Feasibility of Implementing a Photovoltaic Array at Eastern Sierra Regional Airport in Bishop, CA

Eric Muckley

University of Tennessee Knoxville, TN 37996

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Abstract

Owens Valley in eastern California receives some of the highest insolation in the United States, but its solar energy production is currently limited by environmental constraints. However, solar energy generation at airports is becoming an attractive alternative to utility-scale solar plants far from large population centers. Photovoltaic (PV) implementation at the Eastern Sierra Regional Airport in Owens Valley would bypass many environmental constraints and alleviate some of the strain on Bishop's energy supply, which is used primarily to pump groundwater to the city. This paper proposes implementing a 60 acre, 9 MW array of 15-17% efficiency PV modules with single-axis tracking on currently unused land at Eastern Sierra Regional Airport. It is estimated that the proposed project can achieve a levelized energy cost of 3.5 ¢/kWh. This LEC is less than the average wholesale electricity price in California of between 4 and 7 ¢/kWh, and significantly less than the average residential electricity rate of 20.06 ¢/kWh in Bishop. Depending on future changes in wholesale electricity prices, it is estimated that the proposed 9 MW array can result in profits of between 17 and 100% if the PV array operates for a 25 year period.

Introduction

Despite improvements in technology, high generation and distribution costs currently prevent solar energy from achieving grid parity. Insolation levels and real estate prices require that most utility-scale (>1 MW) solar plants are located in deserts far from large population centers where energy is consumed. Long-distance transmission and distribution of power from producers to consumers accounts for over 6% of the energy lost in the United States each year [1]. In an effort to move energy production closer to consumers, reduce transmission loses, and avoid high real estate prices, many municipalities have incorporated solar energy collectors into existing urban structures like rooftops, parking garages, and airports.

Solar energy generation at airports has recently attracted attention because of the proximity of airports to existing grid infrastructure, high-density population centers, and flat land which is either undervalued or cannot be commercially developed because of aircraft

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flight patterns. Solar concentrator systems are generally not suitable for installation at airports because of issues with reflectivity, vertical airspace penetration, and the presence of thermal plumes [2]. However, photovoltaic (PV) projects have been implemented (or are currently under construction) at several major airports in the United States, including those in Denver, Bakersfield, Indianapolis, and Oakland.

Owens Valley in eastern California is an attractive location for airport PV development because it receives some of the highest insolation (2400 kW m^{-2} yr^{-1}) in North America and houses a 100 kV transmission line which connects Los Angeles to the Pacific Northwest [3]. However, several plans to develop large solar projects in Owens Valley have been unsuccessful in the past. These include a Los Angeles Department of Water and Power (LADWP) proposal for a 3,100 acre, 200 MW PV ranch in southern Owens Valley. The LADWP plan has remained under review since 2010 because of resistance from the public for its proximity to cultural and archaeological sites (including Mount Whitney and Manzanar National Historic Site) and for its anticipated negative environmental impact [4]. The environmental costs associated with solar plant development should not be underestimated; the owners of the Ivanpah solar project in California's nearby Mojave desert have spent over $20 million to mitigate habitat destruction of the threatened California desert tortoise, which is native to the project site [5]. PV projects on airport property are typically immune from severe environmental and cultural constraints because airport property is generally cleared of vegetation and historical structures for aircraft safety reasons.

In addition to its high insolation and proximity to transmission lines, northern Owens Valley makes an attractive site for solar power generation because of its high electricity prices. In the city of Bishop, the average residential electricity rate in 2014 was 20.06 ¢/kWh [6], nearly 17% higher than the state average of 16.94 ¢/kWh [7]. High energy prices in Bishop affect not only electricity costs, but water costs as well. Treatment and transport of water and wastewater accounts for up to 35% of energy expenditures by municipalities in the U.S. [8]. These costs are exacerbated in Bishop, where all of the municipal water is pumped out of the ground, resulting in correspondingly high costs to pump operators [9]. This is reflected in the $59.58 flat rate monthly water and sewage bill for a single family residence in Bishop [10], which is nearly 19% higher than the state average of $49.25 [11].

Solar energy is not a perfect source of electricity. Changes in insolation, cloud cover, and seasonal cycles cause solar energy output to be variable and unpredictable in nature. This makes seamless incorporation of solar energy into the electricity grid especially challenging. For grid stability to be maintained, solar energy generation must be complimented with power plants that have enough output flexibility to respond to rapid grid fluctuations [12]. Hydroelectric plants are highly flexible in nature and allow for rapid changes in energy output. Of the sixteen closest power plants to Bishop, fifteen are hydroelectric plants [13]. This makes the area around Bishop especially viable for the development of variable energy generation projects like PV arrays.

This study aims to explore the economic feasibility of installing a PV array at the Eastern Sierra Regional Airport, also known as Bishop Airport, in Bishop, CA. In the following sections, we describe the exact location and size of the proposed PV array and estimate the

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costs associated with its implementation. Finally, we estimate the profitability of the project for different wholesale electricity prices and operation lifetimes.

Project Proposal

The proposed project involves the implementation of a 60 acre PV array in the city of Bishop, CA. The proposed site lies entirely on Bishop Airport property which is not currently developed for aeronautic purposes. The majority of land surrounding the city of Bishop is owned by the LADWP [4], which severely limits the amount of municipal development which can take place outside the city limits. This lack of development not only makes it difficult to install a solar plant near the city; it also means that no major residential or commercial development will take place which would significantly increase the size of the local population and warrant expansion of the bishop airport. Therefore, conversion of non-aeronautic land into aeronautic land on the airport property in the near future is unlikely. This makes the unused land on the airport property especially attractive for the development of a PV array.

The Bishop Airport (KBIH), is owned by the City of Los Angeles and managed and operated by Inyo County. The airport occupies a total of 830 acres and lies 2 miles east of the city of Bishop. A map of the proposed site for the 60 acre PV array site is shown in Fig. 2. The site is flat, has access to roads, is clear of major vegetation, and is removed from aircraft takeoff and landing routes. Adjacent to the proposed site is a series of sewage treatment ponds. The close proximity of the site to the ponds suggests that the implementation of PV structures will not significantly reduce property values or impact an especially environmentally sensitive area.

This proposal explores the feasibility of installing heterojunction with intrinsic thin-layer (HIT) silicon PV modules[1], which exhibit power conversion efficiencies of 15-17% [14]. Focus is placed on these particular modules because of the availability of recent data on the implementation and performance of these and similar devices in MW-scale PV arrays [14, 15, 16]. In addition to using relatively high efficiency PV modules, electricity production per unit area can be maximized by employing sun-tracking technology. Single-axis sun-tracking systems which cost roughly 10% of the total project cost can increase energy generation by 15% or more [15]. In order to maximize energy output from the proposed 60 acre site, we include the cost of single-axis tracking in our proposal.

There are several aspects of PV project analysis which are not discussed in this proposal. These include taxes associated with the project, future rates of inflation, future inflation of electricity prices, and land-leasing costs. The costs estimated in this proposal do not include the cost of the land on which the proposed site is located. If the project is principally undertaken by the LADWP, which owns the entire proposal site, then it is reasonable to neglect the land cost because no purchasing or leasing of additional land is required. It is possible that it would be more cost effective for LADWP to instead lease the land to a

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[1]A HIT PV module, developed and sold by Sanyo Electric Co., consists of a thin layer of monocrystalline silicon sandwiched between two ultra-thin (nanometer-scale) layers of amorphous silicon. Since charge separation occurs in the monocrystalline silicon layer, estimates of efficiency losses and degradation over time discussed here are adapted from studies on monocrystalline silicon, not amorphous silicon.
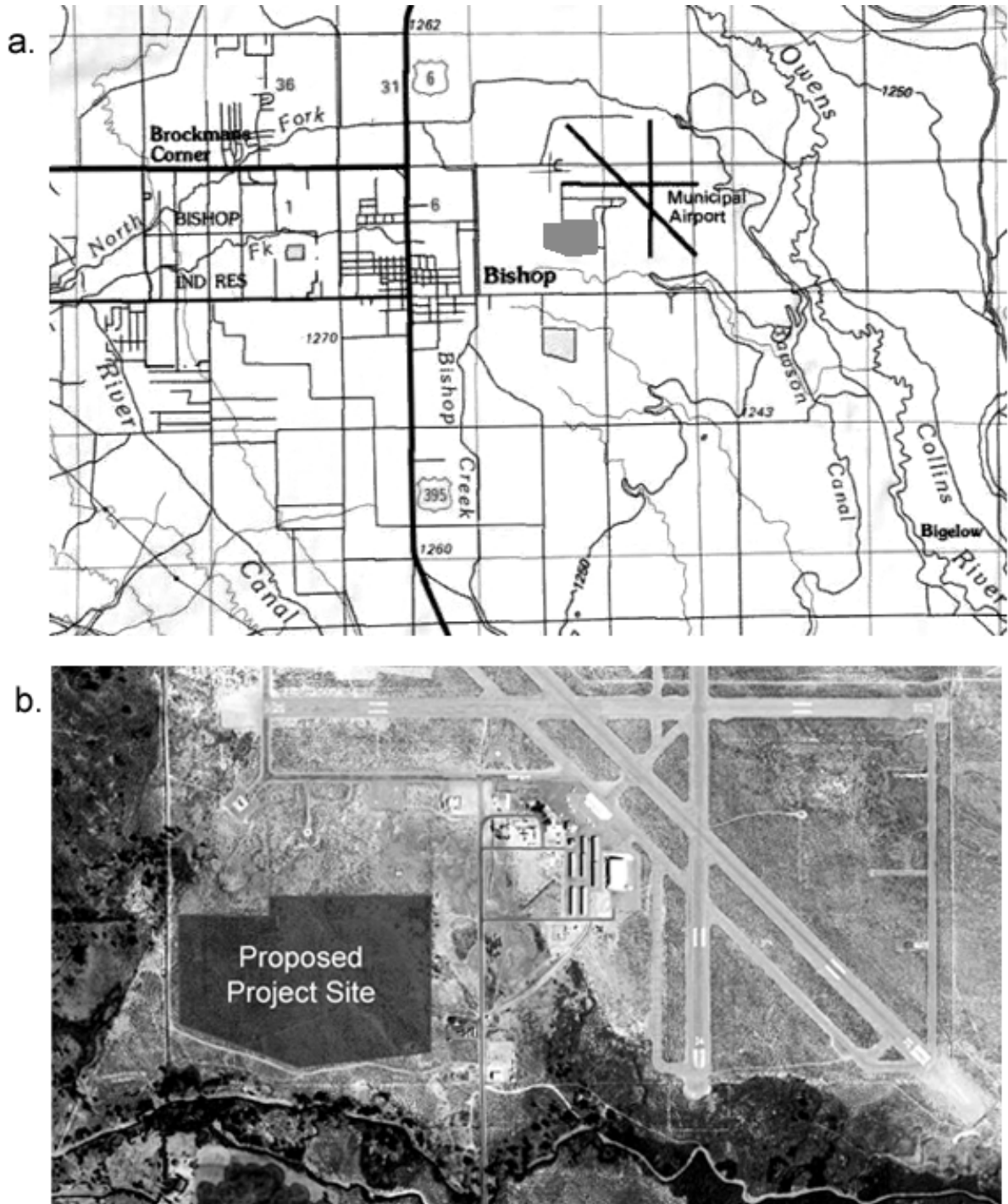
Figure 1: a. The 60 acre site lies on unused airport land about 2 miles east of the city of Bishop. The site is highlighted in gray in the center of the map. The lighter gray region just south of the proposed site marks the location of the sewage disposal ponds. b. A satellite image of the airport reveals that the site is flat, clear of vegetation and structures, and has access to existing roads and grid infrastructure.

third-party solar developer who would then undertake the project. This proposal will focus on a scenario in which LADWP owns and manages the project directly. This is a reasonable assumption because of LADWP's recent willingness to develop solar generation capacity [4].

Economic Analysis of Proposal

A useful economic analysis of PV array implementation requires estimations of several important parameters. These include the initial system cost, operation and maintenance costs, energy output of the system over time, and the levelized energy cost (LEC) of the system. The current industry standard is that PV panels are expected to retain over 80% of their initial efficiency after 25 years, and are protected under warranty during that period. For the remainder of our cost analysis estimates, we will assume that the proposed PV array will be operational for 25 years before substantial costly retrofitting must take place.

We first estimate the amount of energy the system will produce over its lifetime. Using modules with efficiencies in the 15-17% range, MW-scale PV arrays typically achieve power densities of between 150 and 200 kW/acre [14, 16]. At the conservative estimate of 150 kW/acre, a 60 acre site can accommodate a maximum power output of 9 MW. After energy loses due to cloud cover, non-peak sunlight hours, seasonal changes, and DC to AC conversion, it is expected that a 9 MW system will produce at least 15 million kWh annually [14]. Due to semiconductor degradation and the development surface scratches, HIT silicon PV modules typically exhibit output losses of roughly 0.36% per year [17]. Taking this degradation into effect, the total energy E_{tot} generated over the 25 year lifetime of the project is

$$E_{tot} = \int_0^{25} (15 \times 10^6 \ kWh)(1 - 0.36\% \times t) \ dt \approx 3.6 \times 10^8 \ kWh$$

where t is the duration of the project operation time in years. For the remainder of this analysis, we assume that the proposed PV array will produce 3.6 $\times 10^8$ kWh, or 360 GWh, during its lifetime[2]. Implementation of the proposed project would increase LADWP's current electricity generation capacity of 7200 MW by about 0.125%, which is a small but helpful step towards achieving California's ambitious Renewable Portfolio Standard (RPS) of 33% renewable energy consumption by 2020.

We now estimate the initial capital cost of implementing the proposed system. A breakdown of the expected costs of a 9 MW array of HIT silicon PV modules is shown in Table 1. The expenses are adapted from [15], where the costs of implementing a similarly-sized array are thoroughly expounded. Here, we estimate that the initial capital cost of the system is roughly $11.9 million. This estimate neglects the cost of the land on which the proposed site is located. If the project is undertaken by a third-party, then land leasing costs would be included here.

To get an idea of the total cost of the project over its lifetime, it is important to account for costs associated with normal day-to-day system operation and unexpected servicing. These

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[2]The average fossil fuel-burning power plant in the United States emits about 2.6×10^8 kg (287,000 tons) of CO_2 in order to generate this much energy [18].

Table 1: Breakdown of PV installation costs (adapted from [15]).

Expense for 9 MW Array	Estimated Cost (Thousands of Dollars)
PV module purchase and installation	5,890
Mounting structures and brackets	1,180
Single-axis sun-tracking technology	1,180
Purchase and installation of inverters	883
Cables and wiring	589
Inverter and control room	442
Data acquisition, grounding protection	368
Purchasing and testing of transformers	265
Meters, isolators, lighting	265
High tension panel	221
Engineering and labor	221
String combiner boxes	177
Insurance	132
Distribution boxes, batteries, chargers	118
Total	**11,900**

costs include regularly-scheduled maintenance, unexpected electrical and mechanical repairs, module cleaning, removal of vegetation, visual inspections, and power inverter replacements. Each year, MW-scale PV plants are expected to incur total maintenance and repair costs equal to between 0.1 and 0.2% of the initial capital investment [19]. Using a value of 0.15%, an array with an initial capital cost of \$11.9 million should incur a total system cost C_{tot} over its 25 year lifetime of

$$C_{tot} = \$11,900,000 \times (1 + [0.15\% \times 25]) \approx \$12,300,000.$$

Making useful statements about the economic feasibility of the proposed PV array necessitates an estimation of the levelized energy cost (LEC). LEC estimates for PV installment are relatively simple because PV plant costs are dominated by initial capital and require little in the way of maintenance and fuel for ongoing operation. The LEC calculation is further simplified if we assume that the discount rate on the investment will be similar to the rate of inflation of electricity prices [20]. Using these guidelines, we can simplify the estimate of the LEC by

$$LEC = \frac{C_{tot}}{E_{tot}} = \frac{\$12,300,000}{3.6 \times 10^8 \ kWh} \approx 3.5 \ \text{¢}/kWh.$$

The LEC estimated here is roughly half that of the 2014 average LEC for crystalline silicon utility-scale PV systems (between 7 and 9 ¢/kWh) [21]. One reason for this difference is the cost of land, which is neglected for in our estimate. The purchasing or leasing of land on which to implement a PV array can contribute to a large percentage of the total project cost, which leads to a significantly higher LEC.
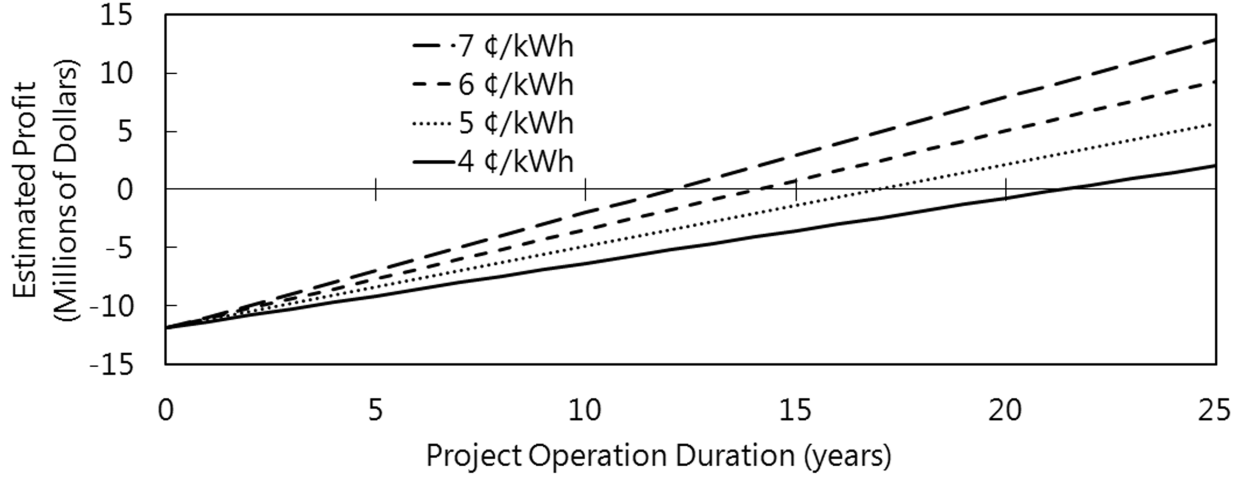
Figure 2: Estimated profit generated from the proposed project. The profit starts below zero, signifying that the project operates at a loss for several years before becoming profitable. The four different lines represent profits if the electricity is sold at different wholesale prices. Unsurprisingly, selling electricity at a higher wholesale price results in higher overall profits and a shorter break-even times.

The profitability of the proposed project can be estimated by comparing its LEC with the average wholesale electricity prices in the same region. In 2013, the wholesale price of electricity in California was roughly 4.2 ¢/kWh [23], but wholesale electricity prices in California can fluctuate between around 4 ¢/kWh in the winter and 7 ¢/kWh in the summer [22]. Since these prices are predicted to increase by at least 30% in the next 15 years [22], it is useful to estimate the projected profits associated with different wholesale prices. The results are illustrated in Fig. 2. For the remainder of this proposal, we will use the term *break-even time* to refer to the duration of time that the PV array must be in operation for it to generate enough electricity to pay for itself. It is clear from Fig. 2 that selling electricity at a higher wholesale price results in higher overall profits and shorter break-even times. The results are described in more detail in Table 2. During the 25 year lifetime of the project, selling electricity at prices between 4 and 7 ¢/kWh will result in total profits of between $2.1 and $12.9 million, and result in break-even times of between 22 and 13 years. It is also interesting to note the values of the last column in Table 2, which describe total profits after 30 years. Even though we assume for the purpose of this proposal that the project operates for 25 years, PV modules retain at least 80% of their efficiency after this time. Since the costs associated with the project are dominated by initial capital, extending the project lifetime by 5 years can lead to increases in profitability of as much as 130%.

It is instructive to estimate the percent profit obtained after both 25 and 30 year project lifetimes. The percent profits are displayed in Table 3 for different wholesale electricity prices. It is expected that the actual percent profit will lie somewhere between 20 and 100% after the 25 year lifetime of the project. Contingent on the amount of repair and refurbishment

Table 2: Estimated project profits and break-even times for different wholesale electricity prices.

Sale Price (¢/kWh)	Break-Even Time (Years)	25 Yr Profit (Millions of Dollars)	30 Yr Profit (Millions of Dollars)
4	22	2.1	4.8
5	17	5.7	9.2
6	15	9.3	13.5
7	13	12.9	17.8

Table 3: Estimated percent profits for different wholesale electricity prices.

Sale Price (¢/kWh)	25 Yr Profit (%)	30 Yr Profit (%)
4	17	39
5	46	74
6	82	109
7	105	144

needed at the end of the 25 year period, it is likely that it will be more profitable to keep the array in operation, even if it is not operating at 100% capacity, than to shut it down.

Up to this point, we have conducted our analysis without mention of government subsidies or tax credits. Utilizing federal subsidies, commercial-scale PV installations in the United States typically result in LECs that are around 22% lower than those of unsubsidized projects [21]. The utilization of subsidies for the proposed project will not be described in detail here, but it is instructive to briefly mention the current subsidy landscape. The 30% federal Investment Tax Credit (ITC) for solar energy expires in 2016, at which point a longer-term 10% ITC will take effect. Utilizing the 10% tax credit will allow future projects to achieve lower LECs and result in higher profit margins than are estimated here. Along with advances in technology, experts are hopeful that this ITC will allow solar projects in California to approach grid parity by around 2020 [24].

As previously mentioned, the California RPS requires that 33% of the energy procured by utilities and electric service providers must come from renewable energy sources by 2020. Since 2010, the California Public Utilities Commission (CPUC) has allowed the trading of renewable energy credits (RECs) among utilities in a manner reminiscent of the way that cap-and-trade systems are used for controlling greenhouse gas emissions. The possibility of trading RECs awards additional flexibility to solar array owners. In addition to selling electricity, utilities can also sell their RECs if it becomes economically favorable for them to do so. As 1 REC is issued for each MWh of electricity produced by solar power, the estimated project here, expected to produce 360 GWh over a 25 year lifetime, can produce an estimated 360,000 RECs. It is difficult to assign a monetary value to REC sales, as the REC market is volatile and exhibits strong elasticity. Although worth nearly $8/REC in California in 2011, changes in legislation and increased supply lowered the average price to

around \$1/REC in 2013 [25]. Although future REC prices are unpredictable, it is reasonable to estimate that the proposed project would produce RECs with a value of at least \$300,000 over a 25 year period.

Conclusion

Implementing photovoltaic arrays at airports has attracted recent attention because of airport proximity to low-cost land, grid infrastructure, and electricity consumers. Building and maintaining a 60 acre, 9 MW PV array for 25 years at the Eastern Sierra Regional Airport in Bishop, CA would cost an estimated \$12.3 million if HIT silicon PV modules with single-axis tracking are used. The project will result in an estimated LEC of about 3.5 ¢/kWh. With the expected wholesale electricity price to hover around 5 ¢/kWh, this results in a break-even time for the project of 17 years, and results in a profit of 46% of the initial investment, and 74% of the initial investment if the project lifetime is extended to 30 years. It is our hope that feasibility studies like this will lead to informed decisions by investors, utilities, and developers.

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