002-7162%28197311%29410%3C52%3ASEAISO%3E2.0.CO%3B2-Y (accessed April 25, 2005).

Mahmoud, Marwan M., and Imad H. Ibrik. 2003. Field experience on solar electric power systems and their potential in Palestine. Renewable and Sustainable Energy Reviews, 7, (6): 531-543, http://dx.doi.org/10.1016/S1364-0321(03)00070-4 (accessed April 26, 2005).

Marcel, Suri, Huld Thomas, and Dunlop Ewan. 2005. PV-GIS: A web-based solar radiation database for the calculation of PV potential in Europe. International Journal of Solar Energy, 24, (2) (June): 55-67 (accessed March 15, 2005).

Michaels, Jim and Donna Leinwand. 2003. Chaos doesn’t drown out sounds of recovery. USA Today, August 28, sec. News; 4A. (accessed April 12, 2005).

Miller, T. Christian. 2005. The conflict in Iraq, millions said going to waste in Iraq utilities. Los Angeles Times, April 10, sec. A1. (accessed April 25, 2005).

Miller, T. Christian. 2005. Violence trumps rebuilding in Iraq. Los Angeles Times, February 21, sec. A1. (accessed April 6, 2005).

Mustafa, Balat. 2004. The use of renewable energy sources for energy in Turkey and potential trends. Energy Exploration & Exploitation, 22, (4) (August): 241-257 (accessed March 15, 2005).

Nailen, Richard L. 2004. Electricity from the sun: Where do we stand? Electrical Apparatus, 57, (8) (Aug): 21 (accessed March 15, 2005).

Nieuwenhout, F. D. J., A. Van Dijk, P. E. Lasschuit, G. Van Roekel, V. A. P. Van Dijk, D. Hirsch, H. Arriaza, M. Hankins, B. D. Sharma, and H. Wade. 2001. Experience with solar home systems in developing countries: A review. Progress in Photovoltaics: Research and Applications 9, (6): 455-474, http://dx.doi.org/10.1002/pip.392. (accessed April 17, 2005).

Nyrop, Richard F. 1979. Iraq; a Country Study. Washington D.C.: American University. Ross, Michael, Charles Hanley, John Strachan, Miguel Angel Plata, Francisco Xochipa, Lilia Ojinaga, Christopher Rovero, Gabriela Cisneros Cisneros, and Robert Foster. Applying solar energy to extend distance education to remote communities in Mexico and Central America. Paper presented at American Solar Energy Society Annual Conference, http://www.sandia.gov/pv/docs/PDF/Ross%20ASES.pdf (accessed April 25, 2005).

Sartawi, M. 1986. ON THE DEVELOPMENT OF PHOTOVOLTAICS IN KUWAIT. Paper presented at Solar Energy Prospect in the Arab World, Second Arab International Solar Energy Conference. (accessed April 26, 2005).

Solar4power. 2005. World Solar Map. http://www.solar4power.com/map13-global-solar-power.html (accessed March 30, 2005).

Tanner, Carey. 2003. Capturing the sun's energy. Imagine 6, (3): 12-13, http://muse.jhu.edu/journals/imagine/v006/6.3imagine.pdf (accessed 25 April 2005).

Tuite, Don. 2004. Bright outlook for solar power cogeneration. Electronic Design, 52, (28) (Dec 16): 44 (accessed April 17, 2005).

United Nations/World Bank. 2003. United Nations/World Bank Joint Iraq Needs Assessment, http://lnweb18.worldbank.org (accessed 25 April 2005).

United States Agency for International Development. 2004. Restoring power, USAID's role in restoring electricity to Iraq, http://www.usaid.gov/iraq/accomplishments/electricity.html (accessed April 25, 2005).

United States General Accounting Office. June 2004. Rebuilding Iraq: Resource, security, governance, essential services, GAO-04-902R, http://www.gao.gov (accessed April 25, 2005).

Zhiqiang, Y. 2005. Development of solar thermal systems in China. Solar Energy Materials and Solar Cells, 86, (3) (MAR 31): 427-442 (accessed April 27, 2005).

THIS PAGE INTENTIONALLY LEFT BLANK

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, VA

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, CA

3. Atira Technologies
   Los Gatos, CA