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Photovoltaics vs. Solar Thermal Technology: Rival or Complement?

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Introduction

In Part One, we begin by giving a chronological/functional account of how solar thermal works, the foundation upon which our understanding of and appreciation for its differences with photovoltaics will be grounded. We will then give an analogous chronological account/functional account of photovoltaic cells, which will set the backdrop for the rest of our investigation.

In Part Two, we conduct a levelized cost analysis comparison between a solar thermal and a photovoltaic power plant to see if we can draw conclusions about the economic validity of PV systems. Here we also address externalities, and speculate on how these numbers could be improved to become more cost-competitive. The power plants studied are the Nellis Air Force Base power plant in Nevada, and the Nevada Solar One, both of which began operating in mid-2007.

Finally, in Part Three, we will consider the ways in which photovoltaics improve on solar thermal with novel methods for solving certain problems. We will look at the inroads photovoltaics have made into making power available to off-grid housing such as those in rural India and Uganda. Next, we will examine the role of photovoltaics in a smartgrid system, and finally we will conclude with the current state and spirit of photovoltaic development as exemplified in the California Solar Initiative.

In our research, we hope to clarify which forms of PV technology are in contention with solar thermal plants as suppliers of energy, and which forms of PV technology fill in a gap where solar thermal fails.

Solar Thermal History and Function

There are currently two main genres of solar technologies for generating electricity. The earliest to be developed is known as solar thermal, so called because it uses the sun's rays to boil a liquid. The steam can then power turbines, which generate electricity in a manner similar to what occurs in most other types of power plants—i.e. through mechanically driving a generator, which can make alternating current using rotating magnets.

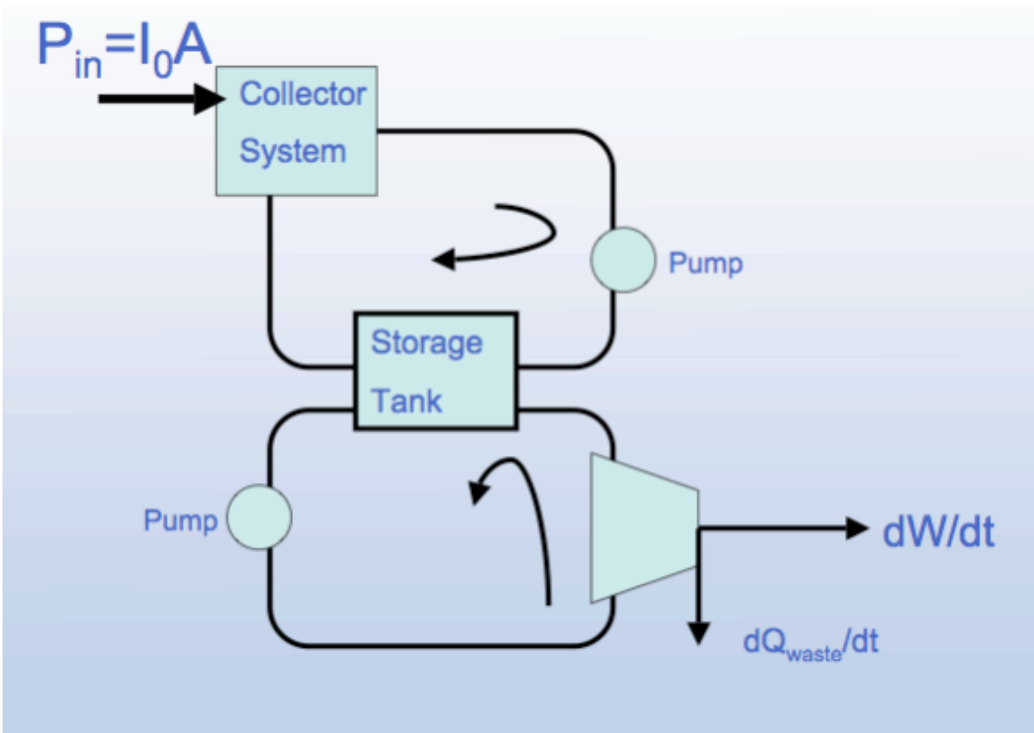

Figure 1: The basic functioning of a solar thermal electricity generation unit. Variations within the technology include different collector system approaches,

special storage materials such as molten salts, and uniquely efficient designs of the generation turbines themselves.[1]

Although solar thermal is considered one of the most cutting edge renewable energy technologies today, it was first conceived in the 1850's by a Frenchman named Augustin Mouchout, who used it as a mechanical means to power machines. Indeed, the basic components required are quite simple so that they were readily available even in Mouchot's time: curved mirrors that can concentrate the sun's energy, a tank of water to be boiled, and a mechanism to transfer the force of the steam generated into a form that can power man-made devices. Mouchot was successful: he helped develop a working printing press that ran thanks to the concentration of the sun's radiation. However, in the following decades, when electrical power began to be adopted, this solar generation innovation was forgotten, largely thanks to cheaply-available coal.

The inherent intermittency of solar power may have represented another factor that discouraged solar thermal's adoption near it's beginning. However, by 1909, John Ericsson had developed a concentrated solar power system that added the ability to store heat so that electricity could be generated at times even after the sun had stopped shining. This time-delaying storage ability gave solar thermal a unique advantage among renewables. In 1913, a Ericsson's basic design was scaled up to form a 55-kilowatt solar-thermal plant in Meadi, Egypt, but the commencement of World War I caused it to be

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[1] Schematic thanks to Professor G. R. Tynan, U. C. San Diego, "Overview of Solar Thermal Power (MANY SLIDES ADOPTED FROM A TALK AT 2005 AAAS MEETING BY E. BOES, NREL" http://maecourses.ucsd.edu/mae118b/PDF-LectureNotes/Solar%20Thermal%20Summary.pdf.

shut down, and thereafter it remained neglected because of the newfound abundance of cheap fossil fuels within the Middle East.[2]

During the 1970's oil crisis, solar thermal had another economic opportunity to develop. A company called Luz International created nine plants in California's Mojave Desert, totaling 354 megawatts of generation capacity.[3] However, over the next twenty years, the economics simply did not work in favor of the technology, and by 1991, Luz had gone bankrupt.[4] A technical report published in November, 1991 by Sandia National Laboratories found that the failure had been largely due to the fact that fossil fuels remained a cheaper alternative in the marketplace despite their costly, but unaccounted-for externalities.[5] Within these circumstances, insufficient government subsidies were provided to keep such solar thermal projects afloat, and this remained the case until the early 2000's, at which point Spain committed to providing guaranteed subsidies for concentrated solar power to begin bridging the gap towards solar thermal's widespread adoption. During this time, thanks once again to rising fossil fuel prices, plants began to be developed once again in the United States as well. This happened mostly in the arid Southwest, where the technology is most suited to thrive thanks to few clouds and much wide open desert ideal for large-scale solar collection (Spain, of course, is also a perfect setting for capturing the sun's energy.)

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[2] Joseph Romm, "Technology that Will Save Humanity," *Salon Media Group* (April 14, 2008), http://www.salon.com/news/feature/2008/04/14/solar_electric_thermal/print.html.
[3] Lester Brown, *Plan B 3.0* (New York: Earth Policy Institute and W. W. Norton & Co.), 251.
[4] Joseph Romm.
[5] Sandia National Laboratories, "Barriers to commercialization of large-scale solar electricity: Lessons learned from the LUZ experience," (orig. publ. November 1, 1991), http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=6033984.

It is remarkable then to note that even though solar thermal has been neglected for long periods, as it is currently being deployed, the technology is already producing electricity at approximately 12 to 18 cents per kilowatt-hour, one of the lowest rates among renewables (excluding subsidies).[6] This does pale to the approximately 3 to 5 cents per kilowatt-hour that a baseload coal plant can yield, but it is clear that remains is plenty of room for improvement in the efficiency solar-thermal technology.[7]

It is also important to note that because solar thermal is as dynamic as the moment-by-moment amount of sunshine a given area receives, it is probably wisest to use it primarily as a means of supplementation during peak times, which, fortuitously coincide with midday, when the shines down the most brightly. Currently, natural gas is used widely as such an auxiliary peak fuel, and there have also been trials that have yielded some success in efficiently running hybrid natural gas/solar thermal plants[8] as with SEGS case study, which shall be discussed later.

A 2008 presentation by Sandia National Laboratories projected that, in part thanks to learning by doing, solar-thermal plants will be able to produce electricity at just 8 to 10 cents per kilowatt hour once a certain global megawatt threshold is reached within the

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[6] Douglas Fischer, "Solar Thermal Comes out of the Shadows," *The Daily Climate* (November 20, 2008), http://www.dailyclimate.org/tdc-newsroom/solar-thermal/solar-thermal-comes-out-of-the-shadows. Note that the Arizona Renewable Energy Assessment corroborates this number—it shows that its own solar thermal range in performance from about 16 to 18 cents/kilowatt-hour. See chart by Arizona Public Service Company, Salt River Project, and Tucson Electric Power Corporation, "Arizona Renewable Energy Assessment: Final Report," (September 2007), http://www.bv.com/resources/energy_brochures/renewables/rsrc_AZ_RenewableEnergyAssessment.pdf, section 1, page 3.

[7] Douglas Fischer.

[8] *ibid*.

next few years, even if the price of building materials remains high.[9] Several types of solar thermal technology are also widely expected to improve. Such optimistic predictions are not entirely new, either. Nearly half a decade ago, engineers already felt confident that the technology could soon be adapted to generate energy at a rate of as little as 5 cents per kilowatt-hour, but as with all such estimates one encounters when researching the rapidly developing area of solar power, the amount of time it will take for innovations take to be implemented economically is usually difficult to predict.[10]

In the analysis so far, "solar thermal" has been referred to generically. In reality, there are several variations of the technology. They differ mostly strikingly in how the focusing mirrors are designed and oriented. Despite specific efficiency differences here and there among the different technologies, each nonetheless performs similarly enough to fall under the same basic category of solar thermal. For this reason of near economic equivalence, the specific types will not be analyzed in great detail for the purposes of this paper, which seeks to evaluate the current and likely future marketplace viability of solar power. The important trend is simply that the more innovative, efficient, and cheap plant designs thus far have and should continue to replace the older ones over time.[11]

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[9] *ibid.*

[10] Professor G. R. Tynan, U. C .San Diego, "Overview of Solar Thermal Power (MANY SLIDES ADOPTED FROM A TALK AT 2005 AAAS MEETING BY E. BOES, NREL" http://maecourses.ucsd.edu/mae118b/PDF-LectureNotes/Solar%20Thermal%20Summary.pdf.

[11] For a highly detailed and broad-reaching assessment of the performance differences and economic potentials of conventional and recently burgeoning solar thermal plant designs, see Arizona Public Service Company, Salt River Project, and Tucson Electric Power Corporation, "Arizona Renewable Energy Assessment: Final Report," (September 2007), http://www.bv.com/resources/energy_brochures/renewables/rsrc_AZ_RenewableEnergyAssessment.pdf.

A clear example of this trajectory occurred recently when Sandia and a solar thermal equipment company, Sterling Energy Systems, made a joint breakthrough in February 2008. A new design for the focusing mirrors along with other innovations increased the sunlight capture to grid efficiency rating to 31.25 percent compared to the old 1984 record, which was had long remained unsurpassed at 29.4 percent. Further, in this case, it does seems clear that the revised type of solar-thermal plant will in fact be implemented on a large scale soon in order to fulfill recent contracts made with southern California utilities.[12] Given solar thermal's basically-dormant history from the 1970's oil shock up until recently, it should be no surprise that we are beginning to see many more such technological advancements now that conventional energy prices are clearly rising globally. This highlights the potential for rapid solar thermal innovation that was simply not incentivized before.

The solar thermal method of electricity generation is well-suited for use in large-scale plants that compete directly with traditional ones such as those powered by coal. Although while solar thermal can indeed generate at this large scale, again, it should be noted that it cannot do so full-time. Solar thermal requires at least some sunshine that has been converted to heat within the last few hours. While solar thermal still costs 2-6 times more than coal (though, tantalizingly, it remains only a cent or two more expensive per kilowatt-hour than peak-load natural gas generation), it is certainly moving towards becoming absolutely cost-competitive with conventional generation.[13] In comparison to

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[12] Sandia National Laboratories, "Sandia, Stirling Energy Systems set new world record for solar-to-grid conversion efficiency 31.25 percent efficiency rate topples 1984 record," (February 12, 2008), http://www.sandia.gov/news/resources/releases/2008/solargrid.html.
[13] statistic derived from numbers available at from Fischer, Douglas, "Solar Thermal Comes out of the Shadows," *The Daily Climate* (November 20, 2008),

photovoltaics, the other major category of solar generation technology, solar thermal is already quite close to this goal, while PV is arguably a bit farther away from proving perfectly competitive in most large-scale settings.

Photovoltaic Cells History and Function

Electricity yield-for-cost statistics for PV must be evaluated very carefully because of variations in the technology itself. PV usually costs somewhere between 40[14] cents per kilowatt hour at the high end (for residential use) and 21 cents/kilowatt-hour[15] where the large scale of industrial applications apparently allow it to be run significantly more cheaply at present. Thus, PV is between 4 and 13 times costlier than baseload coal. And unlike solar thermal, which can suspend hot liquids as future energy potential, PV has no inherent ability to store energy for later use, so it would be impossible to consider this source as providing a reliable baseload for a cohesive portion of the day.[16] Thus, when viewed strictly in contrast to solar-thermal's clear advantages, it might seem that photovoltaics should not be a terribly valuable technology in the marketplace.

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http://www.dailyclimate.org/tdc-newsroom/solar-thermal/solar-thermal-comes-out-of-the-shadows.

[14] 40 cents/kilowatt-hour statistic derived from numbers available at from Fischer, Douglas, "Solar Thermal Comes out of the Shadows," *The Daily Climate* (November 20, 2008), http://www.dailyclimate.org/tdc-newsroom/solar-thermal/solar-thermal-comes-out-of-the-shadows.

[15] 21.40 cents/kilowatt-hour is the "Solar III" (industrial photovoltaic index) for November 2008. According to the ongoing studies by the Solarbuzz consultancy group, industrial photovoltaic uses have recently yielded the cheapest electricity, while residential applications have yielded costs much closer to the 40 cents/kilowatt-hour statistic cited earlier. Commercial PV costs remain in the middle at about 30 cents/kilowatt-hour. See "Solar Electricity Prices November 2008," Solarbuzz | Portal to the World of Solar Energy, http://www.solarbuzz.com/solarprices.htm.

[16] Note that certain load balancing technologies such as the "smart-grid," discussed later in the paper, might alleviate this daytime excess/nighttime dearth distribution problem.

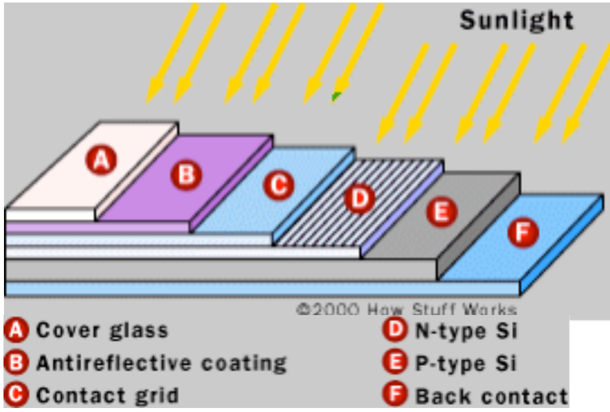
However, PV has its advantages, too. It, unlike solar thermal, can work successfully even at small scales—a homeowner, or even a group of villagers in a developing country, could purchase a photovoltaic panel or two for personal use, for example. This brings up the possibility of shifting the entire energy paradigm from a conventional system in which electricity is only generated from a single central power plant to an alternative model that includes more *distributed* generation. This is a topic that will be discussed at length later in the paper.

Another advantage of solar cells (another term for photovoltaics) is that they are inherently compact and lightweight, especially the newer thin-film type, which can even be imprinted on existing materials such a roof's shingles.[17] This is made possible by the fact that in all solar cells, the sunlight to electricity conversion process occurs chemically rather than mechanically. Solar cells generate electricity after photons hit light-sensitive compounds, exciting them, and eventually resulting in the emission of a flow of electrons—a useful direct electrical current. The name "photovoltaic" derives from this very effect.[18] Unlike the solar thermal generation mechanism, the photovoltaic process involves no moving parts or liquids, so solar cells require little maintenance.[19]

Figure 2: As this diagram illustrates, photovoltaic generation of electricity can occur through the chemical reaction of light with a compound such as the ubiquitous silicon telluride crystal technology.

Because the conversion process requires no moving parts, PV cells , especially the most common types, which are single or polysilicon-based, can be applied in many environments, need little maintenance and are generally long-lasting, as demonstrated by the continued functioning of numerous decades-old satellites and space probes.

[17] Arizona Public Service Company, Salt River Pro ... ssessm ... ures/re
Assessment.pdf, section 4, page 40 [PDF page #81
[18] "NREL Learning—Photvoltaics," *National Rene*
November 24, 2008), http://www.nrel.gov/learning
[19] *ibid.*



Basic structure of a generic silicon PV cell.[20]

Compared with solar thermal, historically there has been more consistent incentive to improve the efficiency of PV technology due to its versatility for unique small-scale applications. It makes sense that the need for electricity in isolated wartime locations such as deserts, in space travel, and for satellites all have strongly encouraged government-scale funding for research to improve PV.[21]

Indeed, since the technology's advent, there has been a clear trend both of rapid solar cell efficiency improvements and of steadily falling costs per watt generated. In the 1950's, Bell Labs began developing photovoltaic technology for the space program and

[20] Scott Aldous, "Anatomy of a Solar Cell" *How Stuff Works,* http://science.howstuffworks.com/solar-cell3.htm.

[21] The Arizona Renewable Energy Assessment confirms that indeed,

> *Solar PV was originally developed as a power source for the space program. PV found its first terrestrial uses in remote industrial and residential applications. This 'off grid' use of solar has been cost effective for some time, as it is generally less expensive than extending the electricity grid to remote locations.*

Arizona Public Service Company, et all, section 4, pages 41-42 [PDF page #82-83]. Note that since 2004, the global silicon supply has not been able to meet demand, thus slightly driving up the price for PVs and encouraging the adoption of less silicon-intensive technologies—even those that are less efficient like thin-films.

by 1954 had invented the Bell Solar Battery, the first practical solar cell.[22] It was the first of a type known as single-crystal silicon.[23] Though it initially yielded only 4.5% efficiency, this was surpassed within a matter of months by another team, which managed to develop similar cells with 6% efficiency.[24] Having no moving parts and generally being made of durable materials, single-crystal silicon PV's have proved to be very reliable, as has a more recent, less silicon-intensive, therefore expensive, though slightly less efficient variation known as polysilicon.[25] Indeed, silicon-based photovoltaics have long been used successfully to power devices that enter space, or remain in other extreme environments isolated from conventional, nonrenewable energy sources.

As soon as 1955, a single-crystal silicon PV design was developed commercially, though this only ran at 2% efficiency and cost $1500 per watt. Then just four years later, a 10% efficient cell design became commercially available.[26] Throughout the next decades, several new PV variations were developed using some different materials and layouts. Amazingly, by 1975, cost was down to around $100/watt, and a decade later, incremental progress largely thanks to Australian research had led to single-cell silicon photovoltaics with over 20%[27] efficiency. By this time, conventional cells, of lesser efficiencies, had

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[22] Alcatel-Lucent, "Bell Labs Celebrates 50th Anniversary of the Solar Cell – Timeline," (2004), http://www.bell-labs.com/news/2004/april/anniversary50_timeline.html.
[23] Windy Dankoff & Dankoff Solar, "Three Photovoltaic Technologies: Single Crystal, Polycrystalline and Thin Film," (accessed November 24, 2008), http://www.wholesalesolar.com/Information-SolarFolder/celltypes.html.
[24] Mary Bellis, "History: Photovoltaics Timeline," *About.com*, (accessed November 24, 2008), http://inventors.about.com/od/timelines/a/Photovoltaics.htm.
[25] Windy Dankoff.
[26] Mary Bellis.
[27] School of Photovoltaics and Renewable Energy Engineering, "Online Course—World Records," *University of New South Whales,* http://www.pv.unsw.edu.au/online-course/world-records.asp.

dropped to $10 per watt. As figure 3 shows, the price per watt has continued to fall since that time thanks to progress in PV research and development. Indeed, by late 2006, the cost was down to $4/watt; it can be noted that if this trend continued and PV units reached $1/watt, that would make the technology cost-competitive with coal.[28]

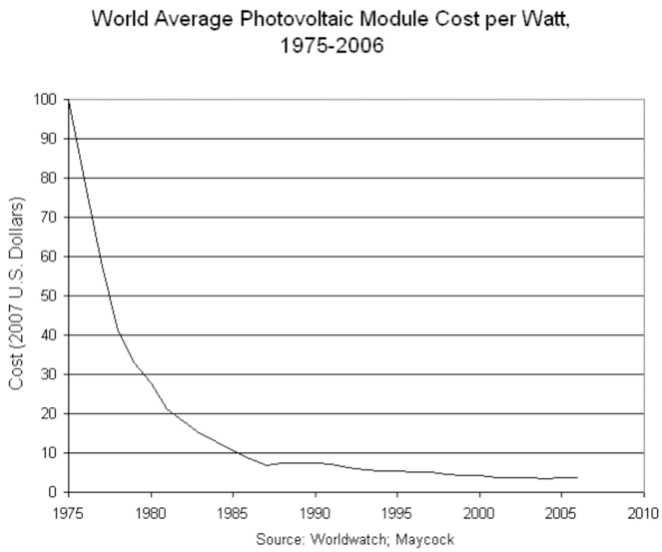

Figure 3: The costs per watt of photovoltaics has decreased steadily over the last several decades. One of the reasons the technology has progressed so admirably is due to the push for its development by the United States space program beginning in the 1950's.

Solar thermal, on the other hand, experienced no such large-scale developmental push.

Data Presentation Courtesy of the Earth Policy Institute[29]

Still, it has taken time for the advent of improved-efficiency cells in the lab to translate into panels that are sufficiently cheap and mass-produced. Today, most common silicon-based cells average about 17% efficiency although recent scientific breakthroughs have already made 40% efficiency attainable.[30] As with some potential

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[28] Dollars per watt from 1975 onwards and other useful information on recent PV trends are from Jonathan G. Dorn, "Solar Cell Production Jumps 50 Percent in 2007," *Earth Policy Institute*, (December 27, 2007), http://www.earth-policy.org/Indicators/Solar/2007.htm.

[29] "Eco-Economy Indicators: Solar Power--Data," *Earth Policy Institute*, (December 27, 2007), http://www.earth-policy.org/Indicators/Solar/2007_data.htm#fig7.

[30] "Converting Sunlight Into Electricity: European Project Breaks Efficiency Record," *Science Daily* (November 20, 2008), http://www.sciencedaily.com/releases/2008/11/081120162704.htm. This article explains

innovations with solar thermal, it remains to be seen how quickly and cost-effectively these solar cell improvements will trickle down from laboratories into the marketplace. But the plethora of technological improvements that have began to appear on the radar indicate that PV may become a much better economic performer soon. Most of these innovations can be traced to government initiatives, both through subsidies and investment in research and development in the United States and Europe. If the past several decades are any indication of the future, PV is destined to continue becoming cheaper and more efficient, especially with the kind of government sponsorship it initially received from the United States space program. But why are photovoltaics receiving such aggressive sponsorship? Is the small-scale initiative all there is to it, or do we also see photovoltaics becoming a contender with solar thermal plants for utility energy generation? This is what we will examine next.

Economic Analysis

Cost

We have thus far examined several notable benefits of both solar thermal and photovoltaic technologies Now we will enter into an economic analysis regarding the levelized cost of energy for both cases.

Levelized Cost of Energy (Life-Cycle Energy Cost)

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a very recent experiment in Spain that yielded 39.7% silicon PV efficiency. Slightly higher efficiency ratings have already been made earlier this year in the U.S. See. for example, "NREL Solar Cell Sets World Efficiency Record at 40.8 Percent," *National Renewable Energy Laboratory Newsroom* (August 13, 2008), http://www.nrel.gov/news/press/2008/625.html.

Simply put, the Levelized cost of energy of a solar system is the total cost accumulated over its life cycle divided by the total energy produced over its life cycle, all discounted for interest. This allows us to calculate the cost per kWh of energy averaged over the entire lifetime of the system, discounted for present value. For the plants we are considering, we can assume negligible operation and maintenance costs, negligible degradation to the efficiency of the system over time, and negligible residual value (the plant will have depreciated in value 100% after its life-cycle). The variables we end up taking into account, then, are the capital costs or initial investment (measured in $), the estimated annual energy production (measured in kWh), the discount rate of 7% interest, and the life-cycle span of 20 years.

The relevant equation becomes:

$$\frac{\text{Initial Investment}}{\text{Estimated Annual Energy Production}} \times \frac{1-(1+r)^{-t}}{r}$$

Solar Thermal and Photovoltaic Plants Compared

We will compare a large-scale PV plant to a large scale Solar Thermal plant. We have already noted that PV is beneficial for individual homes as well, but to compare it to a solar water heating system would be to only address heat on the one side and electricity on the other. Therefore, we will compare two large-scale systems, both of which have the capacity to produce and supply electricity to households.

Specifically, we will deal with the Nevada Solar One solar thermal plant and the Nellis photovoltaic plant. We chose these to compare because they are located in the same state and therefore are subject to similar lighting and climate. In addition, they were both put into operation around mid-2007, so their technologies should be contemporary.

Nellis

The solar power plant at Nellis Air Force Base in Nevada began operating in October 2007 and is the largest US photovoltaic power plant to date. Operating at a peak capacity of 14GW, the Nellis will generate between 25-30 million kilowatt hours of electricity per year, which provides the base with 25-30% of its total energy use. [31] Equipped with Sunpower solar panels, the plant has a capacity factor of 0.24. It also has an initial investment of $100 million, and a projected lifespan of 20 years. Land rental does not factor into annual costs because under the terms of the contract, land usage over these 20 years will be free. [32]

Nevada Solar One

The Nevada Solar One is a solar thermal plant that employs a parabolic trough technology and began operating in June 2007. Spanning 400 acres and with a capacity output of 64 MW, it is the third largest solar thermal plant in the world. The initial investment for this plant was more than $266 million, and it produces an estimated 134 million kilowatt hours per year.

Assumptions

	Nellis	Nevada Solar One
Initial Investment	$100 million	$266 million
Estimated Annual Energy Production	25-30 million kWh	134 million kWh
Operating Capacity	14MW	64MW
Capacity Factor	0.20-0.244	0.24
Operation and Management Costs	0	0
System Depreciation	0	0
Residual Value	0	0

[31] "PV System Completed at Nellis Air Force Base" (December 18, 2007) http://www.renewableenergyworld.com/rea/news/story?id=50895

[32] "North America's Largest Solar-Electric Plant Switched On" (December 28, 2007) http://www.metaefficient.com/news/north-americas-largest-solar-electric-plant-in-switched-on.html

Life-cycle	20 years	20 years
Discount Rate	7%	7%

Results

	Nellis	Nevada Solar One
investment per kWh for one year	$3.330/kWh	$1.985/kWh
discounting denominator (20 year cycle)	10.59	10.59
discounting denominator (30 year cycle)		12.41
Levelized cost of energy (20 years)	$0.314/kWh	$0.187/kWh
Levelized cost of energy (30 years)		$0.160/kWh

We can see that even granting the Nellis plant an estimated 30 million kilowatts per year rather than 25, we still end up with a levelized cost of energy that is close to twice that of the Nevada Solar One, $0.314/kwh and $0.187/kwh respectively. Calculations were made assuming that both plants had a life-cycle of 20 years. This is included in Nellis's land lease terms, which expire in 20 years, but such is not necessarily the case for Nevada Solar One.

Let's now assume that Nevada Solar One has a life-cycle of 30 years. The levelized cost then becomes $0.160/kwh, close to exactly half of Nellis's. This is a small difference, but nevertheless one against Nellis's favor. Considering that these are contemporary technologies that are geographically similar, there must be another reason for Nellis's shortcomings. That reason, we will find, is a lack of energy storage.

Efficiency

A key problem for cost-efficiency of photovoltaic systems is the lack of a reliable form of energy storage. Other peaking plants, such as solar thermal, at least have the option of thermal storage whereas photovoltaics can only use batteries. If an adequate storage device were available, capacity factors for photovoltaics would increase to 0.5-0.7. [33]

Let us assume this is possible and perform the calculations. With a capacity factor of 0.5, we get an estimated annual energy production of 61.32 million kWh, and with a capacity factor of 0.7, we get an estimated annual energy production of 85.848 million kWh. Compared to the original 30 million kWh, the gains are enormous.

Let us now calculate the levelized cost of energy given these capacity factors. We still assume a 20 year life cycle and a 7% discounting rate. We first find the price per kWh produced, which at a capacity factor of 0.5, is $100 million/61.32 million kWh which equals $1.63/kWh. After discounting for 20 years, this becomes $0.154/kWh. Repeating the process for a 0.7 capacity factor, we have $100 million/85.848 million kWh which equals $1.1698/kWh. After discounting for 20 years, this becomes $0.110/kWh, and at this point it begins to look extremely cost competitive. We can achieve this through developing a workable battery storage system, which has been mostly unfruitful in the present but as it is being heavily researched, it is hopeful that such a technology should come into existence very soon.

Benefit

The Nellis plant saves the residents of the air force base $1 million a year in electricity as they are in an agreement to pay $0.022/kWh for this solar power rather than the $0.09/kWh they were paying to Nevada Power.[34] Pricing 24,000 tons at $35/ton via

[33] DOE Tribal Energy Program California Workshop Concentrating Solar Technologies and Applications. Sandra Begay-Campbell. Sandia National Laboratories. p.17 (Jan 23, 2008)http://apps1.eere.energy.gov/tribalenergy/pdfs/course_tcd0801_ca17ax.pdf,

[34] "North America's Largest Solar-Electric Plant Switched On" (December 28, 2007) http://www.metaefficient.com/news/north-americas-largest-solar-electric-plant-in-switched-on.html

the Kyoto Protocol[35], we save an additional $840,000 per year on the benefit side. But for 20 years, even *without* being discounted, we are still nowhere near breaking even.

What about the Nevada Solar One? Saving close to 100,000 tons[36] of carbon emissions per year amounts to an annual savings of $3.5 million per year in carbon reduction. The Nevada Solar One is capable of providing 40,000 households with power during the day[37], and at current capacity provides 14,000 households with power annually.[38] Because it sells electricity at 9-13 cents per kWh, and compared to the Nevada average of 9-11 cents per kWh, they are really no better off.[39] Thus the benefits are only carbon emissions. Again, $3.5 million compared against the $266 million initial investment will also yield a net loss.

Why do these plants continue to be made if they are seemingly not economically viable? Moreover, why is so much R&D being placed into photovoltaics when they have nearly twice the levelized cost of solar thermal? One answer is that new technologies on the horizon such as MIT designed PVs reaching over 40 percent capacity factor will soon drive down costs as efficiencies increase. Increased economies of scale will also allow more PV cells to be produced more cheaply. But there is another reason for the popularity of PV, which is its ability to perform certain tasks that solar thermal systems cannot. These will be discussed next.

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35 "The Cost of Carbon"http://www.ecologisticsllc.com/cost.html
36 "Beyond zero Emissions". http://www.climatechange.gov.au/greenpaper/consultation/pubs/0458-beyond-zero-emissions.pdf
37 "Solar One Concentrated Solar Power (CSP) Plant, Nevada, USA"http://www.power-technology.com/projects/solaronesolar/
38 "ACCIONA's Nevada Solar One™ — Demonstrating the Commercial Competitiveness of Solar Energy"http://www.nevadasolarone.net/the-plant
39 "Nevada Solar One" (last updated December 9, 2008) http://www.reuk.co.uk/Nevada-Solar-One.htm

Photovoltaic Innovations

Off Grid Use in Rural Areas

The term "distributed solar" refers to systems in which individual buildings equipped with solar panels are connected to a grid. Consumers then both feed into and take from the grid depending on their generation capacity and energy needs. The model of distributed generation is practiced in other ways: through small scale generators that run on diesel, biomass, or a variety of other fuels, wind turbines, and fuel cells, but under the appropriate circumstances, solar offers particular benefits.[40] One of the main benefits, in general, of distributed generation systems is that they can be set up in areas where access to main grids powered by large scale power plants is not feasible, and where setting up an isolated large scale power plant is not cost effective. Despite great gains in access to electricity in recent decades, 1.6 billion people live without access, and a further 2.4 billion rely on traditional biomass for heating and cooking needs. Of these people, four fifths live in impoverished, rural regions of South Asia and Sub-Saharan Africa.[41]

Of the following three case studies, two look into programs in these regions which aimed to provide rural access to electricity through off the grid home solar systems. Included is information on the political development of the program, its structure and goals, and an analysis of the success of the program. The final case study is on the California Solar Initiative, which, through government subsidies and support, aims to increase solar capacity by 1,750 MW within the next ten years. Important questions for this program regard how it is changing the energy marketplace in California, its effects

[40] Mollly Sterkel, "Distributed Generation and California Solar Initiative: CPUC Policies and Programs," (presented to the Air Resources Board Workshop, May 2, 2008), 3.
[41] "Poverty, Energy, and Society," The Baker Institute Energy Forum, http://www.rice.edu/energy/research/poverty&energy/index.html.

the efficiency of energy distribution, and whether or not it is effectively driving down costs of PV cells. For some of these questions it is too soon to come to conclusive answers, but there is already a great deal of information from which to extrapolate.

Rural India: Solar Loans

In rural India, remote areas too far away from a conventional electricity grid often resort to heavily polluting diesel-powered generators. Such systems are a prime example of unsustainable-development, but in most communities the great increase in pollution is seen as a worthwhile tradeoff for much needed access to electricity.[42] Starting in 2003, a United Nations programs started to make a clean alternative economically viable for many villagers in the state of Karnataka. The UN's Indian Solar Loan program worked with the two of India's largest banks, Syndicate and Canara, to provide villagers access to credit to fund the installation of a PV system on the roofs of their homes. Before the programs inception, the only option for installing such a system was paying by cash, which put it out of reach for the vast majority of villagers. From the pre-UN program days of that all cash market, today, 50% of solar home sector sales are financed through bank loans.[43] Throughout the program, the loan interest rate reduction, which ran from 5-12% initially, was phased out, allowing such projects to be financed within the marketplace by purely commercial means.[44] Lending is competitive with many banks beyond the initial two that worked with the UN offering such loans, and with over 2,000 bank branch locations involved across India.[45]

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[42] Keith Bradsher, "Paying in Pollution for Energy Hunger," *The New York Times*, January 9, 2007, World Business Section.
[43] "Awards and Events," UNEP, *Our Planet Magazine*, May 2007.
[44] "Indian Solar Loan Program Offers Access to Light," Renewable Energy World, August 8, 2008, http://www.renewableenergyworld.com/rea/news/story?id=53274.
[45] "Three UNEP Projects win UN wide Awards," UNEP, July 11, 2008, http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=540&ArticleID=5870&l=en.

To residents of developed countries the goals and results of the program might seem quite underwhelming, but they led to drastic improvements in the lives of 100,000 Indians with the installation of 18,000 total systems. The $1.5 million project saw incredible returns for the relatively little investment, resulting in a 13-fold increase in rural solar installations. The systems funded generally ran in price from $300-$500 dollars, are capable of power 2-4 lights or small appliances, ran in the range of 18Wp to 40 Wp, and replaced either polluting, expensive kerosene, or very unreliable grid electricity. Systems included the panels, a storage battery, "charge controller, interior wiring and switches and electric lighting fixtures."[46] The benefits of having reliable light, even on such a small scale, can't be overestimated, for those living in circumstances such as those experienced by the beneficiaries of this program. Gains range from extending working hours for light sensitive cottage industries, to scaring off deadly cobras, to improved air quality in homes.[47] The relationship between energy access and the poverty cycle is all too often overlooked, but successful programs such as the ISL showcase beautifully the potential for economic empowerment by way of even slight improvements in energy access for the rural poor.[48]

The program is today one of the UN Environment Programme's (UNEP) most famous, winning a prestigious Energy Globe Award in 2007, "considered today's most prestigious and acknowledged environmental award bestowed on projects from all over the world." The success of the Indian project has led to its being used as a model in other

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[46] "UN Engages Banks to Light up Rural India," UNEP, http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=504&ArticleID=5570&l=en

[47] Peter Fries, "Indian Solar Loan Program Offers Access to Light," Renewable Energy World, August 8, 2008, http://www.renewableenergyworld.com/rea/news/story?id=53274 and "Solar loans light up rural India," BBC, April 29, 2007, http://news.bbc.co.uk/1/hi/sci/tech/6600213.stm

[48] "Poverty, Energy, and Society," The Baker Institute Energy Forum, http://www.rice.edu/energy/research/poverty&energy/index.html.

developing areas without functioning or dependable conventional grids, such as Morocco, Tunisia, Algeria, Mexico and Chile.[49]

Uganda: Photovoltaic Pilot Project for Rural Electrification

While not as widely lauded and not as objectively successful as the India Solar Loan Program, the Photovoltaic Pilot Project for Rural Electrification (UPPPRE) stands as an important case study in rural distributed solar. The motivations behind, structure, and goals of the program were similar to those in the Indian program, although perhaps the circumstances were even direr. The program itself was initially meant to be only a three-year program (it was extended twice), but was eventually integrated into a larger system of programs with a ten-year goal of increasing access to energy for rural Ugandans from 1% of the population to 10%.[50] While access has increased to 4%, that's still far shy of the goal, with a mere three years left to attain it.[51]

Started in 1995, the UPPPRE was financed at $3.6 million, and was intended to provide 12,000 people in rural areas with electricity. While the program certainly was not a failure, it had many shortcomings that prevented it from being an uncontestable success. As the program reached its end, a commercially based loan system was not yet stable, part of what led the program to beyond its initial end date. In a 2002 evaluation report on the project the UNDP found that,

> The UPPPRE project under other circumstances should be continued not because of the outstanding activities, but because now at its end after many lessons and hard work it has launched an innovative and now functioning scheme of lending for PV systems so rare in Africa. If these micro lending

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[49] "UNEP's India Solar Loan Programme Wins Prestigious Energy Globe," UNEP, April 12, 2007, http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=504&ArticleID=5562&l=en.
50 Steve Thorne and Leonard K. Mutesasira, "Uganda Photovoltaic Pilot Project for Rural Electrification," United Nations Development Programme, Global Environment Facility, March 10, 2002, 8.
[51] Umaru Lule, "Bringing electricity to the rural areas: Designing Laws and Policies that work," (presented to the Committee on Natural Resources, Parliament of Uganda), 20.

> modalities and the institutions involved were robust, the argument for closure would be clear – but they are not. They are fragile and need support to mature.[52]

Furthermore, the evaluation found that there had been gross financial and general project mismanagement in the handling of the program on the local level, which caused a great deal of its inefficiency and hampered earlier "maturation." Some of these problems included significant roadblocks to success such as poor record keeping and control of spending, but also details that perhaps indicate an overall lack of organization and centralized control within the project, such as misuse of project vehicles.[53] Mismanagement also happened on a larger scale, due to an inability of the three main sponsors (the MEMD, UNDP, and the ALD) to work together effectively. The same evaluation report notes that during one period, the project sponsors did not meet for an eighteen-month span.[54]

At the start of this program, the reality in Uganda was one of even a greater lack of rural electricity access than in India, banks even more apprehensive to give out loans for such projects, and a completely undeveloped solar energy industry. Given this state of affairs, the gains of the project are not wholly negligible. Among its greatest achievements was building a barebones social-political infrastructure for distributed solar. During the programs lifespan a NGO called the Uganda Renewable Energy association, knowledge of solar and its potential was disseminated, and "national level solar based rural electrification policies were established," all of which provide pieces for this infrastructure.[55] Most analysis of the program seems to imply that the multi-level

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[52] Steve Thorne and Leonard K. Mutesasira, 34-35.
[53] *ibid*, 18-19.
[54] *ibid*, 23.
[55] "The Uganda Photovoltaic Pilot Project for rural Electrification" United Nations, http://www.un.org/esa/sustdev/csd/casestudies/e9_e2_uganda.pdf.

mismanagement, which would naturally impede any program, was to blame for lukewarm results, rather than some inherent incompatibility of solar microlending for the Ugandan situation. The success of small-scale operations within the project, such as a small 100 home project undertaken in 1995 by the Solar Electric Light Fund (SELF) in conjunction with Habitat for Humanity, shows the potential for more positive results under circumstances of more effective management.[56]

Their many differences aside, these the Ugandan and Indian programs both indicate greatest situation strengths of PV, and their potential to act as a green “leap-frog” technology, which is economically wise for rural residents even disregarding such system’s long term health and environmental benefits over the diesel generators, kerosene lamps, and even hydroelectric systems they might replace.

Net-Metering and Smart Grids

Unlike the case in India and Uganda PV installations in off-grid urban areas in the United States have been occurring for some time now and their rate of adoption is still rapidly increasing today. Renewable energy has become an attractive source of energy, for numerous reasons, and PV cells are a particularly great option for private home use. Unlike large-scale centralized plant sources like solar thermal or the common coal plant, PV systems give consumers the option of generating their own renewable electricity to power most, if not all, of their home utilities. Although PV is more expensive than alternative forms of energy, it is one of the easiest options for personal off-grid electricity generation that allows individuals to choose to be eco-friendly for a price. In addition, the federal government has multiple initiatives to assist in the large upfront costs of installing

[56] “Uganda: 1995,” Solar Electric Light Fund, http://self.org/uganda1.shtml.

PV plants. These incentives have led to an increase demand for PV that might eventually lead to a decrease in price through either economies of scale or an increased drive for finding a more cost efficient way of producing PV systems.

There are currently various state government initiatives (like the California Solar initiative) and subsidies, but for the sake of simplicity, we will just be focusing on the federal government's energy program. As stated by the Database of State Incentives for Renewable Energy, the federal government acts in two ways, they provide an initial up-front rebate on the entirety of the project costs as well as pay for the renewable energy that is hooked onto the main grid lines. There are two ways for customers to receive subsidies for their solar panel power while attached to the grid—feed-in tariffs and net metering. Through the feed-in tariff, the government forces regional or national electricity utility companies to buy renewable electricity at a set market price. This set price is higher than the market prices for electricity generated from fossil fuels and assists in offsetting the high cost of obtaining renewable energy sources. The higher price is then divided among all the electricity grid users and the minimal increase in electricity costs will not be realized by the other customers. In net-metering, on the other hand, the customer uses the solar energy to power his or her own home and only pays the difference of energy outflows minus energy inflows[57].

One of the main issues preventing the acceleration of PV installations is the fact that utility companies are not yet fully equipped to handle this new form of electricity generation. That is, connecting PV onto an electric grid can be problematic because most electricity grids do not currently possess the technology necessary to safely accommodate

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[57] DSIRE. "Federal Incentives". December, 2008 http://www.dsireusa.org/index.cfm?EE=1&RE=1

neither the varying generation loads characteristic of energy gained directly from the sun, nor the bidirectional power flow that distributed PV requires. The only thing that utility companies can currently calculate is the amount of electricity used within a certain period of time. Net metering has provided a way to calculate the bidirectional flow but we must now take it a step further if we are looking into a simple, safe and reliable way of using renewable PV electricity.

Not all homeowers take the national grid route but for those who do, the system, as it is today, is not the most efficient. The entirety of the country's electric grid is composed of three major grids that were eventually connected. The network of electric lines in this grid is not very organized or efficient. The grid was not created according to a master plan; instead the electric lines were constructed little by little by local utility companies and they were eventually all connected in an effort to have multiple sources of energy in the case of single base plant outages. To provide a clear example of how inefficient the system is, transporting energy from California to New York would consist of sending electricity through a wire that, instead of taking a direct path to New York, would take twists and turns around various state electric lines before reaching New York. PV system integration provides a more efficient local solution to this problem because of the shorter transportation distance. Excess energy generated would be distributed to the surrounding neighbors and utilized instead of energy coming from a central base plant miles away.

A system that has become much more popular and could potentially solve all the current electrical current distribution problems is something called a "smart grid". As described in Thomas Friedman's "Hot, Flat and Crowded", the "smart grid" is a term that has been coined to describe what, in its full deployment, would be a peer-to-peer computerized load balancing network that promises to increase the efficiency with which energy, most notably renewable energy, is distributed and consumed. In accordance with the model, each household unit that consumes electricity—from televisions to computers, to air conditioning systems, to blow dryers—would be regulated by the smart grid. At any given moment, a fully integrated smart-grid system would be able to precisely inform the consumer of how much energy each of his household devices is consuming. The smart grid could also be programmed to set all electricity-consuming devices to run at lower levels when the demand and price for electricity were the highest.

This technology is very well in the process of becoming a reality. At the Pacific Northwest National Laboratory in Richland, as stated by a the Daily Journal of Commerce for example, scientists have created a chip that can be installed in household appliances that monitors the power grid and turns off appliances—for a few seconds to a few minutes—in response to power grid overload or commands. This can all be controlled by a digital overhead display. Costing $25 per chip, the Grid-Wise system might not prove so expensive given that it could potentially save a homeowner up to 10% of electricity usage thanks to the improvements in efficiency allocations. According to a press release from the company Grid-Point, they are currently involved in a plan for a "Smart-Grid City" in Boulder, Colorado that would look much like the previous fully functional system described[i]. The most significant benefits, of course, would come in the case of a utility revolution in which every energy-generation company adopted this type of smart-grid. But such a revolution may not be seen in the near future because of the present complexity of the three main grids that connect the entire United States.

However, the installation of a Grid-Wise system into each house within a new neighborhood could potentially save infrastructure costs in places where currently, utility companies need to erect new transmission lines to accommodate the increase in electricity usage that will arise from the new homes. Subsequent to terms previously agreed upon by consumers, utilities could transmit data via the Internet to a central regulatory smart-grid box within each home in order to temporarily down-power certain nonessential appliances in order to help offset power spike and to prevent blackouts. The appliances could then be directed to come back on once the stress on the grid had passed. In such a manner, a smart-grid system would help to distribute the peaks and troughs of PV generation to accommodate varying energy demands throughout the day. A wide scale adoption of this technology can happen much more quickly than building new power plants or trying to sophisticate the complex network of grids in the United States.

Specific to PV solar power, the smart-grid could control the consumer's appliances based off of how much energy the PV panel is supplying and ensure that power from the main grid is never used. If the household were to produce a surplus of energy, the smart-grid would calculate how much power it fed into the system, similar to net-metering. Smart-grid technology also helps alleviate one of the main shortcomings that PV has versus its main rival solar-thermal; it compensates for lack of energy storage through intelligent load-balancing and could potentially allow other renewables to take over easily at night when there is no sun. All in all, smart grids have become an achievable solution to the various problems that have arisen through the new forms of alternative energy that are entering the national grid, a solution that makes the residential use of PV systems a much more viable option. It was at first a concept that, while slightly ambitious, became a reality—a foreseeable future with a similarly ambitious project, the California State Initiative.

California Solar Initiative

A combination of sunny skies and a strong tradition of progressive, pro-environment politics have made California the leading state in the United States on solar energy, both in terms of capacity and government support.[58] Many government programs, large and small, support the development of the solar energy economy in California. These include NEM (Net Energy Metering), the Self Generation Incentive Program, Feed in Tariffs, and NSHP (New Solar Homes Partnership, but perhaps the most important is the California Solar Initiative (also referred to as the Million Solar Roofs Initiative). First approved by the CPUC (California Public Utilities Committee) in January 2006, and then strengthened and passed into law later the same year, the CSI has been called "one of the most ambitious (solar programs) in the world."[59] The main goal of the program is to create 1,750 MW of new solar energy capacity, mostly by placing PV cells on preexisting homes and businesses by 2016 (the NSHP is a smaller program which focuses on installing solar into new homes and businesses). The CSI is a part of the broader Go Solar California! program, along with the NSHP and the Publically Owned Utilities (POU) component, which demands that municipal utilities offer solar incentive programs.[60] Together, these programs are projected to create a total of 3,000 MW in new solar capacity. The other main goal of the CSI is to, by its end in 2016, have developed a

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[58] GreenBiz Staff, "California Leads in Customer and Utility Solar Capacity," Green Biz, http://www.greenbiz.com/news/2008/07/28/california-leads-customer-and-utility-solar-capacity

[59] "Schwarzenegger Signs Legislation to Complete Million Solar Roofs Plan," State of California, August 21, 2006. http://gov.ca.gov/index.php?/press-release/3588/, and Gregory Dicum, "Plugging into the Sun," *New York Times,* January 4, 2007, Home and Garden Section.

[60] The California Public Utilities Commission (CPUC or Commission) Energy Division Staff, "California Solar Initiative: California Public Utilities Commission Staff Progress Report," CPUC, January 2008, 8.

dynamic, independent solar economy in California, in which competition will have driven costs down to a point where subsidies are no longer needed. Keeping with this goal, with each year subsidies are to be reduced slightly, such that they will be phased out slowly over the life of the program, rather than cut off in their entirety at the end.

While the initiative also includes a requirement that, starting in 2011, developers building more than fifty single-family homes must offer solar paneling as option to buyers, the main focus is on installation in preexisting buildings.[61] Of the $3.2 billion allocated to the program, $216 million is being divided between two subsidiary projects, which focus on integrating solar energy into the housing of low-income residents of California.[62] One of these programs is focused on single-family homes, and the other on multi-family affordable housing. The latter is still under development, but the single-family program is currently available to those who qualify, and provides fully subsidized systems. For those who don't qualify for the low-income programs, the CSI functions by providing consumer rebates on the systems they purchase, which are allocated out in proportion to the expected performance of the system. For systems under 50KW in capacity, owners can receive their rebate in one payment (Expected Performance Based Buydown, EPBB), whereas for larger systems, the repayment takes place over the course of five years after installation (Performance Based Incentive, PBI).[63] The table below shows rebates available at different "steps" of systems, and the differences between rebates for residential, commercial, and government or non-profit owned

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61 "Schwarzenegger Signs Legislation to Complete Million Solar Roofs Plan," State of California, August 21, 2006. http://gov.ca.gov/index.php?/press-release/3588/

62 Mollly Sterkel, "Distributed Generation and California Solar Initiative: CPUC Policies and Programs," (presented to the Air Resources Board Workshop, May 2, 2008), 22.

63 "California Solar Initiative: Program Handbook," California Public Utilities Commission, November 2008, 9.

systems.

Step	MW in Step	EPBB Payments (per Watt)			PBI Payments (per kWh)		
		Residential	Non-Residential		Residential	Non-Residential	
			Commercial	Government/ Non-Profit		Commercial	Government/ Non-Profit
1	50	n/a	n/a	n/a	n/a	n/a	n/a
2	70	$2.50	$2.50	$3.25	$0.39	$0.39	$0.50
3	100	$2.20	$2.20	$2.95	$0.34	$0.34	$0.46
4	130	$1.90	$1.90	$2.65	$0.26	$0.26	$0.37
5	160	$1.55	$1.55	$2.30	$0.22	$0.22	$0.32[3]
6	190	$1.10	$1.10	$1.85	$0.15	$0.15	$0.26
7	215	$0.65	$0.65	$1.40	$0.09	$0.09	$0.19
8	250	$0.35	$0.35	$1.10	$0.05	$0.05	$0.15
9	285	$0.25	$0.25	$0.90	$0.03	$0.03	$0.12
10	350	$0.20	$0.20	$0.70	$0.03	$0.03	$0.10

[64]

The CPUC has designated Pacific Gas & Electric, Southern California Edison, and California Center for Sustainable Energy to territorially administer the program. Since its launch in 2006, the CSI has received over 10,000 applicants, the vast majority of whom are still in the three-stage application process (Application to Request Incentive Level, Demonstrate Installation Progress, and Complete Project to Claim Incentive).[65] According to progress reports from early 2008, the CPUC is confident about the CSI's future and potential to reach its goals. Actual installations per year were at 59MW in 2006, 81MW in 2007, and are projected to hit 100MW in 2008. Among home and business owners, there is a great deal of enthusiasm for the program, and that at this point demand looks sufficient to ultimately meet the set goals.

Initially one of the strengths of CSI was the ease with which homeowners could attain bank loans for PV installations in California, as they are considered a home improvement that increases its value. With a bank loan, the homeowner could then

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[64] "The California Solar Initiative Rebates," The California Energy Commission and the California Public Utilities Commission, http://www.gosolarcalifornia.org/csi/rebates.html

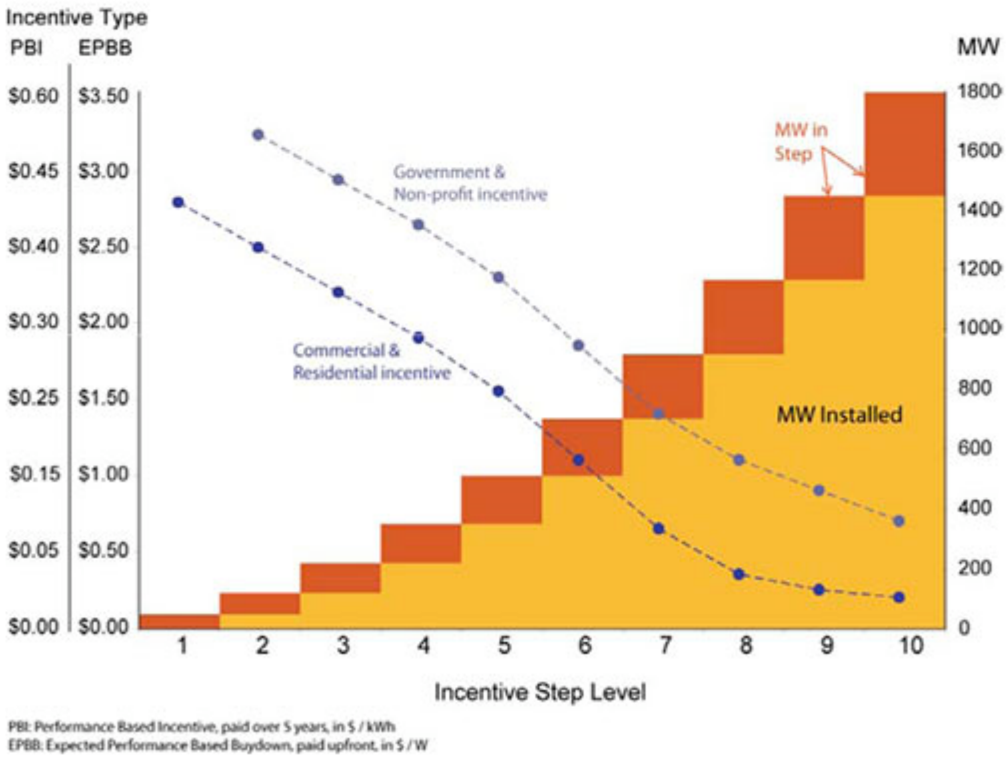
[65] The California Public Utilities Commission (CPUC or Commission) Energy Division Staff, "California Solar Initiative: California Public Utilities Commission Staff Progress Report," CPUC, January 2008, 28.

purchase her system, install it, attain her rebate from the CSI, and then pay off the loan with the savings on her energy bill, eventually making a profit or at least not spending anything on electricity (how long this would take depends on the system and its purchasers energy use patterns, but it is usually well over ten years). Now, in the time of the financial crisis, it is yet unclear whether or not the credit crunch will affect the overall viability of the CSI model, but it certainly one reasonable concern to have about the program.

One major lesson to take away from the CSI is about government potential to alter consumer behavior. As is generally the case with new technologies, before the CSI a much larger proportion of Californians were apprehensive or flat out disinterested in installing solar in their own homes. Particularly within more affluent neighborhoods, as individuals make decisions to install PV, often for financial reasons, it spreads rather quickly to nearby homeowners, to the extent that feeding into the distributed solar system is considered normal behavior.[66] Along with its establishment as something of a social norm, rising eco-concern and awareness, and the feeling of consumer empowerment many cite getting from possessing their own system, the tides of social change in California are certainly in favor of development of the PV sector. While probably this won't drive the program to its 1,750 MW goal, currently consumers making the decision to partake are doing so not just out of economic interest, but in hopes of actualizing a certain ethical self-identity and gaining some social status connected with being "green" and particularly with home PV installations.[67] The number of companies installing solar

[66] Gregory Dicum, "Plugging into the Sun," *New York Times,* January 4, 2007, Home and Garden Section. and Susan Carpenter, "Solar power incentives make it easier to switch," *LA Times,* November 1, 2008, Home and Garden Section, The Idealist Realist.
[67] Gregory Dicum, "Plugging into the Sun," *New York Times,* January 4, 2007, Home and Garden Section.

systems in California has also gone up since the program's passage, creating competition in the sector, which is a step towards the goal of creating a self-sufficient PV economy, not dependent on CSI-like subsidies.



[68]

Conclusion

From the progress predicted in the California Solar Initiative, we see that the outlook is bright for solar on the whole. Photovoltaics play a special role in this. Its uses in rural areas without a grid system and in net-metering and smart grid integrated systems make it largely innovative over the current uses of solar thermal. As a competitor, we've seen that economically photovoltaics are not yet on par with solar thermal, but that an

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and Susan Carpenter, "Solar power incentives make it easier to switch," *LA Times,* November 1, 2008, Home and Garden Section, The Idealist Realist.

[68] "The California Solar Initiative Rebates," The California Energy Commission and the California Public Utilities Commission, http://www.gosolarcalifornia.org/csi/rebates.html

addition of a storage device would make it just as cost-competitive if not more. Considering the aggressive efforts being put into photovoltaic R&D (surpassing that of solar thermal R&D), the development of such a storage device in the near future is quite feasible. As a complement, we've seen that PVs are able to fill in many gaps that solar thermal simply cannot and does not aim to satisfy. So our initial intuition to compare PV to solar thermal technology as mere competitors in the same realm was a misguided one. In the long run, they will be competitors in large scale electricity production, and in the short run, photovoltaics already serve as a complementary form of electricity generation in situations where solar thermal energy production is just not feasible.

Bibliography

—. ACCIONA's Nevada Solar One™ — Demonstrating the Commercial Competitiveness of Solar Energy http://www.nevadasolarone.net/the-plant

Aldous, Scott, "Anatomy of a Solar Cell" How Stuff Works, http://science.howstuffworks.com/solar-cell3.htm.

—. Arizona Renewable Energy Assessment: Final Report Arizona Public Service Company, Salt River Project, and Tucson Electric Power Corporation, (September 2007), http://www.bv.com/resources/energy_brochures/renewables/rsrc_AZ_RenewableEnergyAssessment.pdf, section 4, page 40 [PDF page #81].

Begay-Campbell, Sandra. DOE Tribal Energy Program California Workshop Concentrating Solar Technologies and Applications, Sandia National Laboratories. p.17 (Jan 23, 2008)http://apps1.eere.energy.gov/tribalenergy/pdfs/course_tcd0801_ca17ax.pdf

—. Bell Labs Celebrates 50th Anniversary of the Solar Cell – Timeline Alcatel-Lucent (2004) http://www.bell-labs.com/news/2004/april/anniversary50_timeline.html

Bellis, Mary "History: Photovoltaics Timeline," About.com, (accessed November 24, 2008), http://inventors.about.com/od/timelines/a/Photovoltaics.htm.

—. Beyond Zero Emissions http://www.climatechange.gov.au/greenpaper/consultation/pubs/0458-beyond-zero-emissions.pdf

Bradsher, Keith, "Paying in Pollution for Energy Hunger," The New York Times, January 9, 2007, World Business Section.

Brown, Lester, Plan B 3.0 (New York: Earth Policy Institute and W. W. Norton & Co.), 251.

—. Barriers to commercialization of large-scale solar electricity: Lessons learned from the LUZ experience (November 1, 1991) http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=6033984.

—. California Leads in Customer and Utility Solar Capacity http://www.greenbiz.com/news/2008/07/28/california-leads-customer-and-utility-solar-capacity

— California Solar Initiative: Program Handbook
California Public Utilities Commission, November 2008, 9.

Carpenter, Susan. "Solar power incentives make it easier to switch," LA Times, November 1, 2008, Home and Garden Section, The Idealist Realist.

— Converting Sunlight Into Electricity: European Project Breaks Efficiency Record
Science Daily (November 20, 2008),
http://www.sciencedaily.com/releases/2008/11/081120162704.htm.

Dankoff, Windy, "Three Photovoltaic Technologies: Single Crystal, Polycrystalline and (accessed November 24, 2008), http://www.wholesalesolar.com/Information-SolarFolder/celltypes.html.

Dicum, Gregory, "Plugging into the Sun," New York Times, January 4, 2007, Home and Garden Section.

Dorn, Jonathan G, "Solar Cell Production Jumps 50 Percent in 2007," Earth Policy Institute, (December 27, 2007), http://www.earth-policy.org/Indicators/Solar/2007.htm

— Eco-Economy Indicators: Solar Power—Data
Earth Policy Institute, (December 27, 2007)
http://www.earth-policy.org/Indicators/Solar/2007_data.htm#fig7.

Fischer, Douglas, "Solar Thermal Comes out of the Shadows," The Daily Climate (November 20, 2008), http://www.dailyclimate.org/tdc-newsroom/solar-thermal/solar-thermal-comes-out-of-the-shadows.

Friedman, Thomas. *Hot Flat and Crowded*. New York: Farrar, Straus and Giroux. 2008.

Fries, Peter, "Indian Solar Loan Program Offers Access to Light," Renewable Energy World, August 8, 2008,
http://www.renewableenergyworld.com/rea/news/story?id=53274

— Indian Solar Loan Program Offers Access to Light
Renewable Energy World, August 8, 2008,
http://www.renewableenergyworld.com/rea/news/story?id=53274.

Lule, Umaru. "Bringing electricity to the rural areas: Designing Laws and Policies that work," (presented to the Committee on Natural Resources, Parliament of Uganda), 20.

— Nevada Solar One (last updated December 9, 2008)
http://www.reuk.co.uk/Nevada-Solar-One.htm

— NREL Learning—Photovoltaics
National Renewable Energies Laboratory (accessed November 24, 2008),
http://www.nrel.gov/learning/re_photovoltaics.html.

— NREL Solar Cell Sets World Efficiency Record at 40.8 Percent
National Renewable Energy Laboratory Newsroom (August 13, 2008),
http://www.nrel.gov/news/press/2008/625.html.

— North America's Largest Solar-Electric Plant Switched On (December 28, 2007)
http://www.metaefficient.com/news/north-americas-largest-solar-electric-plant-in-switched-on.html

— Online Course—World Records School of Photovoltaics and Renewable Energy Engineering, University of New South Whales
http://www.pv.unsw.edu.au/online-course/world-records.asp.

— Poverty, Energy, and Society
http://www.rice.edu/energy/research/poverty&energy/index.html.

— PV System Completed at Nellis Air Force Base (December 18, 2007)
http://www.renewableenergyworld.com/rea/news/story?id=50895

Romm, Joseph. "Technology that Will Save Humanity," Salon Media Group (April 14, 2008), http://www.salon.com/news/feature/2008/04/14/solar_electric_thermal/print.html

Sandia, Stirling Energy Systems set new world record for solar-to-grid conversion efficiency 31.25 percent efficiency rate topples 1984 record
(February 12, 2008), http://www.sandia.gov/news/resources/releases/2008/solargrid.html.

Solar Electricity Prices November 2008
Solarbuzz | Portal to the World of Solar Energy
http://www.solarbuzz.com/solarprices.htm.

— Solar Loans Light Up Rural India
BBC, April 29, 2007, http://news.bbc.co.uk/1/hi/sci/tech/6600213.stm

— Solar One Concentrated Solar Power (CSP) Plant, Nevada, USA
http://www.power-technology.com/projects/solaronesolar/

Sterkel, Molly. "Distributed Generation and California Solar Initiative: CPUC Policies and Programs," (presented to the Air Resources Board Workshop, May 2, 2008), 3.

Steve Thorne and Leonard K. Mutesasira, "Uganda Photovoltaic Pilot Project for Rural Electrification," United Nations Development Programme, Global Environment Facility, March 10, 2002, 8.

— Schwarzenegger Signs Legislation to Complete Million Solar Roofs Plan August 21, 2006. http://gov.ca.gov/index.php?/press-release/3588/

— The California Solar Initiative Rebates http://www.gosolarcalifornia.org/csi/rebates.html

— The Cost of Carbon http://www.ecologisticsllc.com/cost.html

— The Uganda Photovoltaic Pilot Project for rural Electrification" United Nations, http://www.un.org/esa/sustdev/csd/casestudies/e9_e2_uganda.pdf

— Three UNEP Projects win UN wide Awards UNEP, July 11, 2008, http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=540&ArticleID=5870&l=en.

Tucker, Libby. Smart grid technology would cut electric bills, slow construction, says study. Daily Journal of Commerce. http://www.allbusiness.com/energy-utilities/utilities-industry-electric-power/8889527-1.html

Tynan G. R. "Overview of Solar Thermal Power" U. C .San Diego, http://maecourses.ucsd.edu/mae118b/PDF-

— Uganda: 1995 Solar Electric Light Fund, http://self.org/uganda1.shtml

— UN Engages Banks to Light up Rural India, UNEP, http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=504&ArticleID=5570&l=en

— UNEP's India Solar Loan Programme Wins Prestigious Energy Globe UNEP, April 12, 2007, http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=504&ArticleID=5562&l=en.

— Xcel Energy Selects GridPoint SmartGrid Platform for its $100 Million SmartGridCity. May 15, 2008. http://www.gridpoint.com/news/press/20080514.aspx