The Place of Solar Power

An Economic Analysis of Concentrated and Distributed Solar Power

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This paper analyzes the costs and benefits, both financial and environmental, of two leading forms of solar power generation. The preeminent form of distributed electricity generation, grid-tied photovoltaic cells under net-metering, allow individual homeowners a degree of electric self-sufficiency while often turning a profit. However, substantial subsidies are required to make the investment sensible. Meanwhile, large dish Stirling engine installations have a significantly higher potential rate of return, but face a number of pragmatic limitations. The paper concludes that both technologies are sensible investments for different sets of consumers.

Contents

I: The Problem

Carbon-based fuel sources are becoming a hot commodity as the future of the domestic electric industry watches the future. The fear of energy shortage, the lingering memories of rolling blackouts, fears of climate change and the constant notion of energy independence all make the concept of renewable energy more appealing and even vital to national interests.

Most observers view renewable energy to be the best way to reduce carbon emissions, diversify the energy market, and create sustainability. Most places within the world have a great deal of natural resources to take advantage of – however, their cost may prove prohibitive. The United States represents an interesting exception, as it has the unique ability to incorporate and develop these technologies.[1] However, renewable energy must combat the already present, tested, cheap, and ultimately reliable methods currently used to generate power. Proponents of renewable energy argue that it will allow for more sustainable energy usage in the future, help support future growth, avoid price spikes, allow for energy independence, and ultimately help slow the progression of global warming. Some recent estimates state that a solar farm, composed of Stirling Engines, covering an area of 100 square miles could replace all the coal burned to generate energy in the United States.[2] Despite these positive externalities, the potential of major cost inequality and the associated fixed costs of renewable resources, a debate rages on.

In this paper we will examine the advantages and disadvantages of different methods of implementing solar power as an alternative to traditional carbon-based energy

[1] (Whittington)
[2] (Port, 3)

sources. We will follow this with an investigation of the positive aspects of renewable energy and attempt to determine whether decentralized photovoltaic farming is more effective and sustainable than a central, Stirling-engine based solar farm for our model city. Calculations related to fixed costs (construction, core technology used, land) and variable costs (labor, upkeep) will determine the final prices of each power source, with a dual comparison planned. Our ultimate conclusion will be based on which power source is better from a consumer standpoint.

II: Power in America Today

Creation of a model city

Our goal is to get an accurate representation of the power needs and consumer habits of a typical city. In order to better account for variances and external influences, such as city demographics and weather, we decided to create a model city to test the two methods of solar-powered electric distribution. Using data from the Census Bureau we estimated that an average American city is composed of 150,000 households. Though more narrowed, city is still a wide term – often composed of mixed residential and commercial space. To further simplify things we decided that our city would be composed solely of residences, much like a suburb close to a metropolitan area. This allowed us to focus our findings on residential consumers, eliminating commercial and industrial electricity use. Furthermore, our model city does not include apartment high rises or town homes. As for the residences themselves, the average American home is 2349 ft^2 in area[3] and an average Californian residence consumes approximately 6960 kilowatt hours of electricity per year. With the current average price of electricity in California hovering at 14.91¢ per kilowatt hour, households have an average yearly

[3] (ABCNews, 2005)

electricity expenditure of $1037.04. This, in turn, leads to 2072 kilograms (4567 pounds) of carbon dioxide (CO_2) emissions per year per household, given that one kilowatt hour generated in California produces 298 grams of CO_2 emissions. Proactive implementation of alternative energy sources, such as solar, can help significantly reduce this staggering number. The question then becomes: *are solar technologies currently cost effective and, if so, which method is preferable – Concentrated Solar Power in the form of dish Stirling engines or distributed photovoltaic cells?*

Following a discussion with an executive at Pacificorp we found that to power a city of this size we would need to generate 120 megawatts of power. In the case of our solar farm, an additional 10 megawatts is necessary to compensate for an average of 7% loss through the transmission lines, bringing the total to 130 megawatts. For the sake of conservatism and round numbers, we rounded this 8.4 megawatt loss up to 10 megawatts.[4]

We will take this model city and utilize it in each of our two case studies. First, we analyzed the requirements of meeting this hypothetical city's needs entirely with residential photovoltaic arrays, with each household equipped with an array of solar panels necessary to meet the household's own electrical needs. For our concentrated dish Stirling engine farm, power will be transmitted from a remote location to the model city. This second case requires the construction of power substation to lower the high voltage being transmitted from the farm into a safer level that can be utilized in homes. The costs of this added piece of capital, along with all the power source-based calculations, will be detailed in section IV.

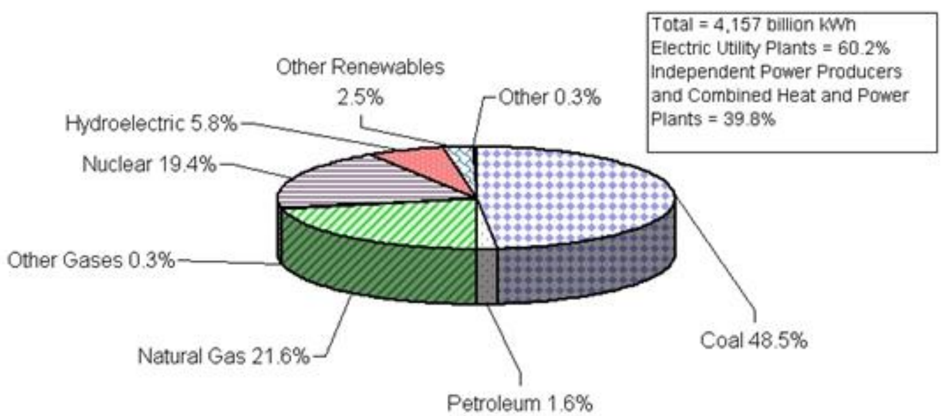
[4] (Pacificorp)

Understanding Power Consumption

We will use conventional energy as a benchmark when analyzing both models' benefits and costs. According to the EIA[5] the average American household consumes 936 kilowatt hours of electricity per month at an average retail price of 10.65¢ per kilowatt hour. This implies that average household consumes $99.70 worth of electricity a month. However, for the purpose of this paper we will focus on numbers specific to California, which we will better represent our model city. Given this specific geographic locality the average household spends $139.56 in electricity a month.

The United States produces 4,156,745 (thousand) Megawatt hours (MWh) per year of which 48.5% comes from coal, 19.4% from nuclear, 21.6% from natural gas, 5.8% from hydroelectric sources, 1.6% from oil and 3.1% from others, such as solar and wind energy.

Figure 1: US Electric Power Industry Net Generation, 2007



Sources: Energy Information Administration, Form EIA-923, "Power Plant Operations Report" and predecessor form(s) including Energy Information Administration, Form EIA-906, "Power Plant Report;" and Form EIA-920, "Combined Heat and Power Plant Report."

[5] (U.S. Department of Energy, 2009)

Formulating Pricing Assumptions

Since 1970, the retail price of residential electricity in California has risen by an average of 6.7% annually.[6] For our analysis, we assume that this trend will continue for the next 25 years. Under this criterion we expect the price of energy to be 22 cents per kWh by 2015, 42 cents per kWh by 2025 and 80 cents per kWh by 2035. Furthermore, we assume a discount rate of 7%. This rate represents the opportunity cost of investing in a risk free asset plus an extra 2% to accommodate price shocks to electricity. Using these values we estimate the total cost of energy for our model city at a present value of $3,471,909,155. This value represents the aggregate cost of supplying electricity to our 1,044,000,000 kWh town for 23 years. Doing the same calculations for the next 23 years we get a net present value of $3,763,352,167. These results will be used when comparing the costs of the photovoltaic and Stirling engine models.

In order to properly discount for the two technologies we are going to use two separate discount factors. For the home photovoltaic system we will assume the same discount rate we used for discounting energy coming from the national grid, 7%. Here again we assume an initial 5% discount, which measures the opportunity cost of investing in a risk free asset. However, the additional 2% represent the uncertainty in the future price of raw materials such as silicon. For the Stirling engine technology we are going to use a 10% rate. The higher discount rate makes sense in this case due to the higher upfront capital costs and the fact that there is uncertainty due the scale of this endeavor because nothing of the sort has been yet to be implemented.

III: Understanding the Power of the Sun

[6] (Ongrid Solar, 2009)

The Potential of the Sun

To truly understand the potential impact of solar waves as a viable energy source an improved knowledge of the inherent energy and amount absorbed by the earth is necessary. The United States is of considerable interest for this study, as it receives an enormous amount of solar heat when compared to the rest of the world. Each year the Earth intercepts a large amount of radiant heat, equaling roughly 5×10^{20} kilocalories. Thought of in terms of area, a typical square foot of land in the United States receives more than 1 kilocalorie per square foot, per minute, or 500 kilocalories per day. Aggregated over an acre, those 40,000 square feet receive 20,000,000 kilocalories per day! Now, a conservative estimate for energy usage derived from coal, barrels of oil, and cubic feet of gas is somewhere around 150,000 kilocalories per day. When compared with the above stated estimate for light energy, the Sun could supply 2,000 times the heat energy currently used in the United States.[7] Though promising, the illusive issue still remains, turning the potential energy into useful, usable electric energy.

It becomes very obvious that location is of prime importance for successful solar farming and energy production. The intensity of solar radiation outside of the Earth's atmosphere is about 1,300 watts per square meter. We must assume that some of this is lost in the haze and cloud cover, leading to an estimate of 80-90% of the solar radiation successfully entering the atmosphere and reaching the ground. For simplicity we estimate this amount to be 1.100 kilowatts per square meter.[8] The composition of light that enters is also of great importance, as it determines the applicable technology. The rays of sunlight are composed of diffuse light (scattered) and also direct rays from the sun

[7] (Daniels, 51-52)
[8] (Leitner, 52)

(normal radiation). The above factors of haze, humidity and cloud cover can effect the light distribution and lead to increased scattering. While flat panel PV power plants use both diffuse and direct radiation, concentrated solar power (CSP) can only harness the direct sunlight.[9]

Section IV: Photovoltaic and Dish Stirling Engines Explained

Photovoltaic (PV) vs CSP (Concentrated Solar Power) Technologies

As the still immature solar energy market has grown we have learned more about different technologies and their ideal application. The first distinguishing factor necessary is between photovoltaic solar power and concentrated solar power. Though photovoltaic technology has been around for sometime, the CSP industry is still in its infancy. Flat panel photovoltaic cells, typically made of silicon, are the best known form of solar technology.[10] The CSP concept, in its most basic form, is quite simple: harness the heat energy from the sun in order to generate electricity.[11] Utilizing reflective material to concentrate the Sun's rays and reflect them powers a steam or more conventional engine.[12] This process requires plentiful sunlight and a large amount of open space to accommodate a solar farming facility. These requirements make location essential for commercial success and, for our study we have selected one of the best areas for a case study: California. California is one of the best locations for this new wave of CSP installation due to the accommodating climate and the great government incentives.[13]

[9] (Leitner, 54)
[10] (Leitner, 50)
[11] (Marathon Capital, LLC, 5)
[12] (Goodward, Jenna; Andrew MacBride; Clayton Rigdon, Britt Childs Staley, 10)
[13] (Marathon Capital, LLC, 5)

Though the previously mentioned PV energy production can prove effective in some areas, it is far more effective when used in a decentralized manner. When designing the large scale, high priced solar farm, CSP is much preferred due to its cost effectiveness.[14] CSP is chosen by virtue of its size and price. CSP is a very effective means of electricity production, but it requires a large amount of room and very large-scale equipment to be effective. Likewise, the scale of PVs is much smaller, allowing for more flexibility in the size of an installation. The most recent plant installations have shown that economies of scale are applicable and therefore, as plant size increases, capital costs decrease.[15] Given this information we have chosen one of the more promising technologies, the Dish Stirling system, as our large-scale electricity producer. Ultimately, CSP is the most efficient and cost effective way to generate electricity from the sun. It is for this reason that we have chosen a two-sided analysis of the solar powered electricity production.

On the one side we have the household installable PV cells, allowing for single home power generation, with a surplus sent back to the grid for profit. These cells, though expensive, are often accompanied by a tax incentive. This allows for an analysis of decentralized means of power production without the large scale fixed costs of a central producer.

On the other side we discuss the scenario of a large, central solar farm creating electricity by use of CSP – in this case, by means of a Dish Stirling System. This type of installation takes advantage of abundant solar rays and open space to build a massive

[14] (Marathon Capital, LLC, 5)
[15] (Marathon Capital, LLC, 11)

facility to harvest this “free” energy. Due to the nature of the equipment, the Stirling engines require large amounts of space.

Despite differences between the two, each provides a means of electricity production. What we are concerned with is at the heart of these differences: the effectiveness. Which is the optimal means of energy consumption for a standard, West Coast suburban area?

V: The Science of Photovoltaic and Dish Stirling Generation

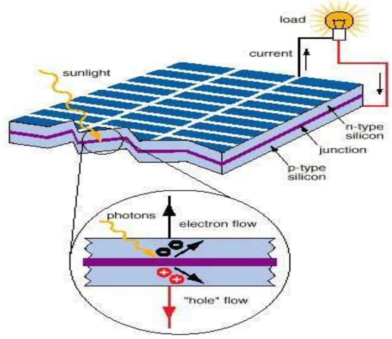
Understanding Photovoltaic Technology

A photovoltaic cell is composed of two thin layers of a semi conducting material, most commonly silicon, separated by a non-conducting junction. Silicon is used because most of our solar radiation photons have energies greater than the band gap of silicon. The two layers are formed by doping, the addition of a small amount of impurities to create positive and negative layers. This construction is called a p-n junction[16]. The lower p-layer contains atoms with electrons in their outer orbital that are easily lost. The upper n-layer contains atoms that lack electrons in their outer orbital and therefore readily gain them. When a photon of light above the band gap of the material hits the layer, the electrons are excited from their valence band into the conduction band, separating the positive holes from the negative electrons, creating an electrical potential between the two layers (see figure 2).[17] This potential provides the energy for the electric current to flow, the electrons flow through the electrical device to the upper layer as a unidirectional flow, a direct current (DC), which needs to be converted into an alternating current (AC) so that it can be entered into the grid and utilized by appliances in the home. This is done

[16] Wright.
[17] Parker

by an inverter.

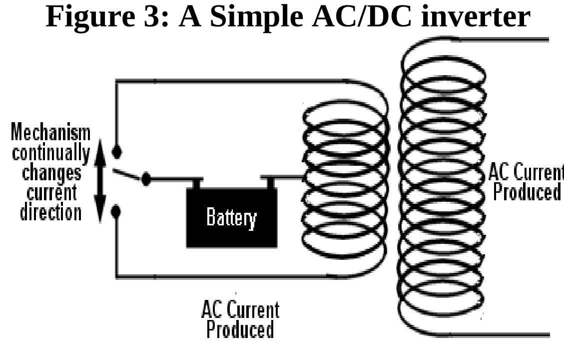
Figure 2: Anatomy of a Photovoltaic Cell



Source: http://zone.ni.com/devzone/cda/tut/p/id/7229

An inverter takes the DC input and runs it into a pair (or more) of power switching transistors. By rapidly turning these transistors on and off, and feeding opposite sides of a transformer, it mimics an AC current into the transformer. The transformer changes this "alternating DC" into AC at the output. This is done by producing a magnetic field, which in turn induces an electrical current of AC nature. Figure 3 is a simplified diagram of an inverter:

Figure 3: A Simple AC/DC inverter



Source: http://www.solar-facts.com/inverters/how-inverters-work.php

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The average efficiency of these cells are said to be between 13-16%[18]. This loss in energy results from reflectance losses, thermodynamic efficiency losses and resistive electrical losses[19]. Reflective losses refer to the radiation that bounces off of the solar cell without being absorbed or altered in anyway, it is estimated that approximately 10% of the sun's energy is lost in this way[20]. Thermodynamic losses arise where photons with energy lower than the band gap of the absorber material cannot generate a hole-electron pair, and so their energy is not converted to useful output and only generates heat if absorbed. For photons with energy above the band gap energy, only a fraction of the energy above the band gap can be converted to useful output. When a photon of greater energy is absorbed, the excess energy above the band gap is converted to kinetic energy of the carrier combination. The excess kinetic energy is converted to heat through phonon interactions as the kinetic energy of the carriers slows to equilibrium velocity[21] and result to up to 75% of the energy loss.[22] Other factors that influence the efficiency of the cell include temperature and soiling. Increase in temperatures decreases the efficiency of the cell because the band gap of the intrinsic semiconductor shrinks decreasing the voltage by a greater amount than the increase in current that results from the increased temperature and so there is a net decrease in power.

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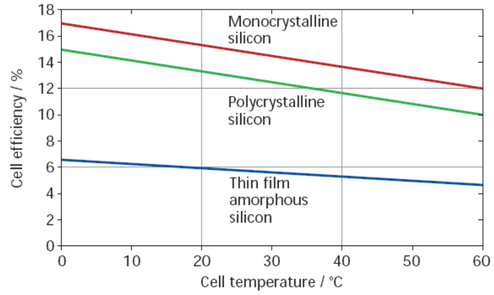
[18] DTR
[19] Wright.
[20] DTR
[21] Cheng
[22] DTR

Figure 4: Efficiency of Different Types of PV Cell as a Function of Temperature



Source: Understanding Building Integrated Photovoltaics, CIBSE TM25: 2000

The loss due to temperature (see Figure 4) combined with losses from dust reduces the energy output by about 10%.[23] In extreme cases, particularly where the arrays are not placed at a tilt of 15° or more, dust accumulation can result in a power reduction of 10% on its own.[24] Finally, allowances have to be made for losses in the inverter (10-15%) and as a result of electrical resistance in the wires (1-3%).[25]

Understanding Dish Stirling Engines

The Dish Stirling system consists of a parabolic solar concentrator, a tracking system, a solar receiver and an engine with a generator. The parabolic concentrator reflects the incoming solar radiation onto a cavity receiver, which is located at the concentrator's focal point[26] and transmits it to the heat engine. The engine is a sealed system filled with hydrogen or helium (a transfer medium), and as the gas heats and cools, its pressure rises and falls. The change in pressure drives the pistons inside the engine, producing mechanical power.[27] The mechanical power in turn drives a generator

[23] Harwell
[24] DTR
[25] Harwell
[26] Schlaich Bergermannund and Partners Structural Consulting Engineers.
[27] Sandia National Laboratories

directly connected to the engine and converts the mechanical energy into electricity (AC).[28]

The tracking system enables the solar concentrator to follow the sun, keeping the reflected radiation at the focal point. It rotates about two axes. The orientation towards the sun is either determined by a sun-tracking sensor, or by a special computer program which predicts the position of the sun.[29] This coupled with the dish's ability to ramp to the grid within a minute[30] allows it to capture the highest amount of solar energy possible.[31]

Each curved glass dish will direct its reflected energy to a 25-kilowatt power generator. The Stirling dish "heat antenna" is the device of choice, as the better-known solar cells still suffer from high costs and very limited efficiency. The typical photovoltaic solar cell harvests only between 10 and 15 percent of the available solar energy, where as the Stirling-brand dish converts 29.4%.[32] Further benefits include its high engine-operating temperature, which allows for air cooling, meaning there is no need for water-cooling and the associated water system required.[33]

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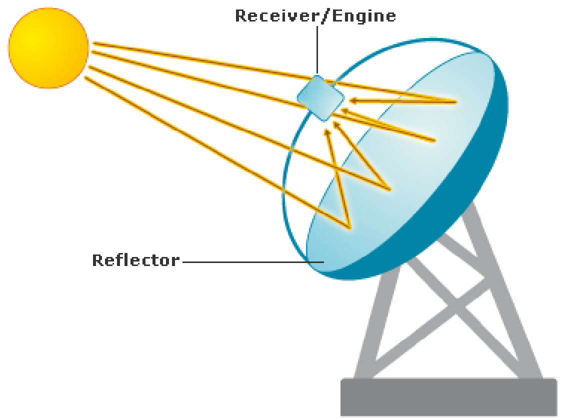
[28] Schlaich Bergermannund and Partners Structural Consulting Engineers.
[29] Ibid
[30] Leitner, 97
[31] Ibid, 96.
[32] Port, 2.
[33] Leitner, 96.

Figure 5: Simple Diagram of a dish Stirling Engine



Source: http://www.abengoasolar.com/sites/solar/en/abengoa_solar_nt/ current_projects/dish_stirling/index.html

Locations and Limitations of Photovoltaic and Dish Stirling Installations

Location of Photovoltaic Installations

In order to utilize the maximum amount of solar radiation possible, location of the solar cells is an important consideration. In general, arrays should face between southwest and southeast at an elevation of around 30° for California.[34] Shading should also be taken into account, bearing in mind the proximity of local buildings, vegetation and the possible future plans of development or tree growth. Even minor shading can have a significant effect because it is the cell of lowest illumination that determines the current.

Location of Dish Stirling Installations

Given our understanding of solar potential and the necessary solar qualities, the primary location for our farm is self-evident. For PV implementation we are less bound by size, scale, and price, as well as limitations related to direct light. CSP requires more ideal circumstances and location becomes key.

[34] Cheng

California is a prime location due to its latitude, low cloud cover and humidity, and the amount of sunlight received[35]. This works for PV, but further modifiers are required for the proposed solar farm. The large land requirements are not difficult to find, especially in the Western deserts of the United States. Not only is space plentiful, but also the conditions are ideal[36]. This land required must be flat, as well as corresponding with other potential limiting factors. These factors, which affect the size of the land available, include military bases, national parks and protected wilderness, cropland, and developing urbanization. The land is also categorized into three resource classes of average solar energy resource (kWh/m^2/day). These are: 6.0 to 6.5 (good), 6.5 to 7.0 (great), and 7.0 and above (excellent)[37]. Given these factors, careful analysis reveals the Mojave Desert as a prime candidate, despite its dwindling size, due to its flatness, availability of sun, and its proximity to major load centers[38].

Potential Problems

Nightly Outages

Though it may seem obvious there is a lack of sunlight during the evening, a problem that represents an important factor when considering solar energy. The alternative trough and solar tower CSP systems can utilize a hybridization system to combat their nighttime losses. Though less efficient, they utilize natural gas to keep their turbines moving. This is not too large a concern as it utilizes equipment that would otherwise be idle. There have been proposals for the incorporation of a hybrid fossil fuel system into the Dish Stirling system, but it would suffer from lower efficiencies and lose

[35] Leitner, 54.
[36] Ibid, 55.
[37] Ibid, 57.
[38] Ibid, 60.

some of its zero emissions appeal[39]. The notion of a mixed fuel system is a disadvantage for the Stirling as it would need to be an integral part of its design[40]. Regarding photovoltaic cells, although during the nighttime energy would not be produced, during the day the cells should overproduce. The net metering enables the photovoltaic cell to take advantage of electricity from the national grid during times of shortages, but due to its overproduction, stay grid neutral.

Cloud Cover and Unpredictability

Both photovoltaic and dish Stirling technologies can fall victim to the unpredictability of cloud cover and weather[41]. However, Dish Stirling units have the unique ability to ramp up to full output within seconds. This coupled with their smaller size and ability to track the sun allows for average output that tracks average radiation levels very well[42]. Still, they suffer similar disadvantages to PV given cloud cover, but they are even worse off given their inability to utilize scattered light.

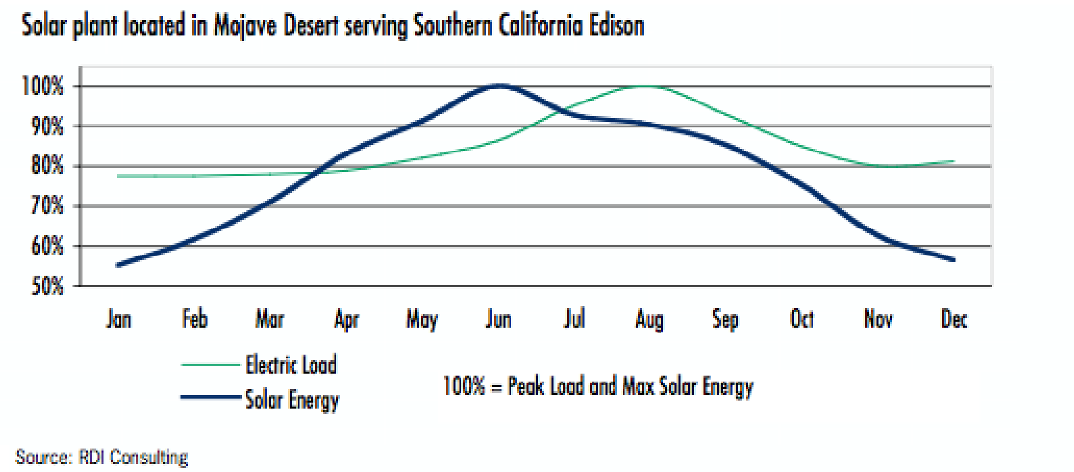
Seasonality

Solar farms and PV cells are also affected by yearly fluctuations in seasonality. Clouds and haze reduce output by 20% in December and January[43]. Likewise, shorter days and less direct exposure to sunlight are instrumental in the total output of the Stirling engines. The summer remains the strongest time period for sun collection. However, despite these short falls, solar energy closely matches the electricity consumption cycle of consumers. The energy production is closely correlated with load,

[39] Ibid, 62.
[40] Ibid, 67
[41] Leitner, 67
[42] Ibid, 67
[43] Ibid, 68.

increasing in summer when it is most required – air conditioning being a *huge* factor in this region. The result is almost simply a downward parabola, centered at June.[44]

Figure 6: Solar resource and electric load in the Mojave Desert



VI: The Case for Distributed Photovoltaic Generation

Distributed electricity generation is an attractive technology. By reducing or eliminating dependence on the national power grid, the consumer may provide for his or her own electricity demand at essentially zero marginal cost, whilst often recouping the initial capital investment associated with setting up the generation system in future electricity savings and in the value of electricity sold to the power grid.

Photovoltaic solar power is the quintessential distributed generation technology. The power produced by a photovoltaic array scales linearly with the area of the system, so as long as the array produces enough revenue to compensate for the non-generating sunk cost of the system (the inverter, etc.), a photovoltaic array is a sensible economic choice. The only traits required of a location is open, south-facing[45] space for installation (most often in the form of rooftop space). They have very low maintenance costs, require

[44] Ibid, 69.
[45] Photovoltaic cells must face southerly directions in the Northern Hemisphere; in the Southern Hemisphere, they must face north.

little attention from their owner, and have a lifespan (25 years)[46] commensurate with the time horizon of many home planning decisions (most mortgages are 15 or 30 years).

Unfortunately, commercially-available photovoltaic cells remain very expensive for most residential consumers. The key to making photovoltaic arrays a cost-effective alternative to fossil fuels lies in two economic maneuvers on the part of the federal and California state governments.

First, the United States Congress has mandated that a technology and accounting practice called "net metering" be available to all electricity consumers.[47] Under a met metering scheme, any consumer attached to the power grid is given credits for electricity that user produces above his or her own electricity consumption through the use of distributed generation technology. When the consumer is using more electricity than he or she is producing, the electricity is purchased at the normal rate. Then, at the end of the billing period, the credits are subtracted from the bill, and the consumer only owes the utility the difference between the value of the electricity he or she produced and the value of the electricity he or she consumed. Due to net metering, a photovoltaic array allows a consumer to continue to consume electricity, but at a lower price than he or she would purchase that electricity from the local utility company. These savings in future electricity bills add to the value of an installed photovoltaic array.

Second, both federal and state governments provide subsidies for the installation of solar electricity generating systems. The federal government provides a 30% tax credit for the value of installed residential and commercial photovoltaic systems.[48] This subsidy discounts the taxes of a property owner who installs a photovoltaic system by

[46] Most photovoltaic cells are guaranteed by their manufacturers to remain at 80% of their original capacity after 25 years.
[47] The Energy Policy Act of 2005 §1251
[48] This is the Residential Renewable Energy Tax Credit (North Carolina Solar Center 2009)

30% of the total price of the installed system; for the purposes of our analysis, this is equivalent to the federal government playing 30% of the cost of the photovoltaic array, leaving the remaining 70% to be paid for by state subsidies and the property-owner.

In California, where we have rooted our study, the cost of installing a photovoltaic system is $8.20 per watt of generating capacity (the second lowest in the nation).[49] This cost is increased by the only substantial maintenance cost associated with residential photovoltaic systems: the replacement of the inverter. Over time, inverter coils wear down, and eventually fail. Though there is not yet a consensus over the average life of a photovoltaic array's inverter, estimates range from as little as 4.7 years[50] to longer than the lifespan of the array. For the sake of this analysis, we assume one inverter replacement half way through the lifespan of the array.[51] This increases the cost of each installed watt by 39¢ per watt. This brings the total cost per installed watt of photovoltaic generating capacity to $8.69.

This cost is very high when compared to the cost of grid electricity to residencies, at 14.9¢ per kilowatt hour.[52] For the purposes of this analysis, we have assumed the array receives five equivalent noontime hours of sun exposure on an average day,[53] and has a 25 year lifespan,[54] the lifetime productivity of one watt of photovoltaic generating capability is 45.6 kilowatt hours. Given a 7% annual discount rate and a 6.7% increase in the cost of electricity, the present value of those generated watts is $5.92; this is only

[49] (Wiser, et al. 2009, 2)
[50] (Bonn 2002, 1353)
[51] The price of a solar array inverter is 71.9¢ per watt of generating capacity (Solar Buzz, LLC 2009). Assuming 2% inflation and a 7% discount rate per annum, the present value of this replacement is 38.6 per watt. As the price of inverters has been dropping over time, this allowance for inverter replacement will also allow for some routine inverter maintenance in addition to the inverter replacement midway through the 25 year span of this analysis.
[52] (U.S. Department of Energy 2009).
[53] (Black 2009)
[54] Most photovoltaic cells are guaranteed to remain at 80% of starting efficiency after 25 years. In this analysis, we have assumed that the cells lose generating capacity at a compounded .9% per year, which leads to a final efficiency of 80.4% at the end of the array's lifespan.

68.9% of the initial capital investment required to acquire that one watt of generating capacity. However, after the 30% federal tax credit, the array has paid for itself, leaving a 21¢ cost to the consumer per installed watt of generating capacity. This means the lump-sum rebate given by the state of California through its California Solar Initiative (CSI) is almost entirely profit for the consumer, leaving the present value of an installed watt of photovoltaic generation capacity as substantially positive.

This analysis is complicated by the way California has structured its rebate. The level of the California Solar Initiative incentive drops as more solar arrays are installed in the state, and these drops are not applied uniformly across the state. The current rebate for residential consumers ranges from $1.10 to $1.90 per watt of installed generating capacity, depending on the consumer's utility company.[55] This level of subsidy leads to a profit for the consumer of $0.90 to $1.70 per watt of installed solar generating capacity (a 10.4% to 19.7% return on investment). In the future, this rebate is scheduled to drop as low as 20¢ per watt, but even in this case the present value of each installed watt is almost exactly zero.[56]

The meaning of these numbers is more readily grasped by considering the case of a typical home. The average Californian residence consumes 580 kilowatt hours of electricity per month, or just under two-thirds the national average.[57] At 14.9¢ per kilowatt hour, the annual electricity bill of the average Californian residence is $1037.04. In order to fully meet the annual electricity needs of such a home, it would need a photovoltaic array capable of capturing an average of 3.81 kilowatt during the

[55] (California Solar Initiative 2009)
[56] However, by the time the California Solar Initiatives have reached this low level of subsidy, the technology's efficiency and cost will likely have improved enough for the photovoltaic array to remain a profitable investment. See Appendices 1 and 2 for capacity and present-value calculations.
[57] By way of comparison, the average American residence consumes 936 kWh of electricity monthly. (U.S. Department of Energy 2009).

approximately 5 daily noontime hours available to all Californians.[58] During these hours, each square meter of California receives at least 5 kilowatts of power from the sun. Assuming a solar array (after the efficiency losses due to inversion, wire resistance, etc.) is 13% efficient and captures no energy outside noontime sun, a photovoltaic system of $29.3m^2$ ($302\ ft^2$) would power the needs of the average Californian residence.

By comparison, the average American house is $2349\ ft^2$ in area.[59] Assuming the average house has two stories of equal size, an array covering only slightly more than one-quarter of the house's roof will meet the needs of the average American home in California.

At an initial capital cost of $8.2 per watt, a 3.811 kilowatt system will have a total cost of $31,251. Deducting the 30% federal tax credit reduces the capital cost to $21,875. This cost is further reduced by the California Solar Initiative rebate, which reduces the cost to between $14,635 and $17,683 for the consumer.[60] However, since an array of this size will fully meet the annual needs of the consumer (after annual net metering), the present value of 25 years of electricity bills must be considered. Assuming a 6.7% annual increase in the price of electricity, a 7% discount rate, and a loss to generating capability of .9% per year, the present value of future electricity savings is $22,581. As these future savings are greater than the out-of-pocket costs to the consumer, installing such an array is a revenue-positive action on the part of the homeowner, earning him or her $4,897 to $7,946. After a single inverter replacement halfway through the 25 year lifetime of the array, this present value is reduced to $3,411

[58] This is a slightly conservative estimate; the state's two largest metropolitan areas, Los Angeles and the San Francisco Bay, receive 5.6 and 5.4 noontime hours of sun on the average day, respectively. Parts of the state receive as much as 7.7 average equivalent noontime hours per day. (Black 2009, 1).
[59] (ABCNews 2005)
[60] Several cities and counties offer additional incentives for photovoltaic array installations, most amounting to a few hundred dollars. These are ignored for the purposes of this paper (North Carolina Solar Center 2009).

to $6,475. However, this consumer surplus came at a loss to federal and state governments of $13,567 to $16,616. This means each grid-neutral home creates a dead weight loss of $10,157.[61]

Even in situations where the present value of future savings on electricity is less than zero, additional incentives remain for homeowners to purchase photovoltaic arrays. The most substantial of these is the boon to home resale value. While estimates vary on the precise level of increase in property value due to the installation of an array, the most common estimate is that decreases in annual operating cost increase home value by a ratio of 20:1. That is to say, an array that made a home grid-neutral would decrease the average California residence's annual electricity bill by $1,037, leading to a $20,741 increase in the property's resale value. The logic underlying this figure is that the annual savings allow the potential homeowner to take a larger mortgage to purchase the home, and the roughly $1,000 saved each year may be put into debt service on a 5% mortgage. A more theoretical analysis would conclude that the maximum increase in property value should equal the present value of remaining future electricity bills at the time of the transfer of ownership of the house. In either case, installing a photovoltaic array is revenue-positive decision for the current owner of the house even if the home is sold the day after the array is installed.

It is important to note that these estimates are somewhat conservative. Photovoltaic technology is rapidly improving in efficiency while dropping in cost, meaning systems at any point of electrical demand should continue to drop cost and size. Most systems are guaranteed to remain at 80% of their rated efficiency after 25 years;

[61] Of course, this money does not evaporate – it goes to another agent, the photovoltaic array-producing firm. However, it is a loss to the system between consumers and the government.

this analysis assumed this worst-case outcome occurred, and that the array has no value after year its 25 year lifespan. This analysis also assumes an array generates no electricity outside of noontime hours, and that the array is in the parts of California which receive the least intense sunlight. Finally, it does not address tiered electricity pricing, which is only active in some parts of California. In most cases, tiered pricing on retail electricity will make solar technology more attractive rather than less for most residential settings; in variable cost schemes, the price of electricity tends to be highest during the heat of the day, especially in the summer. At these times, photovoltaic arrays are at their most productive, and are likely to be producing more power than the attached home is consuming. As a result, the array will be pushing electricity onto the grid, generating net-metering credit when electricity is at its highest price. After sunset, when the photovoltaic array is not generating electricity, the residence will be drawing electricity from the grid when the price level is lower.

Of course, the most compelling reason for the widespread adoption of solar electricity generation technology is the reduction of the negative externalities of other forms of power. In particular, the carbon dioxide released by the burning of fossil fuels is understood to be the driving force behind global warming, and is thus a matter of prime concern. As stated above, one kilowatt hour of power generation in California correlates to 0.30 kilograms (0.66 pounds) of CO_2 emissions, meaning a grid-neutral photovoltaic array attached to the average California residence initially reduces carbon emissions by 2.1 metric tons per year. Over the 25 year lifespan of the array, accounting for decay in the quality of the land, total CO_2 emissions are reduced by 45.6 metric tons. This equates to a 12.2 kilograms of lifetime CO_2 emissions reduced per watt of installed generation capacity. The initial capital cost of these CO_2 emission reductions is 67¢ per kilogram over the lifetime of the array; the federal tax credit is 20¢, the California Solar Initiative rebate is 9¢ to 16¢, and the present value of consumer net revenue per kilogram of reduced CO2 emissions is 7¢ to 14¢, depending on the level of state subsidy. The economy-wide cost of these reduced emissions is thus 22¢ per kilogram.

This analysis reveals that heavy subsidies from federal and state governments have made photovoltaic arrays a sensible investment for the average residential consumer. If the consumer possesses the available roof space facing in an appropriate direction, a photovoltaic array is a profitable investment yielding 10-20% returns over the lifespan of the array, even after a 7% discount rate, and conservative estimates for the output of the array. Even as subsidies decrease, the increase to a home's property value provide a strong incentive for homeowners to augment their homes with grid-tied photovoltaic arrays. These returns compare particularly favorably to other investments, as they are not subject to taxation; federal law mandates that photovoltaic arrays do not increase property taxes, and the present value of future electricity savings are already post-tax earnings.

VII: The Case for Concentrated Dish Stirling Generation

We initially looked at a decentralized means of power production by way of household PV units. We will now consider the use of a centralized, large-scale production by means of CSP – dish Stirling in particular. The dish Stirling hardware itself is appealing because it is the lowest cost solar electricity source available. It also provides high-value power at the most desirable time of the day. The engine technology itself is tried and tested and the few small test beds that have been built are proving reliable and promise profitability too. Many developers within California now understand the possibilities and several solar projects are now underway, though most are still in the planning stages. One of the most ambitious is the Stirling Energy Systems plan for California's Mojave Desert. The upstart from Phoenix plans to build the world's largest solar farm. Southern California Edison, the largest buyer of renewable energy in the West, has committed to a 20-year contract, stipulating the sale of all the electricity the 500 megawatt facility can produce. For the sake of our study, we will plan on supporting the model town proposed earlier.

Determining Land Value and Size

For precision's sake we chose our "ideal" location as Barstow, in the Mojave Desert, in San Bernadino County. The weather is typically 102F in the summer, receiving 281 days of sun, and only 22 days of precipitation, with annual rainfall of 5 inches. The land value is cheap, space is plentiful, and it is not too far from major metropolitan centers – it is merely 100 miles from Los Angeles[62]. In terms of land value, there could be a potential increase in value as these domestic resources allow for strategic desert energy reserves. However, due to the new growth in the industry, the land in question is often very attractively priced. This is essential, as the scale of these installments are enormous, comprising thousands of acres and benefiting from economies of scale[63].

After careful research we have come across many different proposed land prices. The price ranges differ substantially depending on the exact location, the proximity to commercial space, the amount necessary, and the intended uses of land. For example a

[62] Yahoo! Real Estate.
[63] Port, 2.

ground known as the Mojave Desert Land Trust cites a figure between $500[64] and $1,522[65] per acre depending on the government subsidy however, they are a land preservation group receiving aid from the government and are not developers. Outside the realm of nature preservation the land prices begin to increase steadily. A survey of available land in Barstow reveals prices of $900[66] per acre in a more rural area compared to $2,163[67] and $4,225[68] per acre closer to the city center of Barstow. Given the requirements of our project we will average the three that best meet our land qualities: $500, $900, and $1,522. Taking these three and averaging them, we get an expected cost of $974 per acre. Not as inexpensive as first hoped, but not prohibitively large either.

We must also determine an adequate size for the land in order to house the large number of generators employed. Each dish Stirling engine produces 25kilowatts on its own.[69] These will be installed in sets of 60, each one ramping to productive capacity when installed. Given our model town's requirements we would need 130 megawatt. This sets up the basic equation: n kW engines x 25kW = 130,000kW. From this we determine a number of 5,200 dish Stirling engines, or 86 2/3 60-dish installations required (rounding to 87 to cover for extra energy spikes, other engines lost due to maintenance, etc).

Finally, taking conventional estimates into consideration[70] we determine that the plant would required between 780 and 910 acres to accommodate the number of dishes necessary to power our farm sustainably. To add precision for the sake of later calculations, we will choose 6.5 acres – the average of 6 and 7 acres cited above – as the

[64] Karl, 1.
[65] Sall, 1.
[66] Weichert Realtors. "160 Acres, Barstow CA 92347: Lots of land in Barstow, CA."
[67] Weichert Realtors. "45.74 Acres, Barstow CA 92365: Lots of land in Barstow, CA."
[68] Weichert Realtors. "20 Acres, Barstow CA 92311: Lots of land in Barstow, CA."
[69] (Stirling Engine Project)
[70] The traditional means of calculating dimensions required for a plant is to assume 6 to 7 acres required per 1MW.

requirement per megawatt. Given this we calculate a land requirement of 845 acres. With an estimated cost of $974 per acre we estimate of cost of $823,030 in order to fully house the required equipment.

Construction Timeline

After a discussion with Sean Gallagher, the Vice President of Market Strategy & Regulatory Affairs, we gained a wealth of knowledge related to construction and engine implementation. Given our desired 130 megawatt plant size, we would need roughly 150 construction workers. Due to the nature of the construction we fortunately would not need a specialty construction company or a wealth of engineers. This is because the process involves a very systematic installation process. First the pedestals are installed – vibrated into the ground via low frequency vibrations. Next the workers establish the electrical system and hook them to the farm's system. The following step involves a fuel system, which provides liquid to the pedestal allowing the engine to operate, and the final step is an assembly line for erecting the solar dishes themselves. Another bonus of this well-defined, modular construction process is that it allows for 24-hour construction. The optical alignment can take place during the night.

The construction progresses at a typical speed of one megawatt of generating capacity completely installed and completed per day. Given that each dish represents 25 kilowatts – and 1 megawatt equals 1,000 kilowatts – we get a number of 40 dishes installed per day[71]. This allows for four arrays of 60 to go active every week. Now, assuming completion of 40 dishes a day, and given 5,200 dishes required, the construction process would stretch over 130 days, or approximately 4 months.

[71] 1MW = 1000kW. Next, x = 25kW. This implies x = 0.025MW. 1MW = 0.025y. Therefore, y = 40.

The Hardware, Installation, and Construction Costs

There is some difficulty in cost speculation regarding construction as well as parts production related to dish Stirling. This uncertainty stems mostly from the lack of any large-scale plants having been put into commission[72]. Even so we have analyzed the costs associated with similar large-scale construction projects and have come up with the following information. Our facility will cover 845 acres, covered by 5,200 37-foot diameter Stirling engine solar dishes. These thousands of dishes promise amazing efficiency and long sustained power, however; the typical engine brings enormous fixed costs. The system involves a highly precise, exactly angled mirror, which is difficult on a small scale – let alone at 38 feet in diameter! Even more critical is the Stirling engine itself. Ideally, it can be produced by the auto industry, taking advantage of the large economies of scale. There is still uncertainty of the final cost of these units and their reliability as there have been no major installations made to date[73].

A 2005 BusinessWeek article stated that the handcrafted dish itself is a costly monster at $250,000 per rig. Bulk orders, opposed to the one-off tailor made orders, can help lower the costs by roughly $100,000 apiece. Large economies of scale in production promise to lower the cost even further in theory, reaching a sticker price of roughly $80,000 or even $50,000[74]. Further research has shown that the new expectation for "mature price approximation" for the strict production of dish Stirling engines is $1,000 per kilowatt,[75] given larger scale production. This number fits well with the cost adjustments achieved with larger installations. Sean Gallagher cited the notion that a 25kilowatt dish Stirling engine costs $75,000 per dish installed – including both the

[72] Leitner, 75
[73] Ibid, 75
[74] Port, 2.
[75] ACEEE, 1.

fabrication and installation costs. This gives a price of $3,000 per kilowatt. This discrepancy of $2,000 can be accounted for by different production cost approximation and the cost of installation. Therefore, given the situation today we estimate a cost of $75,000 for each engine in an ideal production cycle. This implies a cost of $75,000*5,200, equaling $390,000,000 for both dish production and installation.

The Substation

Any substantial exploitation of the renewable source will depend on being able to transmit the energy from its source to its final point of usage, in this case, an urban center[76]. We must also take into account the transmission loss, a consideration that was performed in Section II. A substation needs to be constructed in order to lower the voltage transmitted by the solar farm. Placing the solar farm roughly one hundred miles from our city means that we need a minimum transmission voltage of 138,000 volts. For the initial calculation we are using a base unit for a 40 megawatt plant and given that these costs are linear we can then adjust for our 130 megawatt solar farm. Assuming high side protection, a circuit breaker will need to be installed which will cost $75,000. Then at the heart of the substation we have the transformer. A 138Kv to 12.5Kv 40 MVA transformer is going to cost $750,000. In addition there is a low side breaker, which recent estimates put at $20,000. Now that we have the large pieces of capital accounted for there is the engineering and parts and pieces need to connect it all together and make it work. A conservative estimate was given of $155,000, which brings our grand total to $1,000,000 for our 40 megawatt substation. Adjusting for our 130 megawatt farm leaves us with a fixed cost of $3,250,000.

[76] (Whittington)

Maintenance Costs

Over the lifetime of the farm certain routine maintenance will have to be performed. This includes a complete washing of the reflective mirrors of each engine eight times a year. Additionally, routine engine maintenance is performed once every two years[77]. As maintenance is calculated on a kilowatts per hour basis, an estimate of the kilowatts per hours received per day is necessary. Barstow in San Bernardino County, CA enjoys an average number of 7.587 kWh/m^2/day[78]. Knowing that each dish Stirling engine is 38 foot high by 40-foot wide solar concentrator in a dish structure[79], we calculate a surface area[80] of about 111m^2. Knowing that the dish Stirling system has an efficiency rating of 31.25% for converting solar thermal heat into grid quality electricity[81], we calculate that out of a total of 7.587 kWh/m^2/day[82] hitting Barstow only 2.37 kWh/m^2/day will be converted into grid ready electricity[83]. Hence 96,058.5 kilowatt hours per year can be generated per dish[84].

To calculate the maintenance cost incurred by the plant, we first found the cost of maintenance per kilowatt hour of electricity generated, which is less than 2 cents.[85] For our case study we used 1.8¢ per kilowatt hour which results in a maintenance cost of $1,729.1 per dish per year[86] and a total cost of $8,991,078.67 per year for the 5,200 dishes in the plant. Another way of viewing this, which this study will later use to compare it with photovoltaic is, $.069 per watt per year.

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[77] Sean Gallagher Interview, December 1st, 2009.
[78] Solar Power Prospector by National Renewable Energy Laboratory (NREL) found at http://mercator.nrel.gov/csp/
[79] The California Energy Comission at www.energy.ca.gov/.../**solar**one/.../2009-06-22_Site_Visit_Informational_and_Scoping_Hearing_Notice.PDF
[80] 1 foot = 0.3048 meters. Thus, 38 feet = 11.5824 meters and 40 feet = 12.192 meters. The area of the dish is ∏(5.7912)(6.096) = 110.90813289812928 m^2.
[81] Tessera Solar at http://tesserasolar.com/international/award-winner.htm
[82] Solar Power Prospector by National Renewable Energy Laboratory (NREL) found at http://mercator.nrel.gov/csp/
[83] 7.587 KWh/m^2/day * .3125 = 2.3709375 KWh/m^2/day , where .3125 is the efficiency rate.
[84] 2.37KWh/m^2/day * 111m^2/dish = 263.2 KWh/dish/day. Multiplying this by 365 days/year = 96,058.53 KWh/dish/year.
[85] As stated by Sean Gallagher, VP-Market Strategy and Regulatory Affairs for Tessera Solar on Dec. 01, 2009
[86] 96.058.53 KWh/dish/year * 1.8¢/KWh * 0.0001¢/$ = $1,729.1

The present value of the maintenance cost over 23 years, assuming an inflation rate of 2% and a discount rate of 10%, would be 78¢ per watt or $101,855,915 for the whole 130 megawatt plant.[87]

Defining a Farm's Lifespan

Defining the lifespan of the plant is a central issue to calculating the total amount of energy that will be produced as well as determining the amount of time available to distribute the maintenance costs of the plant. Many studies cited a theoretical life span of 20 to 30 years.[88,89,90] Mr. Gallagher provided a way to think of things more concretely for the sake of our study: the lifetime of a dish Stirling engine is 100,000 hours of run time. Now, given that our dishes will run 12 hours a day we get 100,000/12 = 8,333.33 days of lifetime. Next, to determine years, we take 8,333.33/365 = 22.83 years. For simplicities sake, and the potential for downtime due to maintenance in the lifetime of the dishes, we used a lifespan of 23 years.

Investments and Financing – Does it all add up?

Given the scale of the costs of the project and the enormous costs, the natural consecutive question to answer is *will this type of high investment payoff?* From an energy standpoint, the solar farm is primed for commercial success – at least as far as demand is concerned. The solar source delivers very reliable peak power when the sun is shining. This time is ideal for delivery of sunlight, as daytime is the end of the user's peak demand. Therefore, peak load equals peak power.[91]

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[87] See Appendix 3,4 for present value calculations.
[88] Port, 1.
[89] ACEEE, 1.
[90] Leitner, 78
[91] Port, 1.

As the demand side of the equation is now taken care of, a look at the supply and its price is necessary. However, true cost of power is determined not only by its production cost, but also the value of its power within the marketplace.[92] Given several studies, a reasonable assumption for the price of sale for this energy is somewhere between 6¢ and 8¢ per kilowatt-hour. However, peak demand can outpace even this conservative guess. For example, many areas of California can reach 11.33¢ per kilowatt hour.

In order to calculate the lifetime profitability of the plant we must take into account the construction costs as well as the fixed costs and upfront capital required for the initial construction. Given the quick nature of the construction process we would need the construction cost, the substation cost, and the cost of the land upfront. In order to acquire this level of capital from investors we must appeal to them with an attractive internal rate of return based on the perception of risk associated with the technology. We have assumed that the technology has proven reliable, as the installation itself is quite large. That means that speculation remains regarding the viability of the project, but no major doubts exist related to the technology. For this reason we believe an IRR of 20% would help dissuade any doubts of technology risk and allow for us to acquire the necessary level of capital.[93]

In order to derive the revenues generated by the Stirling engines technology we used the total energy needed per year for our city: 1,044,000,000 kilowatt hours. Using a high side estimate of 8¢ per kilowatt-hour, 6.7% increase in electricity per year and 10% discount rate, we arrive at a revenue of $1,402,282,942.

[92] Leitner, 78.
[93] Leitner, 82.

Using the above calculations for capital, land and the substation, we arrived to a total fixed cost of $394,073,030. Given that all this money is borrowed upfront we are giving our investors an internal rate of return of 20%. Total payment to investors is $78,814,606. Finally, we must account for maintenance cost, which has a present value of $101,855,915. Adding these three numbers together we arrive at a complete lifetime cost of $574,743,551.

Given that profits equal revenue minus cost we arrive at total profits of $827,539,391 ($1,402,282,942 less $574,743,551).

VIII: Comparison and Conclusion

Given our analysis in the previous sections, we conclude that the dish Stirling system is a superior option. We found that the dish Stirling consumer receives 6.37 dollars per watt while the home photovoltaic system consumer receives between 0.9 and 1.70 dollars per watt. Given these findings, we see that consumers are better off investing in a dish Stirling system. We see a significantly greater return on this technology compared to photovoltaic cells. This, at first, seems odd given that the expenses for Stirling engines are much greater than that of photovoltaic cells. However, given that the power is ultimately sold back to consumers we were eventually able to realize a profit. Furthermore, once put in the scope of the real world the dish Stirling engine appears to gain more positive moment. For example the feasibility of a solar farm, given its size, can often be brought into question. However, gaining a set of several strong investors seems much more feasible than getting a town of 150,000 households to put Photovoltaics on their roofs. It is far easier to do the former, which intuitively makes sense. Then there is the issue of efficiencies. We said earlier that the efficiency of photovoltaics is between 13-16% while that of the Stirling engine is nearly 30%. Based on the higher efficiency of the Stirling engine, it is not difficult to believe that this technology will out perform its rival. However, one thing we did not take into consideration was potential subsidies or grants given for the construction of the farm. These have the potential to drive the costs down even further, increasing the watts per dollar generated, thus further widening the gap between Stirling Engines and photovoltaic Systems.

If our goal is a reduction of CO_2 emissions, then clearly both methods of electric productions eliminate most CO_2 emissions via reduction of fossil fuel-based production processes. Though there may be some CO_2 emissions during the manufacturing processes these emissions are incredibly small in comparison to the reduction in fossil fuels used.

Policy Implications

Given current levels of subsidies and tax credits, we found that the home photovoltaic system actually *returns* a profit to the homeowner. This indicates that these subsidies are too high and the policy is lagging behind new advances in technology. This misallocation could instead be used in the subsidy of dish Stirling farms where it would receive a much higher return.

Stepping away from subsidy policy we must now also consider the environmental impact concerns of dish Stirling construction. The clearing of vast acreages of land poses serious concerns for wildlife habitats as well as water usage issues. One must remember that these farms are located in the Mojave Desert where water is scarce. The Mojave Desert Land Trust was set up to combat the development of these precious ecosystems of the west. This group has taken the initiative to purchase land an incorporate it into preserves, saving animals from possible extinction.

Ultimately, the positive aspects seem to outweigh any minor concerns or potential externalities. The solar farm, and even the less practical decentralized photovoltaic deployments, help alleviate CO_2 emissions as well as maturing renewable energy technology. The major goal is to one day achieve fully sustainable systems, run completely on renewable energy, giving a cheap source of electricity and an all-important source of energy independence.

Appendices

Appendix 1: Financial Analysis of Installing a Photovoltaic Array

Initial Cost per kWh:	0.149	US$
Home Consumption in kWh:	580	kWh
Annnual consumption:	6960	kWh
Annual electricity bill:	1037.04	US$
Array needs to generate:	19.05544	kWh/day
Noontime solar hours per day:	5	Hours
Size of array:	3.811088	kW
Cost per installed watt:	8.2	US$
Cost of inverter replacement per watt:	0.39	US$
Total present cost per installed watt:	8.59	US$
Total installation cost:	31,250.92	US$

Case 1: For $1.90 CSI subsidy per watt		
Cost after federal 30% tax credit:	21875.65	US$
State subsidy per watt:	1.90	US$
Cost after $1.55/W state subsidy:	14634.58	US$
Plus inverter replacement per watt:	16120.9	US$
Annual loss in efficiency:	0.9	%
Discount rate:	7	%
Increase in electricity price:	0.067	US$
Present value for discount rate rate:	22580.72	US$
Net Savings in Present Value:	6459.82	US$

Case 2: For $1.10 CSI subsidy per watt		
Cost after federal 30% tax credit:	21875.65	US$
State subsidy per watt:	1.10	US$
Cost after $1.55/W state subsidy:	17683.45	US$
Plus inverter replacement per watt:	19169.77	US$
Annual loss in efficiency:	0.9	%
Discount rate:	7	%
Increase in electricity price:	0.067	US$
Present value for discount rate rate:	22580.72	US$
Net Savings in Present Value:	3410.949	US$

Appendix 2: Financial Analysis of 1 Watt Installed Photovoltaic Generating Capacity

1	Watt
5	Hours of noontime equivalent sun per day
5	Wh of daily electricity generation
1825	Wh per year
25	Years of generation
45625	Lifetime Wh output of 1W
$ 8.2	Cost of initial installation
$0.39	Cost of inverter replacement
$8.59	capital cost per watt
$0.18827397260274	capital cost per lifetime kWh

Case 1: For a $1.10 per watt CSI rebate

Starting Price of Electricity	$0.149
Rate of Change in Electricity Price	$1.067
Discount Rate	7%
Annual loss in efficiency	0.9%
Present value of 25 years future value	$5.92
Capital Cost after 30% Fed Subsidy	$5.74
Value of State Subsidy/W	$1.10
Cost after state subsidy	5.03
Minus present value of future savings	(0.89)
As a share of cost:	-10.3%

Case 2: For a $1.90 per watt CSI rebate

Starting Price of Electricity	$0.149
Rate of Change in Electricity Price	$1.067
Discount Rate	7%
Annual loss in efficiency	0.009
Present value of 25 years future value	$5.92
Capital Cost after 30% Fed Subsidy	$5.74
Value of State Subsidy/W	$1.90
Cost after state subsidy	4.23
Minus present value of future savings	($1.69)
As a share of cost:	-20%

Appendix 3: Calculating the Present Value of Dish Stirling Engine Maintenance in Cents per Watt Capacity (23 years)

Inflation rate^ year	Discount rate	year	Discount rate ^ year	I. rate^year / D.rate^year	Present Value (cents/watt)
1.000	1.1	0	1.000	1.000	0.069
1.020	1.1	1	1.100	0.927	0.064
1.040	1.1	2	1.210	0.860	0.059
1.061	1.1	3	1.331	0.797	0.055
1.082	1.1	4	1.464	0.739	0.051
1.104	1.1	5	1.611	0.686	0.047
1.126	1.1	6	1.772	0.636	0.044
1.149	1.1	7	1.949	0.589	0.041
1.172	1.1	8	2.144	0.547	0.038
1.195	1.1	9	2.358	0.507	0.035
1.219	1.1	10	2.594	0.470	0.032
1.243	1.1	11	2.853	0.436	0.030
1.268	1.1	12	3.138	0.404	0.028
1.294	1.1	13	3.452	0.375	0.026
1.319	1.1	14	3.797	0.347	0.024
1.346	1.1	15	4.177	0.322	0.022
1.373	1.1	16	4.595	0.299	0.021
1.400	1.1	17	5.054	0.277	0.019
1.428	1.1	18	5.560	0.257	0.018
1.457	1.1	19	6.116	0.238	0.016
1.486	1.1	20	6.727	0.221	0.015
1.516	1.1	21	7.400	0.205	0.014
1.546	1.1	22	8.140	0.190	0.013
					0.782

Inflation level:	2%
Discount Rate:	10%
Price ($)	0.069

Appendix 4: Stirling Engine Top-Level Cost-Benefit Calculations in Present Value (23 Year Lifespan)

Solar Farm Aggregate Revenue	$1402282942
Aggregate Maintenance Cost	$101855915
Substation	$3250000
Capital	$390000000
Land	$823030
Total	$394073030
IRR for investors	$78814606
Maintenance	$101855915
Complete life time costs	$574743551
Profits	**$827539391**

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