Final Report

Solar Energy Site Assessment (Phase 1)

Prepared for:

The Tucson Water Department and Arizona Electric Power Cooperative, Inc.

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Solar Energy Site Assessment (Phase 1)

1 Executive Summary and Recommendations

1. The City of Tucson Water Department and Arizona Electric Power Cooperative, Inc. (AEPCO) funded CH2M HILL to carry out a preliminary solar site assessment of a plot of land at the Central Avra Valley Storage and Recovery Project (CAVSARP) west of Tucson. The preliminary assessment has been completed and the results indicate that the 140-acre and 560-acre plots are ideal for siting a solar electric power plant.

2. The site is readily accessible to electric transmission and distribution lines, natural gas lines, and water in a proximity that would provide the necessary infrastructure for a solar electric plant.

3. The site is exposed to well above average solar radiation levels. Based on modeling and 30-year measured data, the average sunlight is over 7.1 sun-hours per day of direct normal insolation (DNI). Sites with DNI above 6.75 sun-hours are considered good candidates for concentrating solar power plants.

4. A large concentrating solar plant (CSP) using parabolic troughs could be installed at the site. A 25-megawatt (MW) plant would fit on the 140-acre plot and a 100-MW plant could be placed on the full 560-acre area.

5. A preliminary assessment of the capacity of the local electric utilities lines indicates that the existing transmission and distribution lines could accommodate 25 to 100 MW of solar electricity assuming normal operation. A detailed electric load flow analysis and interconnect study would be required to verify the calculations and finalize a solar plant design.

6. A 25-MW plant would provide most of the renewable energy credits (RECs) required by the retail electric cooperatives through 2012 to meet the Arizona Renewable Energy Standard (RES) mandate.

7. The CAVSARP pumps at the site are about 4 to 5 MW of peak electrical load. The pumps are individually metered at the present time and the existing average electricity prices are about 8.8 cents/kWh through the IS2 rate provided by Trico Electric Cooperative.

8. Trico will be reconfiguring the electric service to the CAVSARP pumps and will offer a new rate tariff to Tucson Water. The majority of the large three-phase pumps will be placed on a single meter and the new rate tariff could result in dropping the average price to about 7 cents/kWh.

9. Tucson Water already appears to be carrying out effective demand side management measures by turning off pumps during the peak times and during the Trico interruptible periods. Further study will be required to make sure that the new rate tariff does not significantly increase peak period charges to Tucson Water.

10. The 140-acre site could accommodate up to 28 MW of flat-plate photovoltaics (PV). If built, it would be the largest PV plant in the United States.
11. Photovoltaics are modular and provide installation flexibility. It may be more practical for Tucson Water and the electric cooperatives to partner in installing a 4 to 5 MW PV plant to match the better pumping loads at the site. A PV plant would be considered a distributed generator by the Arizona RES program and therefore would provide distributed generation RECs.
12. It may be difficult to install a PV or CSP plant to compete with 7-cents/kWh electricity purchased by Tucson Water from Trico. However, the costs and benefits might be shared through a contractual arrangement between the electric cooperatives and Tucson Water to jointly purchase the solar electricity and RECs.
13. Tucson Water and the electric cooperatives are ineligible to take advantage of the highly attractive state and local incentives. It is not recommended that Tucson or the cooperatives directly finance and own a solar electric plant. Rather, they should consider leasing the site to a solar developer that would sell them the solar electricity and renewable energy credits through a long-term power purchase agreement.
14. Through a contractual arrangement, Tucson Water could lease the land to the developers for a nominal fee. Tucson Water could purchase the electricity from the solar plant at a fixed price over a 25- to 30-year period at close to or above the proposed new rate of 7 cents/kWh. The cooperatives could make up the difference by purchasing some of the electricity and the RECs for their Arizona mandate.
15. The most achievable short-term objective would be to install a 4 to 5 MW PV plant on the site. The 30 percent federal tax credit may be eliminated by the end of 2008 unless the U.S. Congress passes an extension.
16. Several solar developers have been identified by CH2M HILL that can provide competitive bids for the solar electric plants. CH2M HILL has received informal bids that indicate competitive pricing.

1.1 Recommendations

1. The Tucson Water Department, AEPCO, and Trico should consider entering into a contractual agreement to take the next steps toward building a 4 to 5 MW solar PV plant on the 140-acre CAVSARP site. A preliminary design and a bid package could be developed and bids could be accepted from PV solar developers by January or February of 2008. Developers would bid to provide a 20 to 25 year power-purchase agreement for solar electricity and the renewable energy credits. If developer bids are reasonable, Tucson Water could lease the land and purchase some or all of the electricity from the plant. The electric cooperatives could also purchase some or all of the distributed generation RECs to help meet their Arizona RES mandate.
2. The Tucson Water Department, Trico, and AEPCO should work together to allow the PV plant to be installed on the customer side of the new meter that Trico will install for the CAVSARP pumps. The cooperatives would benefit from the low-priced, distributed energy RECs and the peak-shaving value of the PV plant.

3. In parallel or separately, a contractual arrangement could be formed to consider developing a preliminary design and bid package for a 25 or 100 MW CSP plant. Prices could be as low as or lower than 13 to 14 cents/kWh. However, this option should only be considered if the U.S. Congress extends the 30 percent tax credit.

2 Background and Project Purpose

The Tucson Water Department and AEPCO engaged the services of CH2M HILL to conduct a preliminary solar screening analysis and assess the potential for a solar plant. The analysis was performed on a 140-acre plot of land at the CAVSARP site owned by the Tucson Water Department, which is interested in using the site for a CSP or PV power plant that could supply electricity and environmental attributes to benefit the city and the retail cooperative electric utilities serviced by AEPCO—namely Trico electric. The general tasks for Phase 1 are summarized as follows:

- Evaluate and assess available concentrating solar plant and flat-plate PV technologies that could be installed on the site.
- Identify potential funding sources, incentives, and partnering arrangements that would optimize the project's economic, environmental and social benefits.
- Carry out a preliminary site assessment focusing on the available solar resource, land topography, and access to transmission and water.
- Based on various partnering arrangements, conduct a preliminary economic analysis for a concentrating solar plant and for a PV plant that would fit on the site.

For this phase, CH2M HILL only evaluated commercially viable CSP technologies (not experimental or speculative technologies) and PV systems suitable for the site.

The Tucson Water Department is part of the City of Tucson. It is responsible for supplying potable water to the city and owns the land at the designated site. AEPCO partially funded the study and is interested in the use of the electricity and renewable energy credits that could be generated by a solar plant at the site. AEPCO is a generation and transmission cooperative serving Arizona customers since 1961. In 1999, the company decided to restructure. AEPCO remained the generation cooperative; Southwest Transmission Cooperative, Inc. became the transmission cooperative, and Sierra Southwest Cooperative Services, Inc. became the energy services and human resources cooperative. Trico Electric Cooperative is a part-owner of all three generation or transmission cooperatives and is the local electric provider that serves the pumping loads at the CAVSARP site. Trico is also part of the team to evaluate solar options for the site.

AEPCO provides wholesale electric service to five major retail electric cooperatives in Arizona and has decided to act on their behalf to obtain RECs to meet the Arizona RES, a mandate established in 2006 requiring utilities to generate 15 percent of their electricity from renewable energy by 2025. The RECs from a solar plant at the Tucson Water site could be available to Trico and the other electric cooperatives through AEPCO.

2.1 Kickoff Meeting and Infrastructure Assessment

The goal of this initial meeting was to charter the team, establish a clear and mutually agreed-upon scope of work, finalize the study schedule, and collect pertinent background information on the site for the solar plant, collect electric utility data, and identify potential financial partners for the project. The primary goal of project chartering was to align all the members of the project team—CH2M HILL, Tucson Water Department , Trico and AEPCO staff—to a common vision for the project and to develop a list of goals which, when met or exceeded, will define project success. A second purpose of this meeting was to visit the 140-acre site identified for the solar plant. The trip entailed observing the topography and identifying transmission and distribution lines for possible interconnection of the solar plant to the grid. The visit also served as an opportunity to obtain existing site maps, owner boundaries, and other documents relevant to the study. CH2M HILL's project manager, Alan Forrest, and senior solar expert, John Hoffner, attended the kick-off meeting held at Tucson Water's offices. The 1-day meeting took place on October 9 2007and was attended by staff from the Tucson Water Department, AEPCO, Trico, and the City of Tucson. John Hoffner also was able to visit the Saguaro Solar site, a 1-MW CSP plant owned by Arizona Public Service (APS). Notes and slides from the kick-off meeting are shown in Appendix 1 and notes from the Saguaro Solar site visit are in Appendix 4.

3 Preliminary Solar Site Assessment

A preliminary site assessment has been carried out by CH2M HILL to evaluate the available direct solar radiation, water supply, electric transmission, and distribution lines accessible for interconnecting the plant to the grid, as well as general topographic (including comments on flood water) suitability for a solar plant. Electric metering issues were also examined. For the analysis CH2M HILL relied on existing publicly available solar radiation data or maps provided by the National Renewable Energy Laboratory (NREL), Sandia, the National Oceanic and Atmospheric Association (NOAA) and other public agencies. Geographic information system (GIS) maps of the site were developed by CH2M HILL using input data from the Tucson Water Department, AEPCO, Trico, and Southwest Gas Corporation (SW Gas). The general goal of the analysis is to provide a preliminary assessment of the size of plant, in MW, that would fit on the land and how and where it might be interconnected with the utility grid.

3.1 Description and Assessment of Solar Site

The Tucson Water Department has chosen an ideal site for a solar plant at the CAVSARP facility. The land is relatively flat with low level vegetation, has above average solar radiation characteristics, and is adjacent to electric utility lines, gas lines, roadways and water—all key elements for a solar power plant. The site was originally used for farming before being purchased by the City of Tucson and is relatively flat, making it highly suited for a CSP or PV plant. Low-level brush has populated the land over time.

FIGURE 1
Photograph of the 140-acre site, looking east.

FIGURE 2
Photograph of access road near site, indicating local electric distribution and transmission lines.

3.1.1 Preliminary Assessment of Solar Radiation

Annual and hourly solar radiation data for the site was obtained from NREL's publicly available, high-resolution (10-km grid) National Solar Radiation Data Base (NSRDB). The data are based on highly reliable modeling techniques using information on cloud cover, atmospheric water vapor and trace gases, and the amount of aerosols in the atmosphere. The original measured data were taken over a 30-year period, from 1961–1990, for 26 major cities.

The solar radiation data for the Tucson Water Department site is a typical year representative of a 30-year average. An actual year could vary depending on the annual rainfall and cloud cover for the particular year. However, over the long term average the data will tend to follow the trends represented by the NREL data set. More information and detail background on the source of the data may be found at the NREL Web site www.nrel.gov.

The site is considered a prime candidate for a CSP and a flat-plate tracking PV plant. Concentrating solar plants rely on direct radiation called direct normal insolation (DNI), which is attributed to the actual disc of the sun. The mirrors and focusing equipment for concentrators cannot focus diffuse or indirect radiation. The important data point is the DNI for concentrators. Designers and developers will not consider sites with yearly average DNI less than 6.75 kWh/m^2 per day (also called sun-hours) (Source: Mehos presentation, NREL). As can be seen below in column 2 of Table 1, the yearly average DNI for the site is 7.1 kWh/m^2 per day, which makes it an ideal candidate for a CSP.

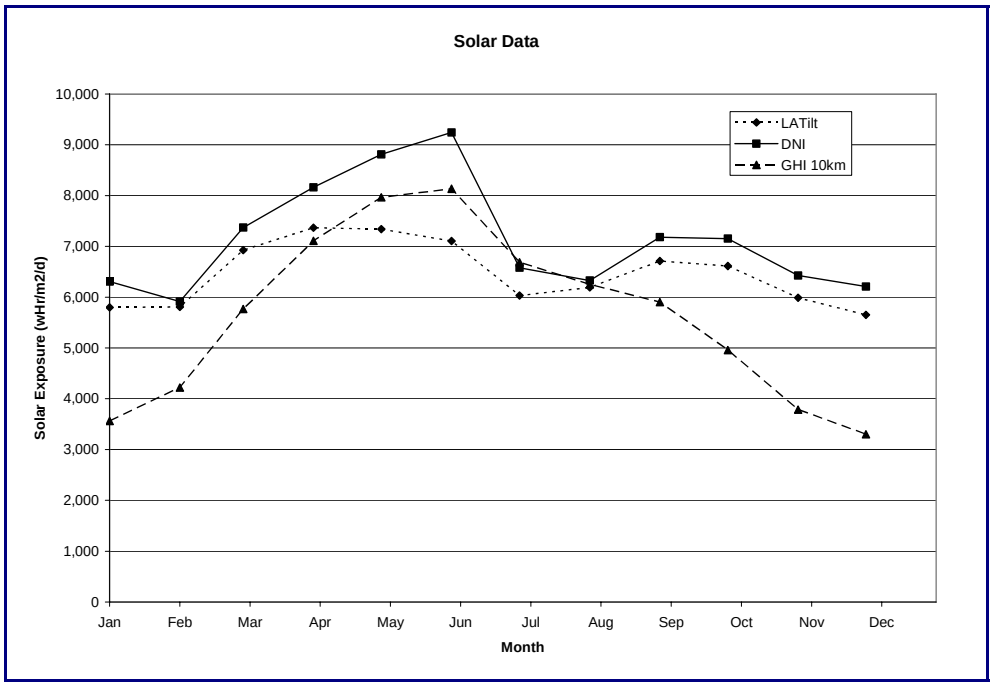

FIGURE 3
Plot of monthly solar radiation for proposed site located at latitude 32.15 degrees north, and longitude 111.15 west.

Similarly, the site provides a prime opportunity for a single-axis tracking flat-plate PV solar plant. Flat-plate PV plants can use diffuse, reflected, and direct solar radiation; the key figure is the solar radiation measured in the horizontal surface, or GHI, shown in Table 1. Sites with a yearly average GHI greater than 5 are considered ideal candidates for flat-plate PV plants. The proposed site has a yearly average of 5.64 kWh/m^2 per day, as shown in column 3 of Table 1.

TABLE 1
Monthly solar radiation figures for the proposed site.

Month	(1) LATilt kWh/m^2/day	(2) DNI kWh/m^2/day	(3) GHI kWh/m^2/day
Jan	5.80	6.31	3.56
Feb	5.81	5.91	4.22
Mar	6.93	7.37	5.77
Apr	7.37	8.16	7.11
May	7.34	8.81	7.97
Jun	7.11	9.24	8.14
Jul	6.03	6.58	6.69
Aug	6.19	6.33	6.26
Sep	6.71	7.18	5.90
Oct	6.61	7.16	4.96
Nov	5.99	6.43	3.79
Dec	5.65	6.21	3.30
Annual	**6.46**	**7.14**	**5.64**

Definitions:

LATilt Solar insolation measured on surface facing due south with tilt = latitude = 32 degrees
DNI Solar direct normal insolation as would be measured with an NIP following the sun
GHI 10km Solar insolation measured in the horizontal surface
Data resolution of 10 km as provided by NREL mapping and modeling

The one anomaly, or concern, regarding the historical solar radiation data is the fact that the monthly average data drops in July and August, which are normally considered the months with the highest sun-hours. According to the local weather data, this is the period when the site receives the most rain and cloud cover. Although the sun-hours for July and August are still well above average, the lower levels should be considered when the solar plant is actually designed.

3.1.2 Site GIS Maps

CH2M HILL has generated detailed GIS site maps for the proposed solar plant location. The maps were generated based on information and shape files provided by the Tucson Water Department, AEPCO, Trico, SW Gas, and the NREL data base. Comprehensive GIS maps are shown as Map 1 and Map 2 in Appendix 2. The actual site for the solar plant is shown in

yellow as the approximate 140-acre area bounded by Mile Wide road to the north and the service roads to the south, east, and west in Map 1.

The close proximity of electric distribution and transmission lines offers the opportunity to effectively offload electrical power from a solar plant. Directly adjacent to the west and the north are three-phase, 24.9-kilovolt distribution lines maintained and operated by Trico. The lines supply three-phase electricity to the CAVSARP system pumps. Each pump is individually metered for monthly billing.

Approximately 1 mile to the east of the proposed solar site is the Sandario substation (shown as a yellow triangle), which is operated and maintained by the Southwest Transmission Cooperative. At the present time, three 115 kilovolt transmission lines originate from the Sandario substation to supply the Sandaraz, Brawley, and Twinpeak stations. Each line is rated at 120 MVA.

SW Gas operates and maintains a high-pressure natural gas line that runs along Mile Wide road, north of the proposed solar site. Several of the CAVSARP pumps are gas driven and receive natural gas from the SW Gas line. Approximately 1 mile to the northeast of the solar site runs a major high-pressure gas supply line, operated by El Paso Gas Corporation and shown in purple on the GIS map.

Also shown on the map are the various storage wells and water facilities operated and maintained by the Tucson Water Department. The majority of the pumps are used to draw water from underground water storage aquifers and to move water to above-ground storage locations.

Map 1 is a comprehensive map with several GIS layers displayed, including electric utility and gas lines. Map 2 shows an overlay of the extended area considered usable for a solar plant (approximately 560 acres).

3.1.3 Transmission and Distribution Lines

Preliminary analyses including modeling of the transmission and distribution lines in the vicinity of the proposed site were carried out. Based on an assumption of typical conductor size and ampacity, the results indicate that the 24.9-kilovolt distribution lines adjacent to the site can accommodate 25 MW of solar plant capacity under normal system conditions (all lines in service). Therefore, up to 25 MW of PV or CSP thermal plant could possibly be interconnected and supply three-phase electricity to the Trico system. A detailed study would be required to ensure that the electricity could be supplied to the electric system.

The 115 kilovolt Sandario substation lines operated by Southwest Transmission Cooperative were also analyzed by our transmission specialists. Based on Western Electricity Coordinating Council study data, the results indicate that the capacity of the lines could accommodate up to a 100 MW solar electric plant under normal system conditions. A 1-mile transmission line would be needed to connect the solar plant to the substation. A detailed electric system protection and interconnection study, in conjunction with AEPCO, would be required before implementing a solar plant project.

3.2 Solar Plant Size

The following section describes the solar plants that could be installed on the proposed 140 acre site. In addition, we estimate the size of solar plant that could be installed using the entire area shown in Map 2, which is about 560 acres.

The plant sizing analyses are based on computer modeling, manufacturer's data, interviews with NREL staff, technical papers, and CH2M HILL solar power plant design experience.

3.2.1 Concentrating Solar Plant

The analyses only cover commercially available solar power plant technologies that have been determined by CH2M HILL to be readily deployable and technically feasible. For this analysis, we are considering CSP parabolic troughs and flat-plate PV plants. As discussed later (and in the appendices), there are several other CSP plants available that have not been commercially deployed and are still in the development or beta stage. CH2M HILL does not recommend that the Tucson Water Department invest in developmental technologies.

The latest state-of-the-art CSP trough plants require 5 acres per MW. The latest commercial plant using the trough technology was installed in El Dorado Valley, Nevada, and began operating in April 2007. It was built by Acciona, a Spanish corporation. The El Dorado Valley plant—called the Nevada Solar One plant—is rated at 64 MW and is contracted, through a power purchase agreement, to produce a minimum of 129 MWh per year for the local utility. The developer projects that the system will actually produce 134 MWh. It is a "solar only" plant that does not incorporate thermal storage or a back-up natural gas turbine. However, the developer is considering adding a salt storage system that will increase the output by 25 MWh per year and allow the plant to produce more during the peak electric periods in the summer months. The Nevada Solar One plant is the first commercial operating CSP system to be installed in the last 15 years, since the 320 MW Luz plants were built in the Mojave dessert. Over that period many technical enhancements have been introduced into the design to improve plant reliability and reduce capital and operating costs.

FIGURES 4 AND 5
Nevada Solar One CSP Trough plant 64 MW electric rating

FIGURES 5 AND 6
Close-up of parabolic trough mirrors with transfer fluid flowing in the focal point illuminated by the concentrated sunlight
Provided by Schott—the glass tube manufacturer

The 5-acre/MW land area for a trough system includes environmental holding ponds, the power block (steam generators, transformers, and electrical interconnection equipment), and the array field. The array field typically includes 900- to 1,300-foot-long rows of parabolic mirrors that focus light on a tube with transfer oil flowing to the main heat exchangers. Two rows constitute a complete loop, which is connected to a main header at the end of the rows. The steam turbines and electrical equipment, including step-up transformers, are installed at a strategic location in the array field to maximize operating efficiency and minimize heat loss.

Based on our evaluation, the 140-acre Tucson Water Department site could suitably accommodate a 25-MW electric CSP plant using parabolic troughs. Map 1 indicates the area that would be used for the 25-MW solar plant. If the Tucson Water Department wanted to use the entire plot, including the three similar sized parcels totaling approximately 560 acres (as in Map 2), then a 100-MW electric CSP plant could be installed. This is considered to be large enough to realize economies of scale, which could result in lower levelized electricity prices.

An analysis by our utility modeling specialist and thorough discussions with Trico's distribution engineers indicate that electric distribution lines adjacent to the site indicate line capacities of at least 25 MW. Thus, it is possible that a 25 MW plant could be interconnected to the distribution line. A final load flow analysis would be required to fully evaluate the line under varied loading conditions and a detailed interconnection study would also be required. A 25-MW solar plant is considered a large power plant and not a distributed power generator. The plant could be connected to the distribution system or transmission system and the electricity would need to be wheeled to the Tucson Water Department, if it were to be the recipient. The sale could be settled through a power supply transaction.

According to Tucson Water staff, the site might experience flooding or sheet flow during rainy seasons. However, discussions with solar designers indicate that the system can be designed to accommodate water issues. PV arrays and CSP systems are typically raised at

least 3 feet above ground level. Berms can also be installed to divert water from the site. According to the site manager at the Saguaro site maintained by APS, the sheet flow should not be a problem

3.2.2 Solar Photovoltaic Plant

The proposed 140-acre site is also highly suited for a flat-plate PV power plant. Three types of plants were analyzed:

1. Fixed array facing due south at tilt angle of 32 degrees
2. Single-axis tracking array on a north-south axis with a zero tilt
3. Single-axis tracking array on a north-south axis with 20 degree tilt

Based on our experience and on industry standards for high solar radiation sites such as the CAVSARP site, these would be the recommended options to consider. The fixed array would require the least amount of land because the rows can be packed closer together without shading from row to row. The single axis tracker tilted at 20 degrees requires the most land, and results in the most annual energy output. Following are the maximum plant sizes that could fit on the 140-acre site:

1. Fixed-array 28 MWdc plant (5 acre/MW)
2. Single-axis, zero tilt 25 MWdc plant (5.5 acre/MW)
3. Single-axis, 20 tilt 20 MWdc plant (7 acre/MW)

Two-axis tracking systems have been shown to require highly sophisticated bearings and tracking control systems that are expensive and generally only result in about 5 percent more energy on an annual basis compared to a single-axis tracking array. We used NREL's computer model, called PVWATTS, to predict the energy output for the three types of PV arrays. The model uses performance algorithms and 30-year solar data to predict the hourly performance for PV systems. Because fixed arrays require the least amount of land, the 140-acre site could accommodate up to a 28 MWdc plant using this type of array.

Fixed System

A fixed array at 30 degree tilt would be the simplest and require the least amount of maintenance of the three designs. However, it would also result in the lowest energy output on an annual basis. The 140-acre site could accommodate up to a 28 MWdc sized PV array that would produce an estimated 44,100 MWh per year as shown in Table 2.

TABLE 2
Photovoltaic plant types that fit on the 140-acre site.

PV Plant Monthly Energy ProductionModeled using PVWATTS (MWh/month)			
	28 MW Fixed Array	**25 MW Single-Axis 0 Tilt**	**20 MW Single-Axis 20 Tilt**
Jan	3,332	2,900	2,820
Feb	3,192	3,075	2,800
Mar	4,060	4,350	3,740
Apr	4,172	5,000	4,100
May	4,116	5,450	4,300
Jun	3,836	5,225	4,060
Jul	3,668	4,575	3,600
Aug	3,584	4,300	3,480
Sep	3,780	4,200	3,560
Oct	3,780	3,800	3,400
Nov	3,472	3,050	2,900
Dec	3,136	2,550	2,560
Totals	44,128	48,475	41,320

The most recent large fixed array was installed by Sun Edison in Alamosa, Colorado. The plant is partially completed and all 8.2 MW will be online by the end of December 2007. The plant will provide electricity to the Xcel energy grid.

FIGURE 7
A 8.2 MW Fixed Axis PV system Colorado

FIGURE 8
A 247 kW fixed array for the Cucamonga Valle Water District installed by SolarWorld

Tracking Array Zero Tilt

A tracking array will increase the annual output and result in a daily profile that better matches the electric utility peak load. Tracking on a daily basis from east to west produces more electrical energy in the late afternoon when the utility peak generally occurs on hot sunny days when residential customers turn on their air conditioners. The heat build up in buildings also coincides with late afternoon. A 25 MWdc zero axis tracking system will result in an annual energy production of about 48,500 MWh, which is the most of the three array designs. As can be seen in Table 2, the tracking system dramatically increases the energy production of the PV array during the peak summer months.

FIGURE 9
The 1 MW single-axis tracking system installed at Semitropic Water District—with array at zero tilt along a north-south axis.

Tracking Array at 20 Degree Tilt

A tracking array with a tilt of 20 degrees similar to the Nellis system install in Nevada will increase the annual output per acre of land, but will require more land area. A 20 MWdc plant could be fitted to the 140 acres that would produce about 41,300 MWh per year.

FIG. 10
Nellis Air Force Base, Nevada—15 MW system tracking at 20 degree tilt; the largest U.S PV power plant

4 Preliminary Solar Technology Assessment

There are several solar technologies under development, such as central receivers and Sterling dish engines, that are not currently suitable for commercial-scale power plant applications. Based on CH2M HILL's knowledge and research into the solar power market, the most applicable solar power technologies for the site are parabolic trough concentrators and flat-plate PV. This section includes a screening evaluation of these two technologies, as well as related screening analysis of hybrid solar-gas and thermal storage options for parabolic trough systems. We have relied on publicly available data and on consultations with manufacturers, NREL, and Sandia to obtain the latest technical and marketplace information about these two technologies.

Using site-specific solar data and simplified modeling techniques, CH2M HILL has predicted the annual energy production (in MWh) and the peak power production (in MW) for the most applicable solar power plant configurations. The analysis includes potential seasonal variations in these parameters and addresses the following:

1. Optimal solar power plant size, taking into account the existing pump loads at the site and existing electric utility rates
2. Optimal solar power plant configuration, including whether it might be one large solar plant or several smaller distributed solar plants
3. Approximate capital costs and Operations and Maintenance (O&M) costs
4. Potential greenhouse gas reductions
5. A high level estimate of costs and values associated with heat storage or natural gas backup to make the CSP more dispatch able
6. Estimated water requirements for the CSP parabolic trough option
7. List of permits required for a solar plant at the site

Based on the screening evaluation, and taking into account the relative advantages and disadvantages of the possible technology options, CH2M HILL presents a matrix of the solar technologies most suitable for the site.

4.1 Solar Power Plant Technologies

4.1.1 Concentrating Solar Power

A detailed overview of the various types of CSPs is included in Appendix 5. The state-of-the technology that is most commercially available for the Tucson Water Department site would be parabolic troughs. These do not present a significant visual constraint and can be permitted in a reasonable time frame. Other options that have been eliminated are as follows:

- **Large Central Receivers (or Power Towers)**, which use large fields of mirrors (heliostats) to focus light on a 300-foot tower, require larger land areas and would not fit on the selected site. Additionally, the large tower, which becomes iridescent during

operation, would be considered a visual negative during permitting and local community input. Power Tower plants will most likely not be available until 2011.

- **Parabolic Dish Sterling Engines**, although they are potentially highly efficient, are not commercially proven on a large scale and would present similar visual difficulties, because they protrude above the desert land.
- **Compound Linear Fresnel Reflectors** are also not commercially available on a large plant scale and may not be available until after 2011.

Our study focuses on parabolic troughs as the CSP option for the Tucson proposed site.

4.2 Photovoltaic Power Plant Technologies

Appendix 6 offers a detailed discussion of photovoltaic power plant technologies and options. The latest state of the art for large PV power plants is to use single crystalline flat plate modules mounted on ground-level structures. To maximize the site for annual and seasonal energy production, a tracking mechanism is generally incorporated to follow the sun on a daily basis. Typical tracking systems follow the sun from east to west and can be either on a horizontal north-south axis or tilted up to face the sun.

For the purposes of this study, we will be focusing on flat-plate PV systems with fixed and tracking arrays. PV can be used as a centralized power plant or a distributed generation option and can be scaled easier than a large CSP plant.

4.3 Pumping loads and metering at the CAVSARP Site

Tucson Water Department has 37 individual pumps in a range of sizes, which are separately metered and connected to the Trico Electric Cooperative distribution system. The majority of the pumps are three phase and are now on the IS2 rate tariff served by Trico. An analysis of the monthly bills for April 2007 was carried out. For simplification, only the major pumps on the IS2 rate with Trico were included in the analysis, which is shown in Appendix 3. According to the Tucson Water Department, the pumps at the site generally run at high load factors. Assuming a 90 percent monthly load factor, the pumps analyzed in the table make up a total load of 4,000 to 5,000 kW.

LF = kWh/(kW x 720 hrs)

Tariff IS2 is an interruptible rate that includes a demand charge of $29.50 per kW applied to the peak coincident demand if the Water Department is unable to turn off the loads. An analysis of the bills for April indicates that very little if any peak demand charges were applied, which indicates that good demand-side operations are being performed.

The analysis indicates that the average rate for the electricity is about 8.8 cents per kWh at the present time. Discussions with Trico and Tucson Water indicate that the majority of the pumps will be ganged onto a single metering point back at the Sandario substation, and a new rate GS-4 will be applied. An analysis provided by Tucson Water indicates that the new average rate of electricity for the pumps will be about 7 cents/kWh.

With the billing data provided it is difficult to estimate the marginal cost of electricity—or the electricity cost during peak periods—which would be when a solar plant provides its

benefit. It is likely that the marginal cost is higher—closer to 10 to 12 cents/kWh. A detailed analysis of the peak electric usage should be carried out to determine the marginal cost to compare to the solar plant performance and for further demand side management options.

According to Trico the new metering configuration and billing will be set up by February 2008. The new configuration will be useful if the Tucson Water Department decided to put in a distributed photovoltaic plant sized at about 4 to 5 MW. Rather than have to connect to each individual pump with a small PV plant, one large plant could be interconnected on the customer side of the new large meter. The plant would then be considered a distributed generator and receive the appropriate designation for the renewable energy credits.

There may be an advantage to sizing the system larger the 5 MW to account for the variation in summer and winter pumping loads. Further analysis of actual hourly load profiles for the main pumps could indicate that a larger PV system would be warranted. The analysis is beyond the scope of this study, but might be considered by the Tucson Water Department before accepting bids from PV developers. It will also be important for Trico and the Tucson Water Department to agree on procedures for allowing solar electricity to back feed into the distribution network when pumping loads drop below the output of the PV system. Metering and system protection issues must be addressed.

Further analysis of the new billing structure under the new metering arrangement is still required to determine resulting savings and associated demand charges. The new rate may save overall, but could include higher demand charges that might be off set by a solar electric plant.

4.4 Evaluation of Specific CSP and Photovoltaic Options

4.4.1 CSP Plant Options

The evaluation of trough CSP options for the site was carried out based on discussion with experts and NREL, with manufacturers, and using the latest NREL Solar Advisory Model (SAM).

The power block of a parabolic trough system is a traditional power plant with steam turbines and electric turbines. Similar to traditional utility power plants, they must be large to capture economies of scale. Several studies (NREL, Kearney and Associates, and Nexant) have indicated that 100 MW is a size where economies of scale begin to be realized. For this analysis, we have evaluated 25 MW and 100 MW CSP options for the Tucson Water site. Three options are considered: solar only, solar with 6 hours of storage, and solar with a gas turbine backup.

Table 3 presents the results of the analysis and a comparison of the 100 MW plant with the 25 MW plant. As can be seen, a 30-year contract for a 100 MW plant would result in the lowest levelized cost of electricity. The evaluation is based on conservative inputs from NREL experts and the industry representation. With today's technology, a CSP plant can be installed for a total cost of from $3,800 to $4,800 per kW depending on whether it includes 6 hours of storage. A 100 MW plant with storage would cost approximately $441 million. Operations and maintenance (O&M) costs are about 1 to 2.5 cents/kWh and are attributable to normal power plant procedures for the power block and the solar array field, which requires washing on a regular basis and repairs as needed.

TABLE 3
Analysis and comparison of CSP plant options

	25 MW Solar Only	25 MW With Storage
Installed Cost ($/kW)	4,244	4,800
O&M Cost Fixed ($/kW-yr)	65	71.5
O&M Cost Variable ($/MWh)	0.7	0.7
Annual Energy Produced (MWh)	63,510	70,080
Levelized Cost Electricity (cents/kWh); No tax credits	20.15	19.64
Levelized Cost Electricity (cents/kWh); Tax credits	14.43	14.02

	100 MW Solar Only	100 MW With Storage
Installed Cost ($/kW)	3,872	4,412
O&M Cost Fixed ($/kW-yr)	65	71.5
O&M Cost Variable ($/MWh)	0.7	0.7
Annual Energy Produced (MWh)	254,040	280,320
Levelized Cost Electricity (cents/kWh); No tax credits	19.34	18.44
Levelized Cost Electricity (cents/kWh); Tax credits	13.94	13.19

There is little commercial experience to date with salt storage systems. Sandia and NREL are conducting research, and the original Solar Two power tower plant tested the salt storage option for a brief period in the 1980s. A plant is now being built in Spain by Acciona to test the storage option and should be completed in April 2009. Figure 11 shows an hourly profile of a CSP plant with storage (green) and without storage (blue) on a typical peak day. The storage allows the operator to provide more peaking power into the late afternoon and smooth out periods when clouds form over the plant. According to NREL, storage adds about $30 to $40/MWh to the cost of a plant and in most cases could be economical, particularly if the cost for traditional electricity is valued during the peak periods (late afternoon). Additionally, storage allows reduction in steam turbine size in the design, yet increases the annual capacity factor.

In general, it is important to note that the CSP plant without storage follows the peak utility period well and may be sufficient to provide peak load power. The thermal mass in the solar-only option provides 10 to 15 minutes of “ride through” for cloudy periods. This is unlike a PV plant, which drops in power output as soon as a cloud covers the site.

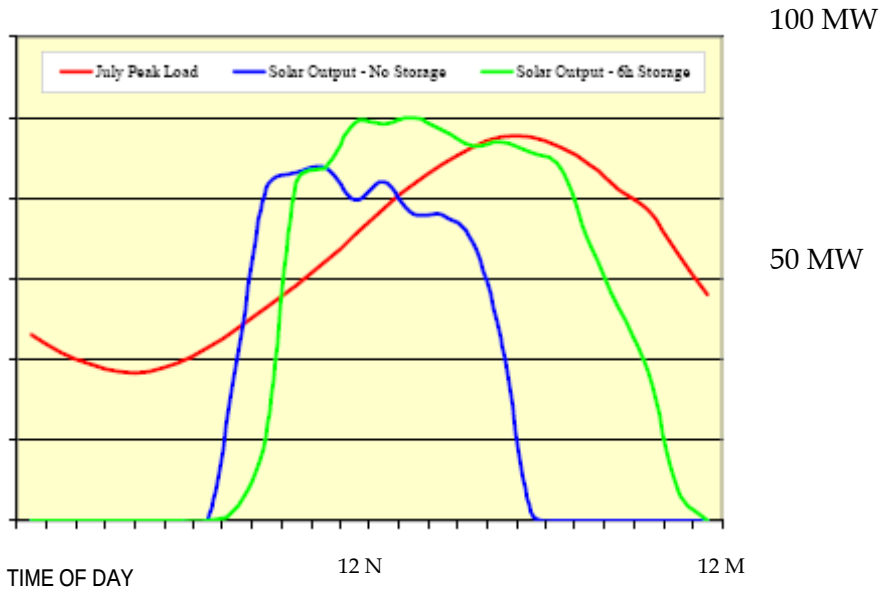

FIGURE 11
Typical profile of a CSP plant compared to utility system profile. Blue is without salt storage, green is with storage, red is the utility load profile.

Natural Gas Backup

CH2M HILL power plant specialists examined the potential for installing a combined natural gas backup plant for the solar CSP options. The gas backup would provide reliability from the standpoint of operation and increase the annual operating capacity factor. Two options were examined: adding a standard Rankine-type steam turbine, and including a combined-cycle plant with steam generator in the plant cycle.

The important issue is whether sufficient natural gas is available at the site and whether the cost would be reasonable. Southwest Gas owns and operates a natural gas main that runs along Mile Wide Road directly north of the solar site. A request was submitted to Southwest Gas to be able to operate the following gas profiles:

- For the combined-cycle gas plant:
  - Gas pressures of 450 psig to 550 psig
  - Gas flow of 250 MM Btu/hr of natural gas for the 25 MW plant
  - Gas flow of 700 MM Btu/hr of natural gas for the 100 MW plant
- For the Rankine cycle plant:
  - Gas pressures are approx 50 to 100 psig
  - Gas flow of 320 MM Btu/hr (LHV) for the 25 MW plant
  - Gas flow of a 975 MM Btu/Hr (LHV) for 100 MW plant

At the present time, Tucson Water Department is paying approximately 93 cents/therm for natural gas at the site for a few small gas power pumps and possibly some heaters. This equates to about $9.30/MMBtu natural gas which would be prohibitively expensive.

In response to the request Southwest Gas indicated that they might be able to supply the required natural gas for a large solar plant from their existing line running along Mile Wide

Road. They would consider negotiating a new tariff and gas rate more suited for a large consumer such as a power plant. Further, they have indicated that if they are not able to supply the natural gas for a large solar plant from the existing line they would work with El Paso Natural Gas Company to install a line connecting the El Paso gas line to a point adjacent to the solar site. The El Paso line is approximately 1 mile to the northeast of the site and is likely to have enough capacity and pressure to accommodate the large solar plant. According to Southwest Gas, they would consider picking up the cost of the new gas line and fittings to bring the El Paso gas to the solar power plant.

If Tucson Water considers a solar plant with natural gas backup, a detailed study of the gas availability, requirements, and permitting should be carried out. As discussed later it would be significantly more costly to permit a gas power backup plant for the solar CSP.

Water Requirements for CSP

Water availability can be a significant issue for CSP systems, primarily because the regions best suited for CSP technology are generally arid, desert areas. The majority of water consumption at the Solar Electric Generating System (SEGS) plants in southern California is for the cooling towers. It should be noted that water consumption in CSP plants would be nominally the same as it would be for any comparably sized Rankine-cycle power plant with wet cooling towers (DOE, 2003). It has been estimated that a 50-MW parabolic trough plant with wet cooling would use approximately 103 million gallons of water per year (Solargenix, 2005b).

A dry cooling system using an air-cooled condenser could be used to reduce plant water consumption. With this type of system, the annual water consumption for a 50-MW parabolic trough plant would drop to approximately 8 million gallons (Solargenix, 2005b). However, a dry cooling system would reduce plant efficiency by approximately 6 percent due to lower turbine efficiencies caused by higher average turbine backpressure, as well as parasitic loads from forced draft air fans (Solargenix, 2005b). The reduced plant efficiency would result in a higher cost of electricity from the plant.

Wastewater Issues

Wastewater discharge from CSP plants can be an issue in some areas. Blowdown from the steam cycle, demineralizer, and cooling towers must typically be discharged to an evaporation pond (DOE, 2003). Crystallized sludge from the evaporation pond would likely have to be removed occasionally and disposed of at an offsite waste facility. However, the wastewater discharge and evaporation pond sludge residues are expected to be the same as for any comparably sized steam cycle in a natural gas combined-cycle power plant with wet cooling towers.

It is important to note that a CSP plant would not have any of the coal bottom ash, fly ash, or flue gas desulphurization waste products that are typically generated in a coal power plant. Moreover, a CSP plant would not require any of the environmental control equipment required to contain or treat these wastes.

Heat Transfer Fluid

The heat transfer fluid used in parabolic trough plants is typically an aromatic hydrocarbon mixture commonly known as biphenyl/diphenyl oxide. DOWTHERM® A and Therminol® VP-1 are commercial products that have been used in the SEGS plants in Southern California. The mixture is classified as non-hazardous by U.S. standards but is considered a

hazardous material in California. Occasional spills of this chemical have occurred at the SEGS plants, primarily due to equipment failures (SDRREG, 2005). When spills of the heat transfer fluid have occurred, contaminated soil has been excavated and removed to an onsite bioremediation facility for treatment (DOE, 2003). Biological treatment restores the soil to normal condition in 2 to 3 months (SDRREG, 2005).

It is possible that a solar CSP plant could be supplied with reclaimed water from the Tucson Water Department. Further studies need to be carried out to determine the feasibility of using reclaimed water, including the infrastructure that would be required to bring the water to the site and the ability to use reclaimed water in the solar plant cooling towers or for mirror washing.

Another option could be to use the water from the CAVSARP site in a "once through" cooling system, which may eliminate most, if not all, of the evaporation losses and any wastewater issues. The water would be in a closed loop system—pumped out of the ground, put through a heat exchanger to cool steam in the CSP plant, and then re-injected into the ground for storage. The CAVSARP site offers this unique opportunity to use the local water storage. However, further study would be required to determine the effect on the underground storage water temperature and research permitting and approval issues.

4.4.2 Large Photovoltaic Plant Options

The PVWATTs model was used to compare the performance of the three types of array configurations. For comparison, a 20 MWdc array for each type was modeled. Modeling results for a 1 kW-dc plant for each design were scaled up to 20 MW-dc (see Appendix 7).

Figure 12 depicts the monthly production for fixed versus tracking PV systems. As can be seen, the tracking system dramatically increases energy production during the peak summer months. The 20-degree tilted array only marginally increases monthly output during the peak months and actually results in more energy in the off-peak winter months.

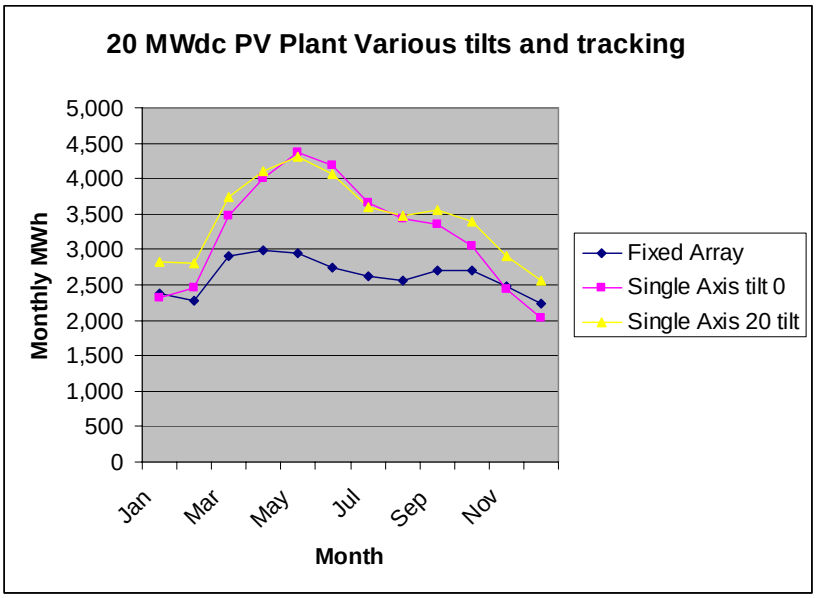

FIGURE 12
Monthly variation in electrical production for various array designs

Figure 13 indicates the results of the computer model for a peak June day for the various array types. The tracking systems increase energy production in the late afternoon to better follow the electric utility peak, which typically occurs later in the afternoon at about 5 or 6 p.m. when residential customers turn on their air conditioners.

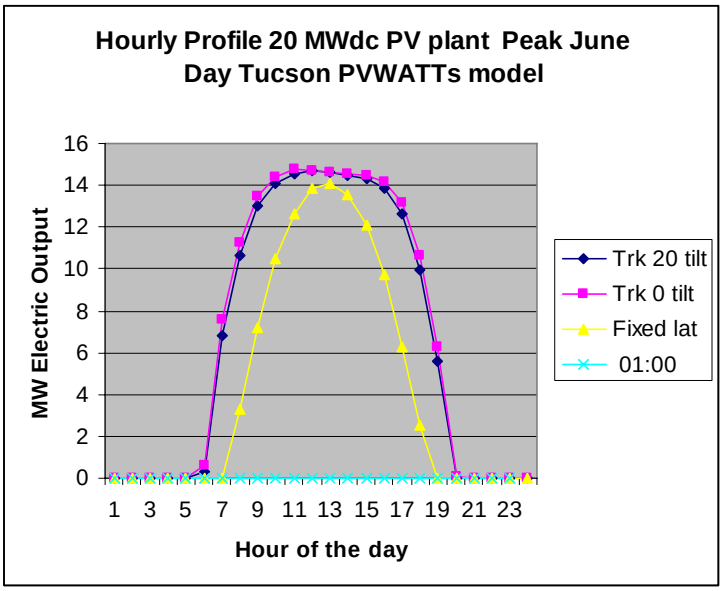

FIGURE 13
Comparison of daily profiles for tracking versus non-tracking PV plants.

In order to maximize the peak value of a solar plant that would be installed on the proposed site, it is recommended that a tracking system be installed.

Costs for PV plants

CH2M HILL has received unofficial bids from solar equipment suppliers and developers for large PV plants. Unlike large CSP plants, PV plants generally hit a level of cost economy at over 1 MW. PV plants are also much more suited to modular installation, where a developer can install several MW per year and gradually build up a large plant.

For the purposes of the study, we assessed the potential for installing a 5 MW plant in 2008. This plant would approximately match the size of the existing loads at the CAVSARP site. If Tucson Water and AEPCO wanted to expand this plant in later years to match the need for meeting the Arizona renewable mandate, additional blocks of power can be added.

Costs estimated for a 5 MW plant in the various array types are shown in Table 4.

TABLE 4
Cost for large PV power plants; tracking and non-tracking

	Fixed Array	Tracking 0-Tilt	Tracking 20-Tilt
Installed ($/kW)	5,750	6,000	6,250
O&M (cents/kWh)	0.85	1	1.1
Annual Electrical Energy (MWh)	7,880	9,695	10,330
Levelized Cost (cents/kWh)	20	17	16

These estimates assume that a third party would own and operate the PV plants and sell the electricity (and renewable energy credits) to Tucson Water and/or AEPCO and the electric cooperatives. The third party can take advantage of federal tax credits and incentives that are not available to the city or the cooperatives. The cost figures above are based on unofficial bids from solar developers that would be prepared to install the system in a turnkey manner and sell the electricity through a 25- or 30-year power-purchase agreement. It is highly likely that better pricing could be achieved through a formal bidding process to promote competition.

Water Requirements

An advantage of PV is that it does not require water for operation like the CSP thermal plants. Depending on how much dust and dirt collects on the solar modules, they may require occasional washing. However, this is not a typical practice for PV operators.

4.4.3 Green House Gas reductions

Arizona is primarily in the Western Electricity Coordinating Council (WECC) Southwest subregion for E-grid. The estimated reduction in CO_2 is 1,254 lb/MWh. The Arizona-specific estimate is slightly lower at 1,219 lb/MWh.

Using the EPA Subregion AZNM, the calculation using 1,254 lb/MWh are as follows:

- 5 MWdc solar PV plant; 10,330 MWh, 12.9 milion pounds of CO_2 per year savings
- 25 MWdc solar PV plant; 48,475 MWh , 60.8 million pounds of CO_2 per year savings
- 25 MWe CSP plant; 63,510 MWh, 79.6 million pounds of CO_2 per year savings
- 100 MWdc solar PV plant; 254,040 MWh , 318.6 million pounds of CO_2 per year savings

It should be noted that RECs cover all attributes. The party that purchases, owns, or retires the RECs can claim the green electricity.

4.4.4 Permitting

This section summarizes a preliminary assessment of permitting requirements for installing the various types of solar plant being considered at the CAVSARP site.

There are four basic plant options for the identified site:

- Option 1—Solar PV electric plant
- Option 2—CSP using synthetic heat transfer oil
- Option 3—CSP using organic heat transfer oil
- Option 4—CSP with synthetic heat transfer oil and a 28 MW natural gas-fired combustion turbine back-up power source

We have summarized what we think are the permitting/approval requirements associated with these plant options in Table 5. Most of these will be issued by Pima County. Exceptions are storm water permitting, which goes through the Arizona Department of Environmental Quality (ADEQ), and requirements associated with the Oil Pollution Prevention Act, which are driven by the U.S. Environmental Protection Agency (EPA).

TABLE 5
Summary of Potential Permitting Requirements
Tucson Solar Plant Site

Permit/ Authorization	Issuing Agency	Applicability	Estimated Timeline	Notes
AZPDES Storm Water Construction General Permit	Arizona Department of Environmental Quality	All options	< 1 month	Coverage obtained through ADEQ Smart NOI process. A storm water pollution prevention plan must be developed and implemented before construction activities begin.
Pima County Activity Permit	Pima County Department of Air Quality	All options	< 1 month	Addresses fugitive dust control during construction.
Pima County Class II Air Permit	Pima County Department of Environmental Quality	Option 4	6 months	Required due to applicability of 40 CFR Subpart KKKK to combustion turbine; assume will be able to permit as minor source due to limited capacity factor (25%).
Pima County Plan Review/Building Permit	Pima County Development Services	All options	4-8 months	Process can be lengthier than County indicates in instructions to applicants.
Pima County Right-of-Way Permit	Pima County Development Services	All options	< 1 month	For work along Mile Wide Road
Pima County Grading Permit	Pima County Development Service	All options	< 1 month	Generally required for grading activities that exceed 14,000 square feet in area
Pima County Flood Plain Use Permit	Pima County Development Services	All options	4-8 month	Flood plain
Biological Resource Survey	Part of Pima County Development Services Review—Pima County Sonoran Desert Conservation Plan	All options	< 1 month	Will want to address the Pima pineapple cactus and lesser long-nosed bat which are listed under the Endangered Species Act; also local special status species including cactus ferruginous pygmy owl and burrowing owl.
Cultural Resources Survey	Part of Pima County Development Services Review Process	All options	< 1 month	Even if no pre-construction survey required, may need to conduct monitoring during construction.
Oil Pollution Prevention Act—Spill Prevention Control and Countermeasures Plan	U.S. Environmental Protection Agency	Options 2, 3, and 4	< 1 month	Addresses procedures for spill prevention and spill clean up related to oil storage and oil-filled equipment.
Hazardous Waste Generator ID	Arizona Department of Environmental Quality	Options 2, 3 and 4	< 1 month	Required for small quantity and large quantity generators of hazardous wastes; limited potential to be triggered by this project.

We have included the need to obtain a hazardous waste generator ID as a potential requirement of this project, but think it is likely that any of the facility options would achieve status as a conditionally exempt small quantity generator. A more detailed project evaluation will create a better understanding whether any of the options could trigger small generator status and the associated requirement to obtain a generator ID for waste shipment.

Please note that options including less than 100 MW of generation capacity will not require approvals through the Arizona Corporation Commission (ACC) and its Power Plant and Transmission Line Siting Committee. Also, we have not included requirements for permitting under the Clean Water Act Section 404 program, because it does not seem that there are any U.S. jurisdictional waters on the project site; however, this may need to be field verified. If there are jurisdictional waters, it is probable that permitting will occur under the nationwide permit process rather than the individual permit process.

We have included the need for cultural resource survey and biological resource survey in the table, but acknowledge that these two activities may have already been completed in support of CAVSARP development. However, if pre-existing surveys were performed several years ago, updating them would be prudent if past findings indicate any resources of concern may be in the project area.

The proposed plant site is in an area covered by Pima County's Sonoran Desert Conservation Plan (SDCP), which identifies the area along Brawley Wash, located just east of the proposed site, as Biological Core Management Area that serves as an important wildlife corridor link and contains important riparian habitat. This land area extends to partially cover the proposed solar plant site. It appears from an aerial photograph underlying the site map provided that the site is occupied by agricultural fields, which would reduce the site's value as wildlife habitat. However, it is important to be aware of the county designations related to the SDCP, because discussion of potential impact to these areas will most likely come up during the county permitting process.

One item that may affect project support in this location is aesthetics. CH2M HILL was involved in the permitting of the Sandario Substation and associated transmission line shown on the site map. During the permitting for this project, the visual impact of the line was of significant concern to the National Park Service and the Bureau of Land Management because of the proximity of the substation and transmission line to Saguaro National Park and Ironwood National Monument, respectively. In addition, potential impacts to visual resources were a concern during the Pima County plan review process associated with obtaining the power substation permit for the project. As any of the solar plant options being proposed will result in a noticeable new feature in the area landscape, we recommend including a visual impact assessment of the facility in the permitting effort.

4.4.5 Comparison and Matrix of Plant Options

TABLE 6
Matrix and evaluation of options

Solar Technology Assessment Matrix—CAVSARP Site, Tucson

	Photovoltaic	**CSP**	**CSP**	**CSP**	**CSP**
	Single Axis Tracking	**Troughs, Solar Only**	**Troughs with Salt Storage**	**Troughs with Gas Backup**	**Troughs, Organic Rankine**
Commercial Viability	Commercial	Commercial	Being Developed	Commercial	Beta
Date for Commercial	2007	2007	2008	2007	2008
Water Usage	Minimal—washing	High—900 G/MWH/yr	High—900 G/MWH/yr	High—900 G/MWH/yr	High—900 G/MWH/yr
Capital Cost ($/kW)	5,750 to 6,250	3,800 to 4,300	4,400 to 4,800	NA	6,000
O&M Cost (cents/kWh)	0.85 to 1.1	1.0 to 2.5	1.4 to 2.5	NA	1.4 to 2.5
LCE (cents/kWh)	16 to 18	13 to 15	13 to 14	NA	NA
Permitting	Lowest	Moderate	Moderate	Difficult	Moderate
Modularity	Modular	Large-scale	Large-scale	Large-scale	Modular
DG or Central Power	DG	Central	Central	Central	DG/Central

The matrix shown in Table 6 compares the solar power plant options considered in our assessment, including the Ormat Organic Rankine engine similar to the plant installed by Arizona Public Service. The matrix indicates that a distributed PV plant, although the most expensive, could result in the lowest maintenance costs and the least effort to permit, and provide modularity for future additions. The trough system with salt storage could be the most economical option for a large-scale central solar plant.

5 Financial Estimates and Potential Partnering Arrangements

For the two highest-ranked options, CH2M HILL has prepared a preliminary economic analysis to estimate the total annual and lifecycle costs. We used available cost data and internal models to assess the net present value of a large solar plant at the 140-acre site. An important consideration in this analysis was the local, state, and federal incentives and funding options that are available.

5.1 State, Local and Federal Incentives and Tax Credits

5.1.1 Federal Tax Incentives

The federal government now offers solar plant owners and operators a 30 percent federal income tax credit. The credit is available to taxable commercial enterprises and residential consumers. The credit for commercial entities is unlimited in magnitude, whereas residential consumers are limited to a maximum credit of $2,000. The 30 percent tax credit is

scheduled to expire at the end of 2008 and, based on recent U.S. Congressional bills (December 15, 2007), the credit will revert back to 10 percent unless a new energy bill or tax bill is implemented. The 30 percent tax credit has been removed from the Energy Bill. Thus, solar plant owners must have a plant operational before the end of 2008 in order to claim the 30 percent tax credit. The Tucson Water Department and the electric cooperatives would not be eligible to claim the federal tax credit since they are non-taxable entities. Thus, it is important for the city and the cooperatives to consider having a third-party developer that can take advantage of all the federal incentives and build the solar plant at the CAVSARP site. The developer could set up a 25 to 30 year power purchase agreement and sell the solar electricity and renewable energy credits to the city and cooperatives at fixed rates.

In addition to the federal tax credit, commercial solar plant owners may take advantage of accelerated depreciation thereby reducing the value of the plant quicker than most assets.

5.1.2 State of Arizona

The State of Arizona has implemented several incentives for solar power plants. The solar equipment is exempt from state sales tax exemption and certain businesses can claim a 10 percent state income tax credit for solar installations. The City of Tucson offers a $1,000 credit on solar permit applications to the city. All solar system installations are exempt from property tax increases. In other words, a solar system on a residence may not increase the taxable property value.

5.1.3 Utility Rebates

The local retail electric utilities throughout the state offer various rebates for installing solar photovoltaic plants.

- TEP $2.50/W (limits on max incentive)
- APS $2.50/W
- SRP $2.50/W
- Trico Elect Coop $4/W (first come, first serve)

5.1.4 Other Funding Sources

Tucson recently received Solar America Cities funding to help move the city toward more solar energy. They have been assigned a Tiger Team to help design and implement solar programs. The Tiger Team representative could help continue the momentum in forming a partnership with the electric cooperatives to install a solar plant at the CAVSARP site.

The City of Tucson would have to decide whether they want to contribute any of the “self directed surcharge funds” toward a solar project at the CAVSARP site. Staff have indicated that the Clean Renewable Energy Bonds (CREBs) obtained by the city are already committed for other projects.

5.2 Arizona Renewable Energy Standard

The State of Arizona Corporation Commission adopted a new RES that requires utilities to meet annual targets for renewable energy. The yearly requirements began in 2006 and step

up annually to reach a total of 15 percent of annual kWh sales that must be from renewable energy by the year 2025. In addition, a distributed renewable energy generation requirement states that 30 percent of the renewable energy generation must come from distributed generators that are on the customer side of the meter. A summary of the annual requirements is shown in Table 6.

TABLE 6
Annual percentage of total kWh sales that must come from renewables; includes all affected utilities in the state of Arizona.

Year	Percent from Renewables (%)
2006	1.25
2007	1.50
2008	1.75
2009	2.00
2010	2.50
2011	3.00
2012	3.50
2013	4.00
2014	4.50
2015	5.00
2016	6.00
2017	7.00
2018	8.00
2019	9.00
2020	10.00
2021	11.00
2022	12.00
2023	13.00
2024	14.00
2025	15.00

The renewable energy standard applies to utilities and has been set up so that in order to meet their standard each utility may purchase RECs. One REC is equivalent to 1 MWh of generation from a renewable plant. The utilities do not necessarily have to purchase the electricity associated with the renewable energy; however, they must purchase and retire the renewable energy credits generated by the renewable electricity.

While the Arizona cooperatives are exempt from meeting the percentage requirements of the RES order, they are required to file a renewable energy plan annually with the Arizona Corporation Commission. That plan attempts to come as close as possible to meeting the RES requirements. Table 7 shows the first 7 years of the cooperatives requirement for renewables as provided by AEPCO. Column 1 indicates the percent of total retail sales that must come from renewable energy as mandated by the state of Arizona. Column 2 indicates the total number of MWh on an annual basis that is to be renewable energy and column 3

indicates how many MWh must come from distributed generation options on the customer side of the meter.

TABLE 7
Renewable energy through the year 2012 that must be purchased by the electric cooperatives served by AEPCO.

Year	(1) % of sales	(2) MWh	(3) MWh Distribution
2007	1.500	30,375	9,113
2008	1.750	35,438	10,631
2009	2.000	40,500	12,150
2010	2.500	50,626	15,188
2011	3.000	60,750	18,225
2012	3.500	70,875	21,263

Table 8 indicates the total of each type of renewable technology that could be installed to meet 100 percent of the annual renewable mandate for the electric cooperatives, assuming typical capacity factors for each technology. As can be seen, a 32 MW solar plant operating at a capacity factor of about 25 percent can provide all the needs for the AEPCO cooperatives in the year 2012 to meet the Arizona RES.

TABLE 8
Number of MWs of each technology that would meet 100 percent of the cooperatives' mandate, assuming typical operating capacity factors.

Year	MW needed to provide 100% of RES for Co-ops		
	Solar (25% CF)	Wind (35% CF)	LFGas (90% CF)
2007	14	10	4
2008	16	12	4
2009	18	13	5
2010	23	17	6
2011	28	20	8
2012	32	23	9

The analysis indicates that if a larger plant (i.e., a 100 MW CSP plant) was contemplated, other utilities in Arizona might need to be involved and available to purchase the additional RECs. Tucson Electric Power (TEP) and Arizona Public Service (APS) might be interested in the additional RECs. Currently, TEP has filed a plan with the Arizona Corporation Commission that will meet their RES. The results of the filing may not be approved until April 2009. APS has an approved plan and is now accepting bids for a 250 MW CSP plant to meet the initial stages of its REC requirement.

Table 9 presents the estimates of renewable energy credits that would be required for the other large utilities in Arizona to meet the renewable mandate. As can be seen, the entire state will require a minimum of about 1800 MW of renewable energy by the year 2025 to meet the mandate. Both TEP and APS could be utilities that would be interested in purchasing the RECs from a solar electric plant on the CAVSARP site.

TABLE 9
Arizona Renewable Energy Mandate.

Arizona Renewable Energy Mandate

		APS			TEP			CO-OPS			State
				Solar MW			Solar MW			Solar MW	Total Solar
Year	Yearly Require	Total MWh	Dist MWh	CF 25 %	Total MWh	DIstributed	CF 25 %	Total MWh	Distributed	CF 25 %	MW
2006	1.250%	150000	45000	68	158025	47407.5	72	25312.5	7593.75	12	152
2007	1.500%	180000	54000	82	189630	56889	87	30375	9112.5	14	183
2008	1.750%	210000	63000	96	221235	66370.5	101	35437.5	10631.25	16	213
2009	2.000%	240000	72000	110	252840	75852	115	40500	12150	18	244
2010	2.500%	300000	90000	137	316050	94815	144	50625	15187.5	23	304
2011	3.000%	360000	108000	164	379260	113778	173	60750	18225	28	365
2012	3.500%	420000	126000	192	442470	132741	202	70875	21262.5	32	426
2013	4.000%	480000	144000	219	505680	151704	231	81000	24300	37	487
2014	4.500%	540000	162000	247	568890	170667	260	91125	27337.5	42	548
2015	5.000%	600000	180000	274	632100	189630	289	101250	30375	46	609
2016	6.000%	720000	216000	329	758520	227556	346	121500	36450	55	731
2017	7.000%	840000	252000	384	884940	265482	404	141750	42525	65	852
2018	8.000%	960000	288000	438	1011360	303408	462	162000	48600	74	974
2019	9.000%	1080000	324000	493	1137780	341334	520	182250	54675	83	1096
2020	10.000%	1200000	360000	548	1264200	379260	577	202500	60750	92	1218
2021	11.000%	1320000	396000	603	1390620	417186	635	222750	66825	102	1339
2022	12.000%	1440000	432000	658	1517040	455112	693	243000	72900	111	1461
2023	13.000%	1560000	468000	712	1643460	493038	750	263250	78975	120	1583
2024	14.000%	1680000	504000	767	1769880	530964	808	283500	85050	129	1705
2025	15.000%	1800000	540000	822	1896300	568890	866	303750	91125	139	1827

5.3 Partnership Options

The Tucson Water Department, AEPCO, and Trico have an excellent opportunity to implement a contractual arrangement to install a solar plant on the CAVSARP site. The partnership could be arranged such that all parties benefit from the project. In general the shared opportunities could be set up in the following manner:

1. **Tucson Water Department** owns the ideal solar site and could offer the site for lease to a solar developer. Tucson could purchase a portion or all of the electricity at a fixed rate through a power purchase agreement (PPA) from the developer over a 25 to 30 year period. They could also purchase a portion of the RECs if they wanted to retain some of the renewable energy attributes.
2. **AEPCO and Trico** have the opportunity to purchase the RECs and a portion of the electricity from the solar plant. The RECs could be from a distributed PV plant installed on the site. The RECs might be less expensive than obtaining them through a $4/Watt rebate to customers. In addition, AEPCO and Trico would receive the benefits of a peak power generator (solar plant) which would help shave peaks, yet allow off peak sales of electricity for CAVSARP pumps at night.

The following presents the possible partnership benefits and options.

5.3.1 CSP plant

A contractual arrangement could be made with Tucson Water and the electric cooperatives to purchase a large solar CSP plant of 25 to 100 MW. A preliminary design and bid package could be developed and bids from developers obtained for a 100 MW or 25 MW CSP plant. In a competitive bid process prices for delivered electricity could be as low as low as 11 to 12 cents/kWh total LCE. Tucson Water could purchase electricity for about 7 to 9 cents/kWh as a hedge against future price increases. AEPCO and the electric cooperatives could purchase the RECs for 2 to 4 cents/kWh. One difficulty might be that a large plant could take 18 to 24 months to design, permit and erect, which would miss the 2008 deadline for the 30 percent tax credit.

5.3.2 Distributed PV Power Plant

Similarly, a contractual arrangement with cooperatives could be formed to purchase power from a 4 to 5. Bids could be received from develops for a 5 MW PV plant (and possibly forward price 5 MW per year for the next 3 to 4 years). Possible that price could be as low as 14 to 16 cents/kWh total LCE. Tucson Water purchases electricity for about 9 cents/kWh and Cooperatives get the RECs for 4 to 5 cents/kWh to satisfy the need for distributed generation RECs. These RECs would be less expensive than those associated with a $4/Watt rebate to customers. For example, if a $4/Watt rebate results in RECs at about 10 cents/kWh, assuming the PV produces 2,000 kWh/kW per year over a 20-year period.

5.3.3 Work with Other Utilities—APS and TEP

It might be possible to team up with solar developers and the AEPCO cooperatives to install a 100 MW plant on the Tucson Water Department site to sell the electricity and RECs to Arizona Public Service. The bids are due in March 2008.

5.3.4 Structure and Principles for a Agreement

The legal structure of a contractual agreement among the Tucson Water, AEPCO, and Trico could take several forms based on Arizona and local law. The actual legal entity for the agreement will need further discussion and negotiation. It may be a joint power agreement, an inter agency agreement (between non-profits), or some other legal entity binding the three public entities. The structure of the agreement is critical; however, it is equally important that the parties agree on the high-level principles for the project. These principles will dictate the success of the solar power installation. A summary of the major principles are as follows:

- The parties must agree that a large solar plant (CSP or PV) will be installed on the site and the electrical output will be connected to the local transmission or distribution system.
- All parties will work diligently to ensure that the majority of the electricity is used on-site for pumping loads, and any excess will be allowed to back-feed into the utility network. It may be that special interconnect and metering arrangements will be required to ensure proper settlement each month.
- The benefits from the PV or CSP plant will be clearly identified and properly assigned, including RECs, kWh, and demand savings.
- Project financial risks will clearly be defined and shared accordingly.
- All parties must be willing to participate in the project over a long term.

6 Summary and Conclusions

The Tucson Water Department and AEPCO have teamed up to finance the solar site assessment for the CAVSARP site northwest of Tucson. The summary and conclusions of the study are:

1. The 140-acre site located at the CAVSARP site has the ideal elements for installing a solar electric power plant. The site is flat, with very little tall vegetation, and has an above-average solar radiation level of 7.1 sun-hours per day of direct normal radiation. The site has immediate access to electric transmission lines and a large natural gas line running along the northern border. Water for power plant operation and maintenance would possibly be available from the local wells.
2. A CSP, which relies on direct normal radiation would perform well on the site. A 25-MW electric concentrating plant using parabolic troughs would fit on the 140-acre site with enough room for the associated piping, power block, and holding ponds.
3. If the entire square area bounding the 140-acre site were expanded to 560 acres, including the three adjacent plots, a 100 MW electric CSP plant could be installed.
4. An assessment of the local transmission and distribution lines indicates that either a 25 MW or 100 MW plant could be interconnected to the Trico or AEPCO system. However, it is recommended that a detailed load flow and protection study be carried out in conjunction with the utilities to verify the capacities.

5. The most economical option would be a 100 MW CSP trough-type plant with 6 hours of storage. A 100 MW plant reaches a reasonable scale of economy. It is recommended that Tucson Water obtain bids from solar developers for a 25 to 100 MW CSP plant at the site. Private developers can take advantage of federal tax credits and would be able to sell the electricity to Tucson Water at the lowest possible rates. To help share the costs, the renewable energy credits could be purchased by the electric cooperatives represented by AEPCO to meet their state renewable mandate. The combined price could be from 13 to 14 cents/kWh for the electricity and RECs over a 25 to 30 year power purchase agreement. Even lower prices might be obtained through a competitive bid process. In a partnership arrangement, Tucson Water might consider purchasing the electricity and allowing the cooperatives to purchase the RECs, or some combination of both. In that case, all parties would benefit from the project. It might be feasible to allow bidders the option to provide storage or natural gas backup if they are prepared to obtain the permits.

6. The cooperative utilities also have a mandate to buy distributed renewable energy from generators connected on the customer side of the meter. The large pumps at the CAVSARP site will be combined to be master metered at the Sandario substation. A total of about 4 to 5 MW of load will then be available for connecting to a PV power plant. It is recommended that Tucson and the cooperatives team up to accept bids from developers for a 4 to 5 MW plant to be installed in 2008. Although the price might be higher than for a CSP plant, PV provides flexibility because it can be installed in smaller blocks and can be added to in the future as prices drop. With competitive bids for a 25- to 30-year power-purchase agreement, the price should be 16 to 17 cents/kWh.

7. The site is also highly suited for a solar electric power plant mounted on steel structures that track the sun on a daily basis to increase daily and annual output. The site could accommodate up to 28 MW of PV. However, it is recommended that Tucson Water consider installing a plant that would provide the pumping loads. A 5 MW plant would provide peaking power to reduce peak loads on the Trico and AEPCO systems.

8. Arizona Public Service is accepting bids for a minimum 100 MW solar electric plant. They wish to purchase the electricity and the RECs. Bids are due in March 2008. It might be possible for Tucson and the cooperatives to team up with a developer to provide the services to APS.

9. An assessment of the permitting requirements for the various types of plants was carried out. The analysis indicates that permits could be obtained within a 1-year period. The quickest to be permitted would be a PV plant and the most extensive would be a CSP plant with natural gas backup.

7 Appendices

1. Kick off Meeting—presentation
2. Site GIS Maps 1 and 2
3. CAVSARP Pumps—electric bill analysis
4. Notes from Tour of APS Saguaro Plant
5. CSP Technology Discussion
6. PV Technology Discussion
7. PV Watts Runs

Tucson Water
Solar Energy Site Assessment
Project Kick-off Meeting

October 9, 2007

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Contents

1. Scope of the Project and Deliverables
2. Solar Technologies
3. Schedule
4. Go over List of Questions and Information to Gather

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Project Overview

- Assessment of the solar project potential on the Tucson Water 140 acre site
- Evaluate and assess available concentrating solar plant (CSP) and flat-plate photovoltaic (PV) technologies that could be installed on the site.
- Identify potential funding sources, incentives, and partnering arrangement that would optimize the project's economic, environmental and social benefits.
- Carry out a preliminary site assessment focusing on the available solar resource, land topography, and access to transmission and water.
- Based on various partnering arrangements, conduct a preliminary economic analysis for a concentrating solar plant and a PV plant that would fit on the site.

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Project Scope of Work Tasks

- Task 1 – Kickoff Meeting and Infrastructure Assessment
- Task 2 – Preliminary Solar Site Assessment
- Task 3 – Preliminary Solar Technology Assessment
- Task 4 – Financial Estimates and Potential Partnering Arrangements
- Task 5 – Project Management, Close Out and Reporting and next steps

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- Task 1 – Kickoff Meeting and Infrastructure Assessment

  - Initial meeting with CH2M HILL team to establish clear scope of work, finalize the study schedule and collect pertinent information.

  - Visit the 140-acre site and identify transmission access issues.

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- Task 1 – Cont'd

  -We have developed a list of questions and information to gather over the course of the study.

- Will work to define who will assist in gathering the information

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- Task 2 – Preliminary Solar Site Assessment

Calling on our staff experience with solar site assessments we plan to:

- Evaluate the solar resources of the site using NREL and Sandia data.
- Evaluate issues associated with connecting the solar plant to the electric grid and electric metering at the site
- Evaluate the existing electric loads at the site,
- Generally assess the topography of the site and its suitability for a large solar installation.
- Consider possible flooding issues at the site

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- Task 2 – Deliverables

  - Summary tables and data files of historical solar radiation information for the site including total radiation, DNI radiation, and temperature profiles.
  - GIS map layout of the site indicating solar data, electric transmission and distribution lines, substations and gas lines.
  - General layout of the existing site
  - Water issues at the site – supply and flood

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- Task 3 – Preliminary Solar Technology Assessment

  Evaluation of solar power plant technologies suitable for the site.

  We will evaluate parabolic trough concentrators and flat-plate photovoltaics. We will only consider commercially available technologies

  We will use publicly available computer models for evaluating the technologies with manufacturers data where available and appropriate

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Solar Power Plant Technologies

- We will also take a look at the new power tower techniques and linear concentrators and only consider commercially available options.
- Evaluate storage options and natural gas backup
- Three basic types of systems:
  - Troughs (linear), central receiver, parabolic dish

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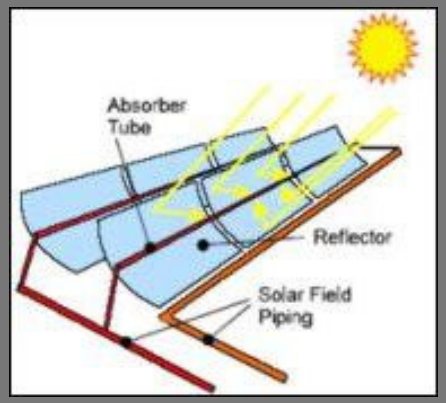
Solar Power Plant Technologies



Parabolic Trough

- Utilize parabolic-shaped mirrors to reflect and concentrate sunlight onto receiver tubes located in the trough's focal line
- Heat transfer fluid (HTF) circulated through receiver tubes at ~750°F.
- HTF pumped through heat exchangers to produce steam, which powers conventional turbine generator in a closed loop cycle

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Some of the Players in the CSP Market Troughs (linear)

- Acciona (formerly Solargenix)
  - the Luz troughs concentrator technology with improved mirrors, receiver and power block. Recently completed the 64 MW plant in Nevada desert. They have contracts in Spain, Greece, Italy and the US.
- Solar Millenium
  - Also have a trough technology but further behind in development than Solargenix
- Ausra – Australian Company
  - Compact Linear Fresnel Reflector, or CLFR. Mirrors reflect onto a tube with water flowing. DIrect to steam and drive turbine. Have tested in Australia – but have not built one yet with the power block.

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- Ormat/Solargenix - Organic Rankine
  - **Saguaro Solar** Power Plant – 1 MW in Red Rock. Arizona Public Service

Well suited for small plants, unattended.

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Central Receiver Technologies

BrightSource

- Luz carryover guys that are making a small version of the central receiver (power tower) in 20 MW blocks. 5 blocks clustered together to make 100 MW plant. Steam turbines – no storage. Have applied for a permit for 400 MW plant in Southern California.

- Rocketdyne
  - Continuation of the Power Tower Concept. High temperature molten salt with storage capabilities

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BrightSource

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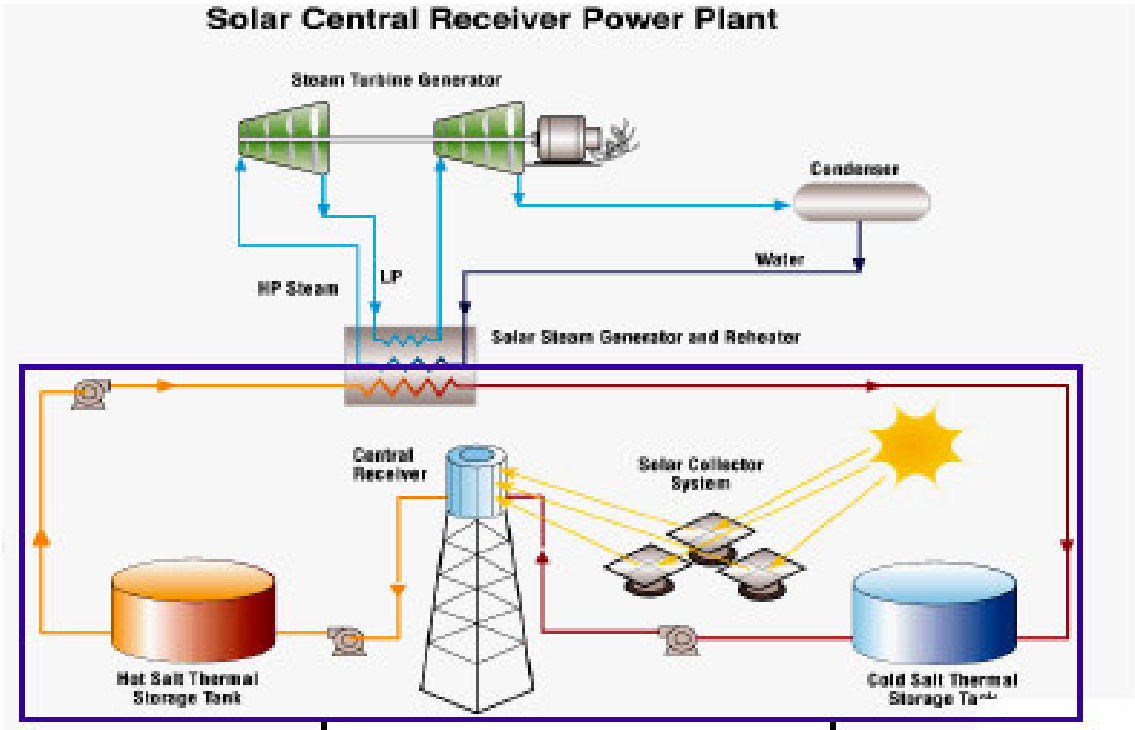
Rocketdyne – Power Tower



Rocketdyne Focus – Solar & Molten Salt System

Collect:

- Sunlight concentrated on tower receiver
- Molten salt heated to 1050F

Store:

- Large scale molten salt thermal storage

Dispense:

- Plant sizes 15 to 100+ MWe
- Long-term electricity cost
  ~5 ¢/kWh Stand Alone
  ~3 ¢/kWh Hybrid
- Dispatchable or 24 hour solar power
- Plant capacity factor raised from 25% to over 65%

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Other CSP Players

- Stirling Energy Systems (SES)
  - Uses parabolic dish to concentrate on a target with a stirling engine. Have a contract for up to 850 MW with Southern California Edison (PPA). Only have built about 300 kW of test units.

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Stirling Energy Systems (SES)

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Solar **Photovoltaics** Power Plants

- Utilize flat-plate PV in megawatt-scale power park
- Scalable technology, easy to site and permit
- Prices dropping steadily

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Solar Photovoltaic Plant Players

Manufacturers

- SolarWorld, BP, Schott, Kyocera, Sharp, Sanyo, SunPower
- Many new players to the market – Asian, Indian, Germany and Spain

Developers

-SunEdison
-SunPower/Powerlight
-Turner Renewables
-Global Solar (now Solon)

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- Task 3 – Deliverables

  - Description of the applicable solar technology that will be suitable for the site showing matrix of options
  - Plant operating characteristics and estimated water requirements
  - Expected maintenance requirements
  - Expected annual energy production
  - Capital cost estimates
  - Include storage options and natural gas backup

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- Task 4 – Financial Estimates and Potential Partnering Arrangements
- Prepare a preliminary economic analysis for PV and Parabolic Trough options
- Will include state, local and Federal incentives
- Will consider partnerships with other public and private entities
- Will consider funds that Tucson may have in place
- Renewable Energy Credits and the Arizona goals for renewables
- Third party financing options to take advantage of tax incentives

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- Task 4 – Deliverables

-Matrix showing priority of available partnerships and project financing, and available technologies.

- Descriptions of various partnerships, financing and tax credits that are available and how to maximize them.

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- Task 5 – Project Management, Close Out and Reporting

  We will provide Project Management services throughout the project

  Final report after discussions with Tucson Water staff

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- Schedule

  Proposed to cover about 2.5 to 3 month period. Assuming we start in October - completion in end of December 2007

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- Questions
- Discuss project questions and information to gather

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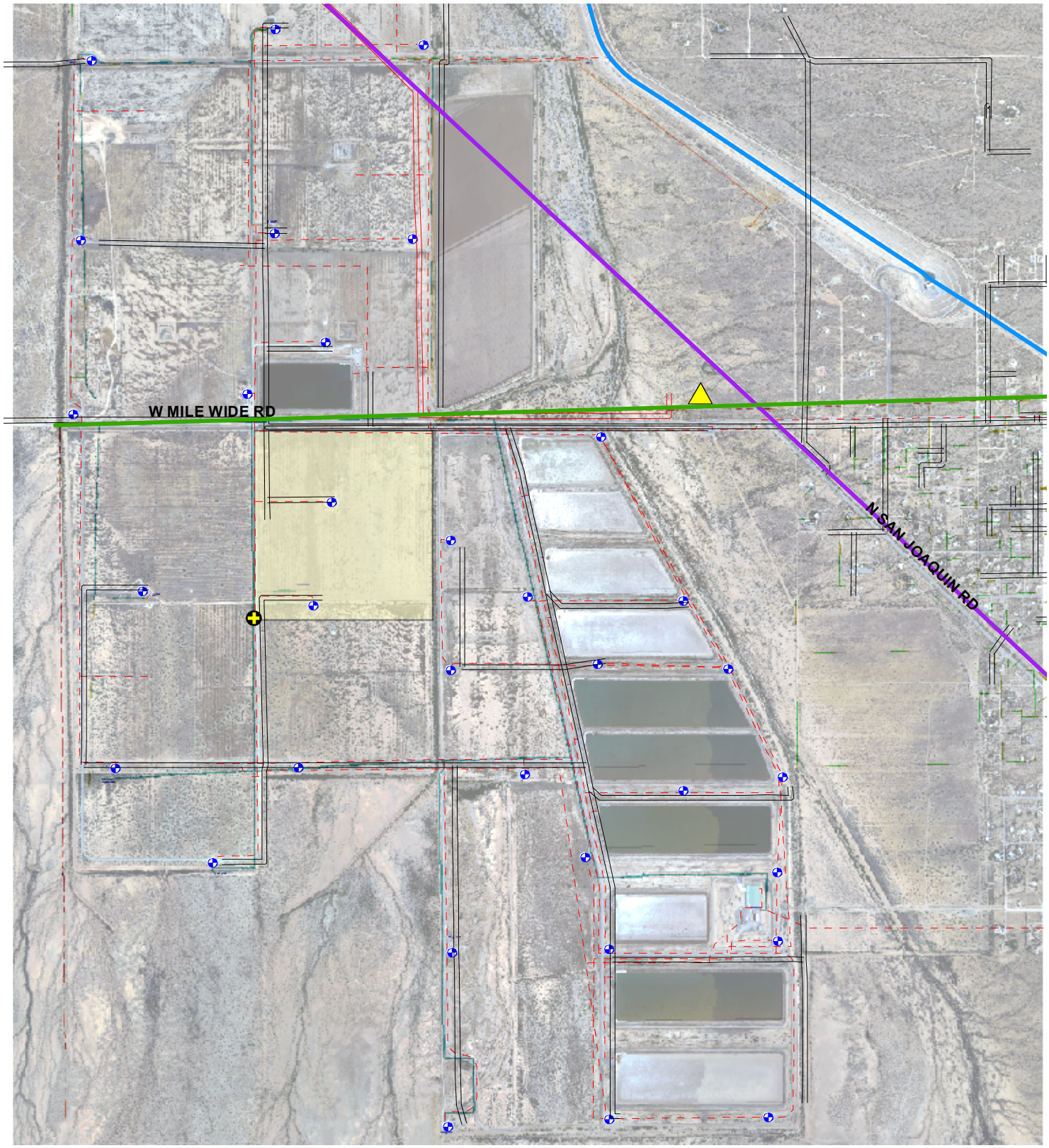

Legend

- SW Gas
- El Paso Gas
- SW Transmission (115 kV)
- Trico Distribution Lines (24.7 kV)
- SW Substations
- CAVSARP Pipelines
- TW Production Wells
- CAP Aqueduct
- 140 Acre Solar Plant
- Water

N

0 1,000 2,000

Feet

MAP 1.
PROPOSED 140-ACRE SITE LAYOUT WITH UTILITIES IN PLACE

TUCSON WATER SOLAR COLLECTOR SITING STUDY

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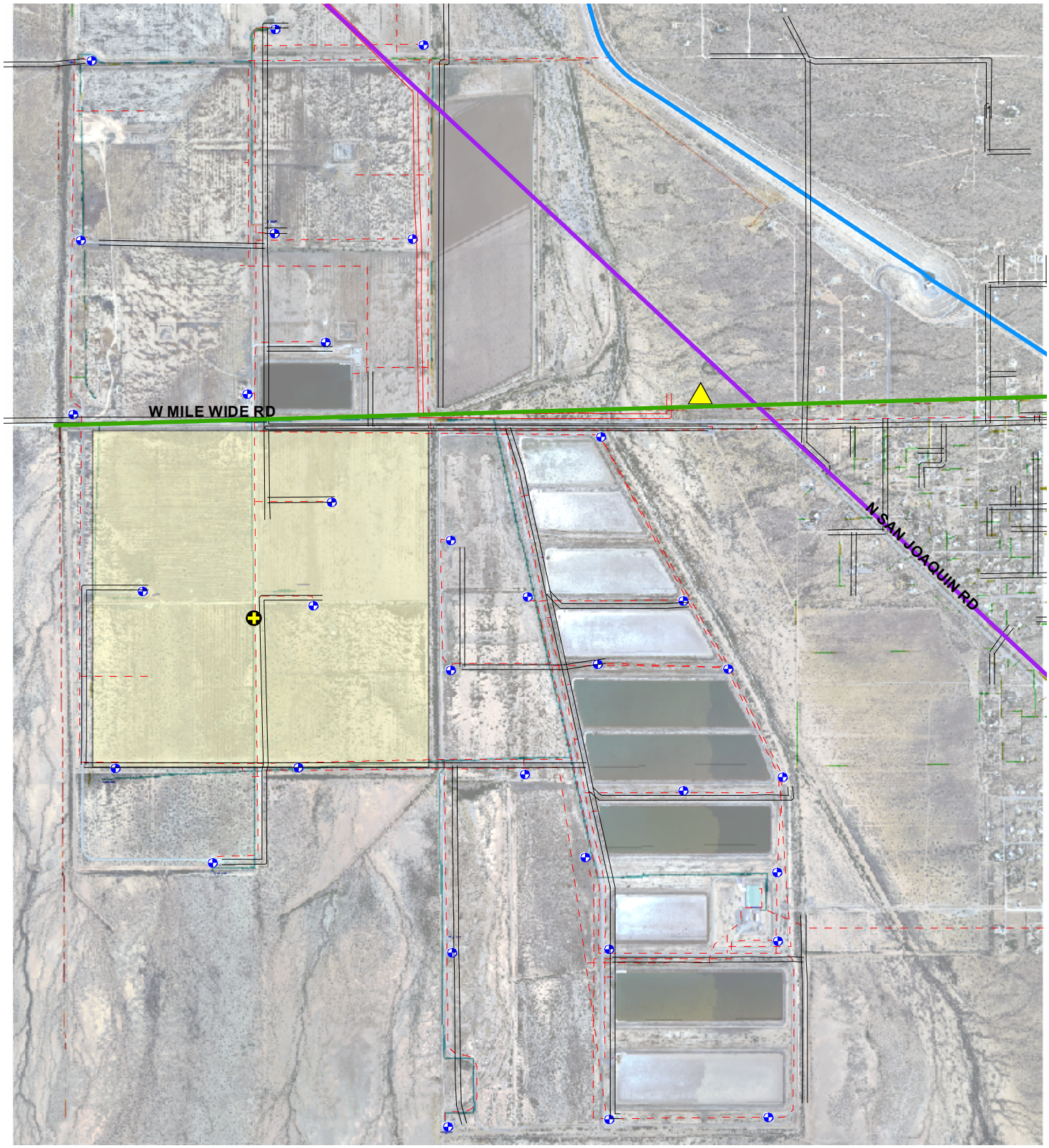

Legend

- SW Gas
- El Paso Gas
- SW Transmission (115 kV)
- Trico Distribution Lines (24.7 kV)
- SW Substations
- CAVSARP Pipelines
- TW Production Wells
- CAP Aqueduct
- 560 Acre Solar Plant
- Water

N

0 1,000 2,000

Feet

MAP 2.
PROPOSED 560-ACRE SITE LAYOUT WITH UTILITIES IN PLACE

TUCSON WATER SOLAR COLLECTOR SITING STUDY

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Appendix 3 – Analysis of April 2007 electric bills for pumps at CAVSARP site

BILLING INFORMATION FROM TRICO

TRICO_ACC	ADDRESS	RATE_CD	BILL_DT	METER_NO	BILL_AMT	CURR_READ	PRIOR_READ	USAGE_QTY	KW_USAGE	(1) KW Load	(2) Avg $/kWH	A $ Energy	B Fuel	C $Base	D Tax	E Total 4
130300	AV-12 5698 SANDARIO	IS2/3	5/9/2007	LGK00181	$5,822.04	10848	10028	65600	2.04	101.23	0.0888	$4,187.90	$1,312.00	$40.00	$310.23	$5,850.14
132600	AV-7 7300 MARSTELLAR RD	IS2/3	5/9/2007	LGK00183	$4,405.19	19286	18049	49480	2	76.36	0.0890	$3,158.80	$989.60	$40.00	$234.55	$4,422.95
2322600	11701 N THORNYDALE	IS2/3	5/9/2007	NHH00011	$8,873.59	102077	5426	96651	355.21	149.15	0.0918	$6,170.20	$1,933.02	$40.00	$456.02	$8,599.24
3053500	CA-003A WELL	IS2/3	5/9/2007	LGK00169	$11,559.71	16606	14970	130880	2.47	201.98	0.0883	$8,355.38	$2,617.60	$40.00	$616.73	$11,629.71
3053900	CA-002A WELL	IS2/3	5/9/2007	LGK00173	$11,524.54	16313	14682	130480	2.44	201.36	0.0883	$8,329.84	$2,609.60	$40.00	$614.85	$11,594.29
3169200	BOOSTER 4,5,6 & 7	IS2/3	5/9/2007	LGK00172	$48,432.67	19590	17870	550400	3.26	849.38	0.0880	$35,137.54	$11,008.00	$40.00	$2,586.39	$48,771.93
3198300	CA-005A WELL	IS2/3	5/9/2007	LGK00184	$13,500.39	19616	17704	152960	3.21	236.05	0.0883	$9,764.97	$3,059.20	$40.00	$720.39	$13,584.56
131800	F-1 13163 W CASTLE RD	IS2P3	5/9/2007	QGK00093	$407.15	61879	57780	4099	0.02	6.33	0.0993	$261.68	$81.98	$40.00	$21.48	$405.15
131900	F-3 12050 W CORNELL DR	IS2P3	5/9/2007	QGK00094	$492.56	86477	81413	5064	0.01	7.81	0.0973	$323.29	$101.28	$40.00	$26.02	$490.58
132800	AV-5 BSTR 6565 SANDARIO	IS2P3	5/9/2007	LGK00182	$4,638.01	7999	7691	49280	0.05	76.05	0.0941	$3,146.04	$985.60	$40.00	$233.61	$4,405.25
2871000	BOOSTER 1,2 & 3	IS2P3	5/9/2007	LGK00171	$30,098.07	14191	13130	339520	0.02	523.95	0.0886	$21,674.96	$6,790.40	$40.00	$1,596.30	$30,101.66
3061300	AF-036B WELL	IS2P3	5/9/2007	LGK00175	$11,936.31	19201	17515	134880	0.01	208.15	0.0885	$8,610.74	$2,697.60	$40.00	$635.51	$11,983.85
3061400	CA-001A WELL	IS2P3	5/9/2007	LGK00170	$15,768.46	27659	25428	178480	0.01	275.43	0.0883	$11,394.16	$3,569.60	$40.00	$840.21	$15,843.97
3205700	17595 W RAYMOND RD	IS2P3	5/9/2007	LGK00160	$341.32	1120	1035	3400	0.01	5.25	0.1004	$217.06	$68.00	$40.00	$18.20	$343.26
3455100	13071 W MILE WIDE-WELL	IS2P3	5/9/2007	LGK00167	$15,051.25	24996	22867	170320	0.01	262.84	0.0884	$10,873.23	$3,406.40	$40.00	$801.90	$15,121.53
3455200	12875 W MILE WIDE RD	IS2P3	5/9/2007	LGK00168	$14,446.54	24159	22116	163440	0.01	252.22	0.0884	$10,434.01	$3,268.80	$40.00	$769.60	$14,512.41
3455300	13375 W MILE WIDE RD	IS2P3	5/9/2007	LGK00180	$15,571.58	22136	19933	176240	0.01	271.98	0.0884	$11,251.16	$3,524.80	$40.00	$829.69	$15,645.66
3682800	CA-013A 13502 W MILEWID	IS2P3	5/9/2007	LGK00159	$11,127.69	18379	16808	125680	0.01	193.95	0.0885	$8,023.41	$2,513.60	$40.00	$592.31	$11,169.32
3682900	CA-011A (WELL)	IS2P3	5/9/2007	LGK00177	$10,115.17	17175	15748	114160	0.01	176.17	0.0886	$7,287.97	$2,283.20	$40.00	$538.23	$10,149.40
4425900	13585 W MILE WIDE RD	IS2P3	5/9/2007	LHK00231	$8,947.95	11862	10601	100880	0.01	155.68	0.0887	$6,440.18	$2,017.60	$40.00	$475.88	$8,973.65
4426600	12995 W MILEWIDE RD/WELL	IS2P3	5/9/2007	LHK00233	$17,167.71	23949	21519	194400	0.01	300.00	0.0883	$12,410.50	$3,888.00	$40.00	$914.96	$17,253.45
Averages/totals					$260,227.90			2936294		4531.32	0.0886	$187,453.01	$58,725.88	$840.00	$13,833.06	$260,851.95

Appendix 4 –Note From Tour of APS Saguaro plant –

1 MW CSP – October 10, 2007

I had the opportunity to visit and tour the 1 MW Saguaro CSP solar plant located north of Tucson. The plant is owned and operated by Arizona Public Service and is located adjacent to their existing natural gas thermal plant. It is basically an unattended plant. I was lucky to have the gas plant manager give me a detailed presentation and tour of the solar plant. Following are my field notes.

General

The solar plant, which is still considered an RandD facility uses the latest technological design for parabolic troughs developed by Solargenix (now Acciona) with and Ormat organic rankine low temperature turbine/generator. This is actually the first trough system (or for that matter CSP) plant built in the US in 15 years since the Luz plants in the Mojave desert. The receiver tubes were manufactured by Schott Glass and the mirrors were by Frabeg, both German companies. The plant has been in operation for 1-year.

Technology

The solar array field comprises 6 rows of mirrored troughs a and receive tubes. Two rows make up a thermal loop which uses a non-toxic mineral oil as the heat transfer fluid. The fluid is heated by the array field to about 500 F and flows to a heat exchanger. The heat exchanger loop uses Pentane which is similar to an anti-freeze that vaporizes at a low temperature (it can vaporize at atmospheric pressure as low as 130 to 150 F). The Pentane is sent to a 1-MW packaged/skid-mounted turbine generator manufactured by Ormat. The condenser located above the turbine generator re-liquefies the pentane using a cooling water loop, that in this case is a wet-cooling tower. The high pressure pentane is returned to the heat exchanger at about 325 F for reheating. The mineral oil is returned to the solar field for reheating at about 200 F.

Array Field

The array field is actually slightly oversized compared to the turbine generator. The troughs and receivers are the latest technology similar in design to the ones used by Acciona (Solargenix) – at the 64 MW plant recently finished in Nevada. Here is the layout: There are six rows - each row is 1300 ft. long, the troughs are 15 ft. across, and the row spacing is 60 ft. Thus, the array field covers approximately 11.6 acres. Each row has 4 tracking motors that have two speeds – high speed for stowing and low speed for tracking. The motors are driven by an algorithm that calculates where the sun should be and the motor drive keeps the troughs tracking the sun throughout the day. An inclinometer and pyroheliometer (solar meter) makes the fine tuning adjustments. The array is typically within 0.5 of the sun. If the mineral oil gets to hot every other row of troughs is moved off track from the sun to reducing heat temperature increase. The array is designed to stow every other row at 25 MPH wind, and at 35 MPH all rows stow. It is designed to survive up to 100 MPH winds.

Water Issues

The system includes (based on the permit requirements) a 1.2 acre holding pond for blow down water and run-off. This is part of the state permit requirement. They periodically check to make sure oil is not filming on the top of the holding pond. If oil is detected in the water it must be sucked-up and not allowed into the environment. The holding pond is double layered and designed to hold the water and sediment for up to 20 years. Daily requirement for cooling makeup water is about 2500 to 3000 gpd. They went to a wet cooling process because the parasitic loads for a dry cooling process would have been excessive and significantly reduced plant efficiency.

Permitting

The permitting took about 14 months. They needed state air and water permits for the site. Federal permits were note required.

Grading and water sheeting issues

The site basically has to be graded and leveled – even though the site was relatively flat. The site has a slight pitch from north to south to allow for water run-off and it is surrounded by berms to avoid water sheeting. Rather than cover it with pea gravel that would have potentially been a liability in high winds regarding the mirrors – the ground cover is compacted native soil with a non-toxic oil to bind the top layer.

Mounting Structure

The mirrors are attached to an aluminum space frame for support. The structure is mounted on steel pillars on concrete piers are 12 to 14 ft deep and about 18 inches in diameter. The array could withstand sheeting water or standing water up to 1 ft.

O&M

The major O&M issues having been washing the mirrors, several motor drives blew out – but have been traced to a particular sealing issue, a few mirrors have broken, and they have had to vent the expansion tank on the generator several times per year. They fully clean the mirrors twice per year. A full cleaning includes spraying and squeegee cleaning each mirror. It is done at night to avoid sudden shock to the mirrors resulting in breakage. The cleaning takes 3 people 3 full nights. The process uses about 10,000 gallons of dionized water. They also spray wash (not a full cleaning) the mirrors twice per year which uses about 3,000 gallons of water and can be completed in 1 night.

Costs and output

The system cost $6 million all installed. The array field is actually sized to provide about 2.5 to 3 MWe so the costs are a little off weight. Cost per kw would be reduced with larger turbines and arrays and when the system is mass produced on a larger scale. Next generation plants will be in the range of $3,000 to $4,000 per kW. The system is projected to operate at an annual capacity factor of about 23 % which would produce about 2,000 MWh per year. According to the plant manager the system appears to be down by about 150 kW per hour which could be attributed to an bad expansion valve.

Appendix 5 CSP Technology Discussion

Solar thermal power plants produce electricity in much the same way as conventional power plants. The principal difference between the two is that conventional plants utilize fossil fuels (e.g., coal or natural gas) to create high-temperature steam to drive a turbine, while solar thermal plants concentrate solar radiation and use the resulting heat to create steam or gas to drive a turbine or motor engine. Solar thermal systems can also be used directly for building and industrial process heating and water desalination.

Four main elements are required for any solar thermal power system: a concentrator, a receiver, transport media or storage, and power conversion. Solar thermal technology can be combined with other conventional and renewable power technologies to create many different types and sizes of power plants, depending on the location and the required application.

Currently, there are three types of concentrating solar power collector systems used for the production of electricity: parabolic trough systems, central receivers, and parabolic dish engine systems. These systems are distinguished principally by the way in which they collect the solar energy, and each can be integrated with fossil fuel combustion systems to improve system reliability and scalability. The various solar thermal technologies and configuration options are described briefly in the following subsections.

Parabolic Trough

Trough systems utilize parabolic-shaped mirrors to reflect and concentrate sunlight onto receiver tubes located in the trough's focal line (see Figure 5-1). A thermal transfer fluid (usually synthetic thermal oil) circulates through the receiver tubes, and is heated to approximately 750°F (400°C) by the concentrated sunlight. The heated oil is pumped through heat exchangers to produce steam, which is converted to electrical energy in a conventional steam turbine generator (SunLab, 1999). Alternatively, the receiver tubes could provide direct industrial process heating, water or space heating, or direct steam generation.

Figure 5-1
Parabolic Trough System

(Source: FLAGSOL, 2006)

Individual parabolic trough units are installed together in collector fields. The troughs are installed in parallel rows aligned on a north-south axis, and utilize a tracking system with a mechanical drive controlled by a programmable logic controller to track the sun from east to west during the day (SunLab, 2004). Parabolic trough units can be built in modular units up to approximately 200 MW (ESTIA, 2005). The required size of the solar field for a given plant capacity is in general directly proportional to the level of direct normal (i.e., perpendicular) insolation at the site (SDRREG, 2005).

Nine parabolic trough plants (collectively known as the Solar Electric Generating Station, or SEGS plants) were built in the Mojave Desert of Southern California in the mid-to-late 1980s (DOE and EPRI, 1997a). These plants have a combined capacity of 354 MW, and have an annual gross solar production of approximately 600,000 MWh (SDRREG, 2005). These plants have been operating continuously since construction, with an annual availability of approximately 96 percent (SDRREG, 2005).

Based on the success of the SEGS plants, project developers and investors view parabolic troughs as a low-to-moderate risk technology that is ready for commercial deployment. As part of an assessment of CSP technologies prepared for the San Diego Regional Renewable Energy Group in 2005, NREL concluded that parabolic trough technology is the only large-scale (greater than 50 MW) CSP technology that is available for application in a commercially-financed power project over the next five years (SDRREG, 2005).

Central Receiver

A central receiver utilizes hundreds of sun-tracking mirrors called heliostats to reflect sunlight onto a tower-mounted receiver (DOE and EPRI, 1997b). The heat captured at the receiver is used to generate steam, which, in turn, is used in a conventional turbine-generator to produce electricity (ESTIA, 2005). Alternatively, molten nitrate salt can be used as the heat transfer fluid to improve heat transfer and energy storage capabilities. Future

commercial plants will likely be sized to produce between 50 to 200 MW of electricity (SunLab, 2004).

The technical feasibility of central receiver technology was first demonstrated during the 1980s. Eight research power plants ranging from 0.5 MW to 10 MW were constructed in Europe, Japan, and the U.S. (DOE and EPRI, 1997b). The total net electrical capacity of these demonstration plants was 22 MW, with an installed heliostat mirror area of approximately 40 acres (160,000 m^2) (ESTIA, 2005). The largest of these projects was called Solar One, which operated from 1982 to 1988 near Barstow, California (see Figure 5-2). During this period Solar One produced over 38,000 MWh of electricity (SunLab, 2004). The plant consisted of a 300-foot tall central receiver and 1,818 heliostats, spread over an area of 72 acres (DOE and EPRI, 1997b).

Figure 5-2
Aerial View of Solar One

(Source: Sandia National Laboratory, 1999)

Solar One was retrofitted in 1988 to demonstrate the feasibility of molten salt for heat transfer and thermal storage (SunLab, 2004). The new plant was re-named Solar Two and was operated between 1996 and 1999 (SunLab, 1998). The central receiver was built using hundreds of vertical tubes through which molten salt was circulated and heated to as high as 1,050°F (565°C). The molten salt was then drained to a thermal storage tank, from which it was pumped through a heat exchanger to generate steam, which powered a conventional turbine to generate electricity (SunLab, 1998). Solar Two successfully demonstrated the efficient collection of solar energy and dispatch of electricity, even during cloudy conditions and after sunset (SunLab, 2004).

Based on the successful conclusion of the Solar Two project, an international consortium of companies and institutions, including Bechtel, Boeing, and Sandia National Laboratories, was formed to help commercialize the technology (SunLab, 2004). A number of small

(<10 MW) central receiver projects have been proposed for development or are in construction in Spain, France, South Africa, Egypt, Morocco, and Italy. However, central receiver technology has not yet been demonstrated in a large-scale (>50 MW), commercial operating environment, and as such there remains significant uncertainty in the cost and performance of these systems (SDRREG, 2005).

Parabolic Dish Engines

A parabolic solar dish engine uses a mirror array to reflect and concentrate incoming sunlight to a receiver (DOE and EPRI, 1997c). The receiver consists of a bank of tubes filled with hydrogen or helium gas. As the gas is heated by the concentrated solar energy, it expands in volume and drives the pistons of a Stirling engine, which provides the mechanical power needed to rotate a crankshaft. The crankshaft drives a generator to produce electrical power (SunLab, 2001).

A Stirling engine's cylinder block includes four sealed cylinder assemblies (pistons, piston rods, and connecting rod domes) along with coolers, regenerators and heater heads (Stirling Energy Systems [SES], 2006). There is no combustion in a Stirling engine; the working gas is exchanged back and forth between the sealed cylinders, which are offset by 90 degrees. The alternate heating (expansion) and cooling (contraction) of the working gas drives the engine at a steady rate of 1,800 rpm. The crankshaft drives the generator that produces electricity with an output of 480 volts and 60 hertz. The generator of each unit in a utility-scale project would be connected by underground wire to a substation where the power could be transformed into a higher voltage for more efficient transmission across the grid (SES, 2006).

Figure 5-3
Stirling Energy Systems Parabolic Dish Engine

(Source: Stirling Energy Systems, 2006)

Parabolic dish concentrators are comparatively small units, usually 15 to 50 feet (5 to 15 meters) in diameter and capable of producing 5 to 50 kW of power output, with 25 kW being the current most economical size. Dish systems are modular in nature, and can be installed in arrays to accumulate power up to the megawatt range. However, the current market for dish/engine systems lies in decentralized power supply and remote, stand-alone power systems (ESTIA, 2005). One potential advantage of dish systems over parabolic trough and central receiver systems is that no water is required for cooling, which can be a significant benefit in desert environments such as the Southwest U.S. (SDRREG, 2005).

Dish engine systems have the highest performance of all solar concentrating technologies. A solar-to-electric efficiency of 30 percent has been achieved using these systems (ESTIA, 2005). The dish structure is designed to track the sun in two axes to continuously reflect the solar energy to the thermal receiver. Dish systems can also be integrated with high efficiency solar photovoltaic cells for concentrating photovoltaic applications (NREL, 2006c).

A number of dish engine prototype systems have been installed in the Southwest U.S., Spain, and Germany. The Nevada Solar Dish Power Project was established in 2002 to supply a 1 MW array of dish engine systems in Southern Nevada. In 2004, Stirling Energy Systems (an American dish developer) built six dish/engine systems of 25 kW each at a test facility at Sandia National Laboratories (Sandia, 2004). SES has recently been contracted to supply several hundred megawatts of solar power to utilities in Southern California. However, parabolic dish engine systems are likely at least 5 years away from commercial-scale deployment.

Compound Linear Fresnel Reflector

A type of parabolic trough technology called a Compound Linear Fresnel Reflector (CLFR) array has been installed at a large coal-fired power station in New South Wales, Australia. CLFR systems approximate a parabolic trough using flat, segmented mirrors installed in rows at ground level, with a linear receiver located approximately 30 feet above the mirrors. The advantage of this configuration is that the mirrors can be installed using lightweight steel supports, thus significantly reducing collector costs. Steam is generated directly in the receiver, avoiding the need for a mineral oil heat transfer fluid. A 1-MW pilot system was successfully installed in 2004, and will be expanded to 5 MW as part of a demonstration trial (Solar Heat and Power [SH&P], 2004). The solar array will ultimately be expanded to 40 MW and the heat will be used for pre-heating of boiler feed water at the power station (Research Institute for Sustainable Energy [RISE], 2006). This system increases the electrical output of the coal station (ESTIA, 2005).

(Source: ESTIA, IEA SolarPaces, and Greenpeace International, 2005)

Major Players

Most of the project development effort in the current CSP market is focused on parabolic trough technology. Key stakeholders in the CSP market include project and equipment

developers, key component suppliers, power plant engineering and construction firms, utilities, and solar research laboratories.

Project and Equipment Developers

The following companies are involved in project development or engineering/development of CSP systems (NREL, 2007a):

- **Solargenix Energy/ACCIONA Energía** – Solargenix Energy (formerly Duke Solar Energy) develops parabolic trough projects alone and as joint ventures with U.S. domestic and international partners (Solargenix, 2006). Solargenix has developed an advanced parabolic trough collector design that has been installed at the 64-MW Nevada Solar One project being developed outside Boulder City, Nevada. Solargenix is a subsidiary of ACCIONA Energía, a large Spanish company specializing in renewable energy project development (ACCIONA, 2005).

- **Abengoa/Solúcar Energía** – Abengoa is a Spanish technology company focused on sustainable development in the environmental and energy sectors (Abengoa, 2006). Abengoa is a major player in the European renewable energy sector. Solúcar Energía is a holding company of Abengoa that focuses on the development, construction, and operation of solar thermal plants (Abengoa, 2006). Solúcar is currently engaged in construction of the PS10 and PS20 central receiver projects in Spain, and has been involved with development of advanced trough collectors and direct steam generation technology. Abengoa recently created Solúcar Power, Inc., a U.S. subsidiary that will respond to utility requests for CSP technologies in the U.S. (Renewable Energy Access [REA], 2007). Solúcar Power has purchased the assets and technology of Industrial Solar Technology Corp. (IST), which manufactures parabolic trough collectors for industrial and commercial applications, including water heating, industrial process heating, building heating, and steam generation (IST, 2005).

- **Solar Millennium AG** – Solar Millennium has developed an advanced trough collector design called the SKAL-ET collector with funding from the European Union. These collectors are being installed at the Andasol plants being constructed in Spain. The company, headquartered in Germany, offers services ranging from project development to engineering to construction oversight. FLAGSOL GmbH is a subsidiary of Solar Millennium. Solar Millennium has strategic alliances with the DLR, which supports parabolic trough development, and with Grupo Cobra/ACS Group, a large Spanish construction services company currently building the parabolic trough projects in Spain.

- **SENER Grupo de Ingeneria**– SENER is a Spanish engineering and consulting company focused on the development of heliostats, trough collectors, molten salt solar thermal systems, and direct steam generation technology (SENER, 2006). SENER is the engineering, procurement, and construction (EPC) contractor for the Solar Tres project, as well as the Andasol parabolic trough projects. SENER worked with aerospace giant The Boeing Company for four years in the development of the solar receiver which will be used at the Solar Tres facility (REW, 2006).

- **Luz II, LLC** – Luz II is a startup company led by the management team that founded Luz Industries, the original developer of the SEGS plants. Luz II has developed a Distributed Power Tower technology (DPT 550) that utilizes relatively small, flat glass mirrors and a central tower with a steam receiver. The DPT 550 technology will be designed to have a solar-to-electric efficiency of 20 percent, and a solar field cost of $\$150/m^2$. A 100-MW plant will require a 500,000 m^2 solar field, giving a total solar field cost of approximately $750/kW (UPI, 2006). Pacific Gas & Electric Company (PG&E) recently signed a Memorandum of Understanding with Luz II to purchase 500 MW of solar energy from Luz II power plants, which will be built in 100 MW units (PG&E, 2006). Luz II has plans to develop thirteen 100-MW power plants by 2013 (Luz II, 2007).
- **Solel Solar Systems, Ltd** – Solel is an Israeli company that designs, manufactures, and installs utility-scale parabolic trough plants. Solel purchased the manufacturing assets of Luz Industries, which developed the nine SEGS plants in Southern California (SDRREG, 2005). Solel has developed an advanced-generation trough collector called the SOLEL #6 (Solel, 2006). In November 2006, Solel signed an agreement with Spanish construction firm Sacyr-Vallehermoso to build three 50-MW parabolic trough plants in Spain (World Peace Herald, 2006).
- **FPL Energy** – FPL Energy has owned and operated the SEGS VIII and IX plants since 1989 and 1990, respectively. In February 2005, FPL Energy and private equity partners Carlyle/Riverstone purchased the SEGS III through SEGS VII plants (FPL Energy, 2005). FPL Energy operates the plants and holds a 45 percent ownership stake in the facilities, making it the largest generator of solar power in the United States.
- **Stirling Energy Systems (SES)** – SES manufactures 25-kW parabolic dish engines. SES has recently signed two power purchase agreements with utilities in Southern California to deploy thousands of dish engine systems in large solar parks.
- **Infinia Corporation** – Infinia is developing a 3-kW Stirling engine that will produce up to 9 MWh of electricity per year, based on a 34 percent capacity factor (Infinia, 2005). The engine will be combined with a concentrator of 86 percent efficiency designed by Schlaich Bergermann und Parnter. The system will have an overall efficiency of 24 percent, and will weigh 985 pounds. The system will also supply 6 kilowatts thermal (kW_{th}) of 122ºF (50ºC) hot water. Infinia intends to market this unit as an alternative to solar photovoltaics (Infinia, 2007).
- **Schlaich Bergermann und Parnter (SBP)** – SBP is developing a 10-kW parabolic dish engine known as the EuroDish, and has installed a number of these systems at test facilities in Europe. SBP is also the structural engineering firm for the Andasol parabolic trough plants.
- **United Technologies Corporation (UTC)** – Through their Pratt & Whitney Rocketdyne, Inc. subsidiary, UTC is engaged in the development of central receivers, heliostats, and molten salt thermal energy storage systems for central receiver systems (UTC, 2005).

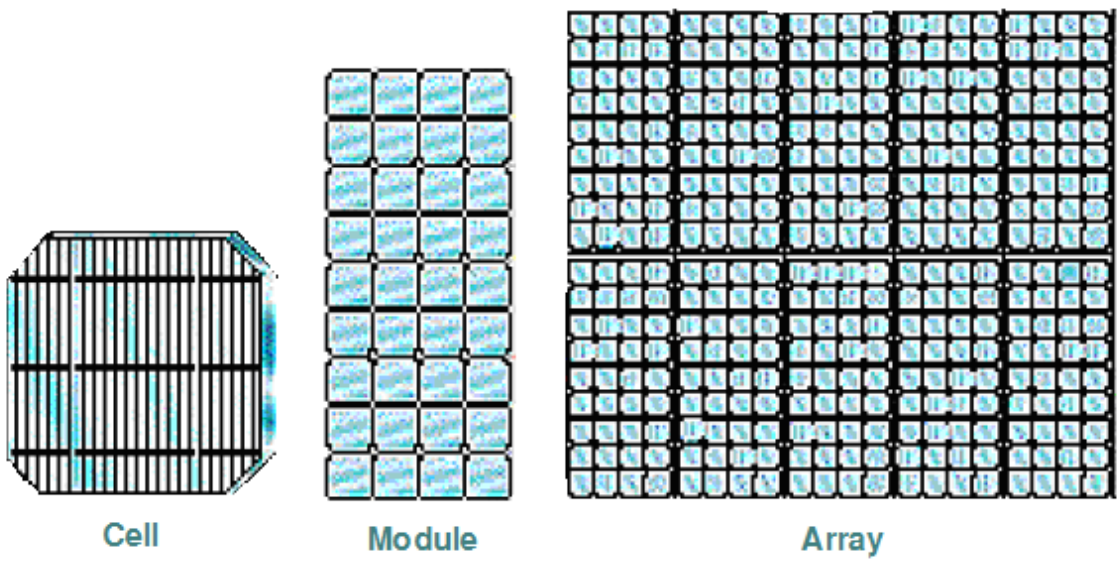
- **Science Applications International Corporation (SAIC) –** SAIC is developing second-generation parabolic dish engine prototypes and heliostats for central receiver plants (ESTIA, 2005).
- **Ausra –** Ausra bought the Australian firm Solar Heat and Power, which developed the CLFR project at the coal-fired power station in New South Wales, Australia. Ausra is now looking to expand the market for CLFR technology in the United States.

Appendix 6 PV Technology Discussion

PV power systems use solid-state devices that use the photoelectric effect of materials with semiconductor properties to convert the energy from the sun directly to usable power. PV technology got its start in the space program, but has progressed through the material science and manufacturing economy to the threshold of usable terrestrial technology for power generation.

PV generation is a fundamentally different technology than fossil fuel based technologies. It consumes no fuel, emits no waste, and has extremely low lifetime operating costs. The solar array is an assembly of solar modules, which themselves are an assembly of solar PV cells, the primary unit of electricity generation.

Figure 6.1-
Solar Cells and Modules



The solar cell technology and materials define its performance as efficiency, the Watts out per Watts in from the sun. Laboratory efficiencies are around 10 years ahead of commercial production. As cells are combined into modules, and then modules into arrays or systems, efficiencies drop. In a complete grid-tied system, inverters and power conditioning to make power suitable for transmission also degrade total efficiency.

Table 6.1-
Current Solar PV Efficiencies

Material	Lab Efficiency (2006) at STC	Commercial Cell efficiency (2006) at STC	Commercial Module Efficiency (2006) at STC	Commercial System Efficiency (2006)
Mono Crystalling Si	24%	15-22%	13-20%	11-18%
Multi Crystalline Si	20.3%	11-17%	8-14%	7-13%
a-Si	13.2%	7-10%	5-7%	4-6%
CIGS	19.5%	12-13%	9-11%	8-10%

STC references Standard Test Condition - 25C, 1000w/m2
Air Mass 1.5 global spectrum

PV arrays can readily combine with incumbent generation technologies. Because peak PV output is coincident with peak demand, PV is useful for peak shaving and avoiding or delaying costly upgrades to capacity or transmission and distribution lines.

The major parameters that affect the performance of a PV installation are location and technology. Location is important because different regions receive different incident annual solar energy. A given 10MW facility sited in Germany will generate considerably fewer MWh than one sited in Southern California because of incident solar insolation (kWh/m^2/time). Technology is important because it defines the installation's conversion efficiency ($Watts_{out}$ /$Watts_{in}$), site selection criteria, lifetime, and overall cost. Other system components, like inverters, wire, etc., perform at their rated level regardless of location.

Peak Watts (Wpdc) is a measurement of the amount of DC power produced under standard test conditions (25 °C, 1000 W/m^2) and is the primary unit to measure a PV installation's capacity. The panel design and materials comprising the PV panels determine the Wpdc. There are many different technologies within PV, many targeted at specific niches. Once sited and installed however, these differences in technologies do not generally effect power generation.

Crystalline Silicon

Crystalline silicon PV representing 85-90 percent of the market, uses technology developed for the microelectronics industry to process pure silicon into wafers and wafer-based modules. Silicon is well understood, safe, and has ideal properties for converting solar energy to usable electricity. However, silicon is also expensive, in part because the processing techniques developed by the microelectronics industry did not consider the volumes and price pressures of PV. The price of silicon is a very significant cost driver for a finished crystalline silicon PV module. Crystalline silicon PV operations are often measured in grams of silicon consumed per Watt. Current best-in-class silicon consumption is 9-12 grams per Wp. Because of the dependence of crystalline silicon PV manufacturers on a silicon

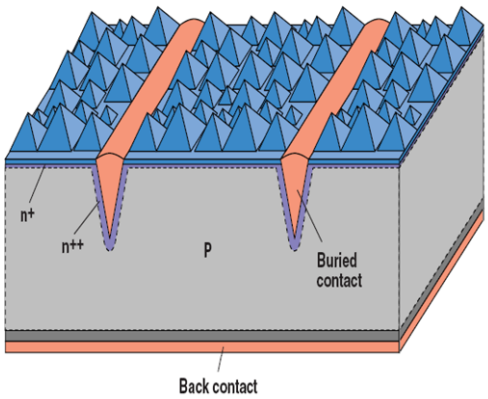
feedstock, many companies are becoming vertically integrated, or entering into long-term contracts for the supply of silicon. Other silicon processing technologies (ribbon, granular, etc.) are also emerging that may reduce silicon dependence by reducing silicon process waste and cost. Other than availability of silicon, many of the PV manufacturing processes are becoming integrated under a single company's solar agenda.

The generic crystalline silicon PV process shown above has many elements in common across technologies. Automation and economies of scale will play a large role in lowering crystalline silicon PV costs over the coming years. To better understand crystalline silicon PV processes, it is convenient to divide it into two major technology divisions: monocrystalline, and multicrystalline.

Monocrystalline

Monocrystalline PV is the most efficient and most expensive non-concentrating PV option. Monocrystalline panels, representing 28 percent of the total market, produce the most power per square meter in a given location at full sun, and the best monocrystalline panels operate at ~20 percent, meaning that they produce ~200 W/m^2 (the Solar Constant ~1000 W/m^2). The high performance of monocrystal PV is the result of more complex and expensive materials, structure, and processing technology. Manufacturers in monocrystal, for example, use light trapping surface geometries, and buried or back contact device structures to improve efficiency and justify the higher cost of their base material. Because of monocrystalline performance and expense characteristics, they are best suited for area-constrained applications like residential rooftops, or limited land area where maximizing W/m^2 is critical. Manufacturer IP and process expertise is vital to monocrystalline performance and success in the marketplace.

Figure 6.2-
MonoCrystalline PV Technology



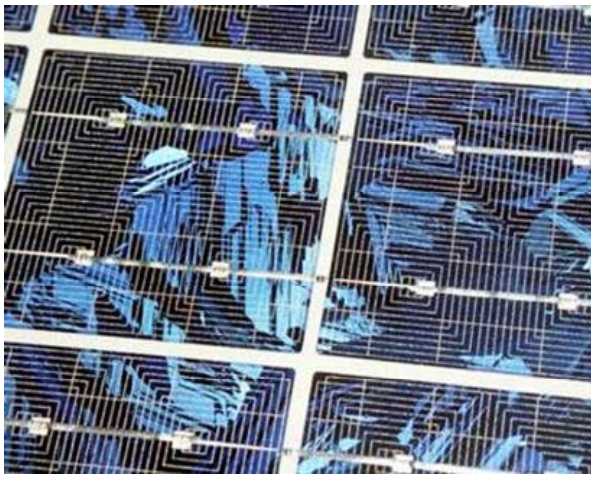
Monocrystalline PV technology typically uses round or semi-round wafers sawn from single crystal ingots pulled almost exactly like those for microelectronics. Pulling single crystal ingots requires pure material, a lot of heat, and considerable time. These ingots are cut into wafers 200-300 microns in thickness with an equal amount of kerf loss (waste material

generated by the cutting tool) before being prepared for the cell process. Cells are the primary generating unit and make 2-3 W. Modules are typically made of 70-180 PV cells, glass, plastics, and an aluminum frame. Strings of modules form an array. Finally, in a grid-tied installation, an inverter changes the module's DC output to AC power meeting the interconnecting utilities' grid requirements.

Multicrystalline

Multicrystalline silicon panels, representing 56 percent of the total market, are not as efficient as monocrystalline panels, but are less expensive per Wpdc. Multicrystalline PV structures and materials are less expensive and complex, and produce lower W/m^2 at a given location. Technical features and performance are important for multicrystalline panels; however, cost is a significant driver. The price of silicon feedstock heavily impacts multicrystalline panel producers; however, their processes are faster and less complex, leading to lower overall costs.

Figure 6.3
Multicrystalline PV Technology



Multicrystalline PV uses wafers sawn from square ingots melted and cast in quartz vessels. Kerf loss is a major issue for multicrystalline PV production. All crystalline silicon PV technologies work to slice wafers thinner for decreased silicon usage. Reducing the amount of grams of silicon per Watt is a major research area for PV manufacturers.

Thin Films

Thin-film PV, representing currently less than 10 percent of the market, has recently received a lot of attention because of its potential ability to reduce cost by simplifying the manufacturing process, and by using lower quantities of materials. In thin-film PV, the semi-conducting material, deposited in an additive process, consists of layers only a few microns thick. The deposition technology, a transplant from the flat panel display and printing industries, is mature and well understood. Thin film offers the possibility of continuous roll-to-roll production, on very large or even flexible substrates, drastically cutting costs per area. The flexibility and substrate options make it very attractive for building integrated structures.

However, commercial thin film efficiencies remain significantly lower than crystalline silicon efficiencies. Many companies and research organizations are working to improve thin film efficiencies with material science and innovative substrate geometries, and the commercialization of these innovations will likely grow the thin films market share to 20% by 2010. Thin films often utilize more uncommon or potentially hazardous material like cadmium.

Within thin-film PV there are three major technologies, Amorphous Silicon (a-Si), Cadmium Telluride (CdTe), and Copper Indium (Gallium) Selenide (CI(G)S).

Amorphous Silicon (a-Si)

Amorphous silicon is a thin film technology based on the deposition of silicon in a disordered, non-crystalline way. The silicon layer is around 1 micron, reducing material costs when compared to crystalline silicon's 400 microns per wafer thickness. When using deposition, amorphous silicon is not limited to wafers. Using existing flat panel display equipment, a-Si can be deposited on module-sized substrates, potentially eliminating all the assembly associated with a smaller cell process and reducing overall process costs. Amorphous silicon PV is currently the leader among thin film PV technologies, and is popular for low power consumer devices. Recently, a-Si has been used in conjunction with monocrystalline wafers to further increase efficiencies, however by itself, a-Si still has too low of efficiencies to be a dominant option as residential power generation.

Copper Indium Gallium Selenide (CIGS) & Cadmium Telluride (CdTe)

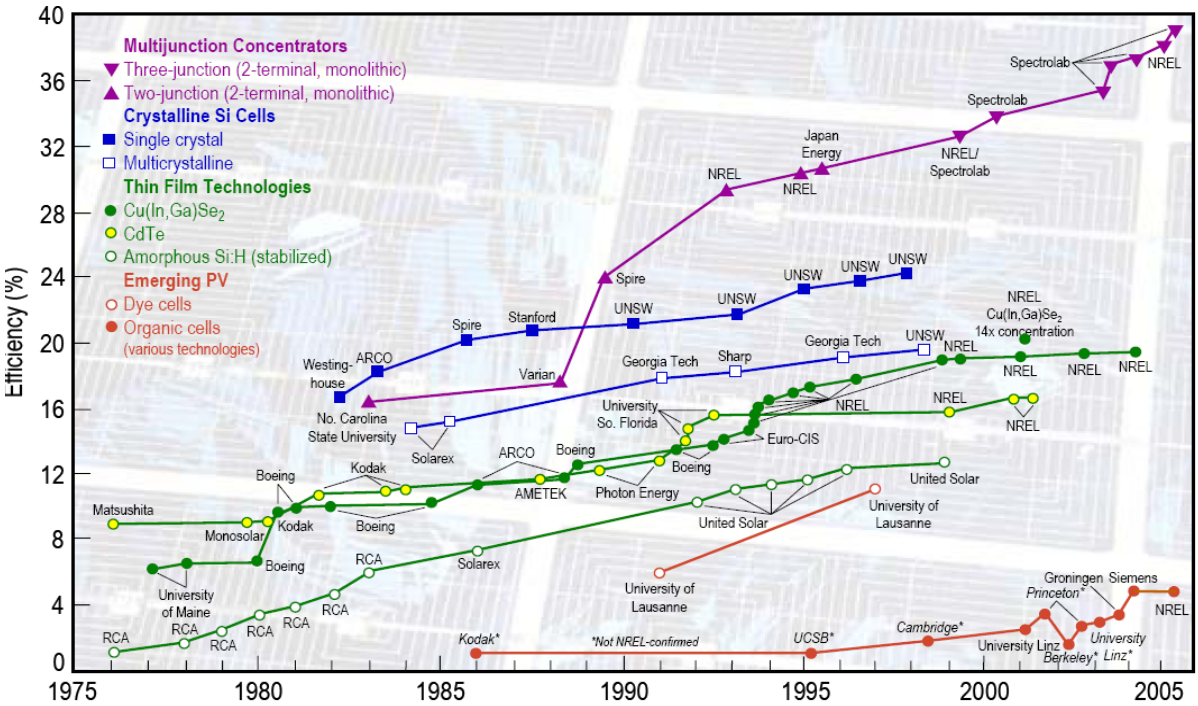
CIGS or CIS PV has the highest efficiencies of thin film PV options in the laboratory (19 percent); however remain at 9-10 percent in commercial modules. Along with other thin film PV technologies, CIGS has great potential for cost savings because of lowered material usage, and the potential for large substrate processing. Because of the possible advantage over other thin film PV in efficiencies, CIGS is one of the most promising thin film technologies. Although there is no silicon in CIGS PV cells, indium costs are up dramatically because of rising demand from the flat-panel display and PV industries. CIGS is also more sensitive to defects and manufacturing variation, as well as high temperatures under operating condition.

Concentrating Photovoltaics

Concentrating photovoltaic (CPV) systems use optics, typically either a parabolic mirror or a Fresnel lens, to concentrate solar energy onto PV cells. The increased insolation from the concentrating optics is measured in "suns," which is simply a multiple of the standard 1000 W/m^2 insolation rate. CPV systems have the potential to reduce costs compared to conventional, flat plate PV systems by reducing the amount of semiconductor material required to make the PV module. Reducing the amount of semiconductor material allows the manufacturer to use the most efficient, and thus the most expensive, material to achieve higher densities. The two principal developers of CVP systems are Amonix, of Torrance, California, and Solar Systems Pty, Ltd, of Australia. The Amonix system uses a Fresnel lens, while the Solar Systems Pty, Ltd uses a parabolic mirror.

Research and development currently focuses on reliability, cost reduction, and advanced cell technology, e.g., III-V multijunction technology.

Figure 6.4
Laboratory Efficiencies of PV Cells



(Source: SETP 2007)

AC Energy & Cost Savings

Station Identification	
Cell ID:	0185374
State:	Arizona
Latitude:	32.3 ° N
Longitude:	111.3 ° W
PV System Specifications	
DC Rating:	1.00 kW
DC to AC Derate Factor:	0.770
AC Rating:	0.77 kW
Array Type:	1-Axis Tracking
Array Tilt:	20.0 °
Array Azimuth:	180.0 °
Energy Specifications	
Cost of Electricity:	0.0 ¢/kWh

Results

Month	Solar Radiation (kWh/m²/day)	AC Energy (kWh)	Energy Value ($)
1	6.05	141	
2	6.85	140	
3	8.39	187	
4	9.67	205	
5	10.14	215	
6	10.13	203	
7	8.70	180	
8	8.30	174	
9	8.71	178	
10	7.81	170	
11	6.66	145	
12	5.51	128	
Year	8.08	2066	206.60

Appendix 7.1 - PV Watts Computer Model Results for 20 degree tilt, Single Axis Tracker in Tucson. 1 kW DC system normalized for scale-up. Default electric pricing (not for Tucson study)

AC Energy & Cost Savings

Station Identification	
Cell ID:	0185374
State:	Arizona
Latitude:	32.3 ° N
Longitude:	111.3 ° W
PV System Specifications	
DC Rating:	1.00 kW
DC to AC Derate Factor:	0.770
AC Rating:	0.77 kW
Array Type:	1-Axis Tracking
Array Tilt:	0.0 °
Array Azimuth:	180.0 °
Energy Specifications	
Cost of Electricity:	0.0 ¢/kWh

Results			
Month	Solar Radiation (kWh/m²/day)	AC Energy (kWh)	Energy Value ($)
1	4.95	116	
2	5.92	123	
3	7.69	174	
4	9.36	200	
5	10.26	218	
6	10.44	209	
7	8.85	183	
8	8.16	172	
9	8.12	168	
10	6.87	152	
11	5.51	122	
12	4.43	103	
Year	7.55	1939	

Appendix 7.2 - PV Watts Computer Model Results for 0 degree tilt, Single Axis Tracker in Tucson. 1 kW DC system normalized for scale-up. Default electric pricing (not for Tucson study)

AC Energy & Cost Savings

Cautions for Interpreting the Results

Station Identification	
Cell ID:	0185374
State:	Arizona
Latitude:	32.3 ° N
Longitude:	111.3 ° W
PV System Specifications	
DC Rating:	1.00 kW
DC to AC Derate Factor:	0.770
AC Rating:	0.77 kW
Array Type:	Fixed Tilt
Array Tilt:	30.0 °
Array Azimuth:	180.0 °
Energy Specifications	
Cost of Electricity:	0.0 ¢/kWh

Results

Month	Solar Radiation (kWh/m²/day)	AC Energy (kWh)	Energy Value ($)
1	5.26	119	
2	5.69	114	
3	6.54	145	
4	7.12	149	
5	7.06	147	
6	6.96	137	
7	6.42	131	
8	6.20	128	
9	6.72	135	
10	6.29	135	
11	5.74	124	
12	4.89	112	
Year	6.24	1575	

Appendix 7.3 - PV Watts Computer Model Results for 30 degree tilt, Single Axis Tracker in Tucson. 1 kW DC system normalized for scale-up. Default electric pricing (not for Tucson study)