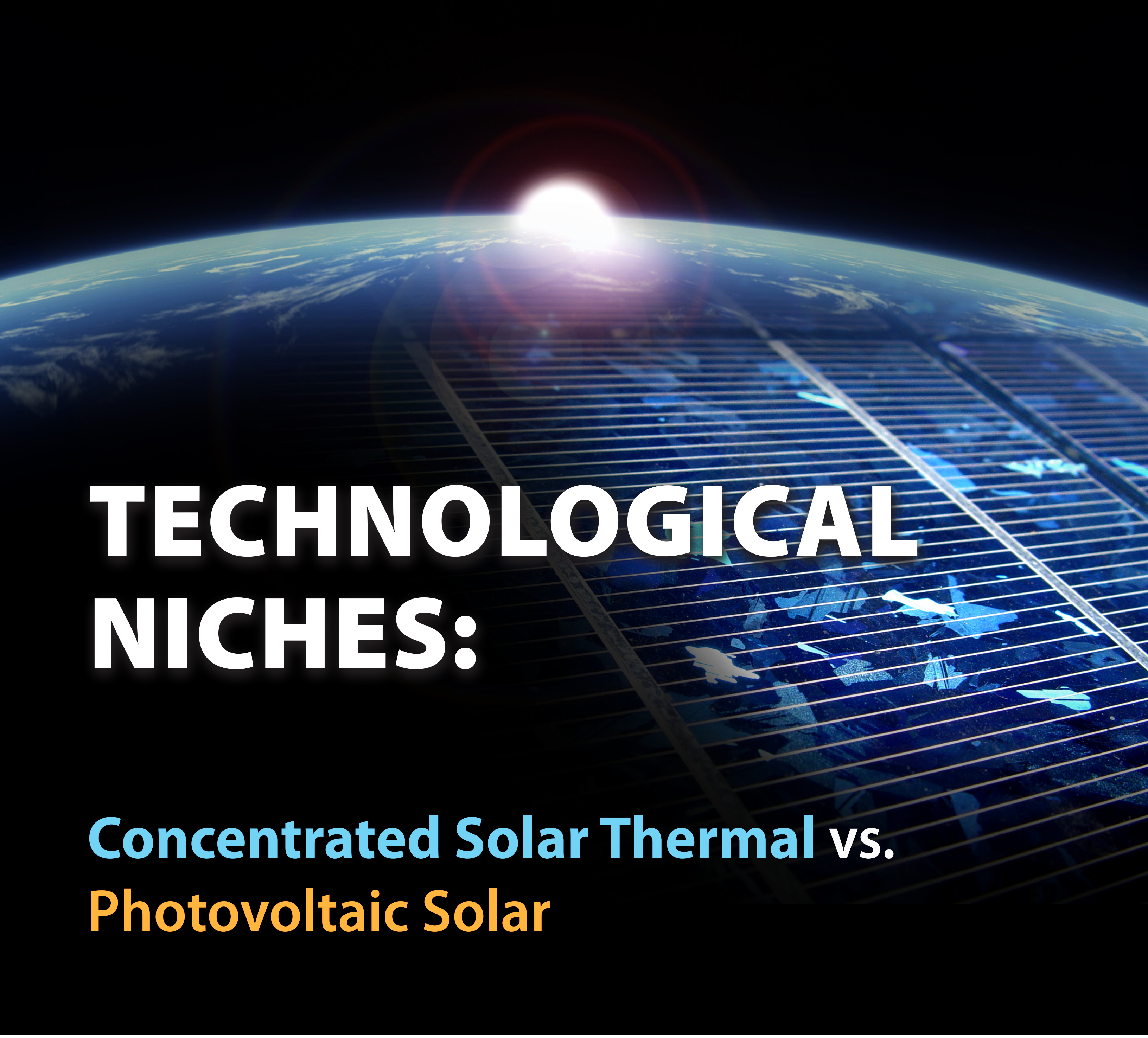

TECHNOLOGICAL NICHES:

Concentrated Solar Thermal vs. Photovoltaic Solar

Brett T. Gage

Research Associate, **Principal Solar, Inc.**

Rick Borry, Ph.D.

Chief Technology Officer, **Principal Solar, Inc.**

PRINCIPAL SOLAR INSTITUTE

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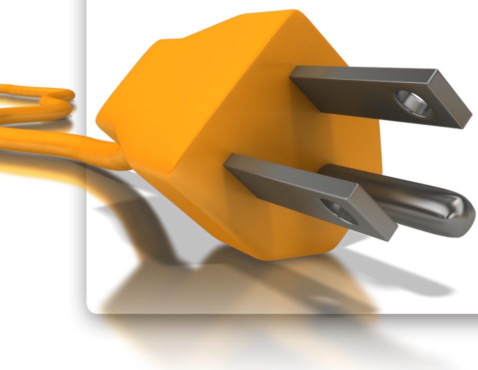
INTRODUCTION

"At Principal Solar Institute, we believe solar electricity will be cost-competitive without subsidies within three years. Since we are technology agnostic, this paper is not intended to stack one technology against another. Rather, we provide an education on the strengths and weaknesses of each."

– **Michael Gorton**, *CEO,* Principal Solar



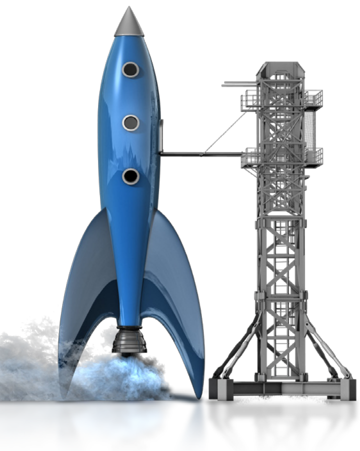
Concentrated solar thermal and photovoltaic solar technologies have evolved independently for decades, and both are approaching "grid-parity" power prices in many applications today. This paper will explore the different situations where each technology succeeds or fails in today's electric power generation marketplace, specifically excluding non-electric applications such as solar hot water heating.

BACKGROUND

Variations of solar technology are used today to power everything from grid-contributing utilities to solar-powered satellites. In early applications, thermal energy from the sun was harnessed as a rudimentary predecessor of modern solar technology. Magnification of solar thermal energy was used as early as the 7th century B.C. to start fires. It was said that the Greek scientist, Archimedes, used a group of soldiers with bronze shields to reflect and concentrate solar thermal energy and set fire to a Roman ship. (Source 1)

It was not until 1839 that the concept of photovoltaic solar energy was discovered.

In 1954, the Bell Telephone Laboratories created the first photovoltaic technology capable of providing sufficient power to electrical equipment. Their silicon solar cell was a very primitive version of the photovoltaic technology that currently exists, with only 4 percent efficiency and a cost of $300 per watt to produce. Restricted by its low efficiency and high cost, the only early applications for the solar cell were in toys and portable radios. However, as the US planned to launch its first satellites into space, solar energy encountered new opportunity. As opposed to traditional chemical batteries that would power satellites for only a few days, solar cells could provide power for years.



Though the Space Race allowed photovoltaic technology to find a more practical application, its feasibility on earth lagged behind that of solar thermal technologies. Whereas concentrated solar thermal energy could be easily adapted to heat water in buildings and power steam turbine engines, photovoltaic remained costly in early years. Finally, in 1970, a photovoltaic solar cell was developed that reduced the price of energy from $100 per watt to $20. Paired with increased efficiency, this breakthrough allowed for photovoltaic solar technology to find more suitable applications on Earth. Subsequently, this reduction in cost allowed residential solar applications to become increasingly realistic, and consumers took notice.[2]

Concentrated solar thermal and photovoltaic solar technologies have advanced over time, and have become increasingly economical energy sources. In addition to defining solar as one of the strongest alternative energy sources, solar technology has evolved to compete with traditional energy utilities. In addition to competing at the utility scale, each technology has evolved to fill a variety of distinctly different niches in the market for clean, reliable energy.

HOW SOLAR TECHNOLOGY WORKS

PHOTOVOLTAIC ELECTRICITY PRODUCTION *starts with a semi-conductor*

—typically silicon, an abundant element that can be produced from sand.

A solar panel contains groups of silicon cells, which become excited as photons of sunlight strike the panel. This stimulation creates an exchange of electrons that form a potential difference inside the solar panel. By extracting a current of electrons through metal contacts at each end of the panel, a steady flow of energy is provided. Photovoltaic cells can be strung together at nearly any scale to provide sufficient current for nearly any energy demand—one of its most valuable features.[3]

In contrast to the molecular-scale science involved in photovoltaic solar panels, concentrated solar thermal technology is much simpler. Much like the carbon combustion processes used in fossil fuel based generation, concentrated solar thermal applications use steam-powered generators to transform heat energy into electricity.

In order to produce the steam that facilitates this process, there a few methods of concentrating solar thermal energy:

Parabolic Trough System—This method uses parabolic-shaped troughs with reflective surfaces to direct the sun's energy towards a thin pipe running along their focal point. As the suns rays become concentrated, they reach intensities up to 100 times their original state; as a result, very high temperatures can be reached within the focal pipe. To collect this thermal energy, heat-transfer fluids are pumped steadily through the pipes and used to produce power-generating steam. Another variation of this technology is the use of mirrored strips, called Fresnel reflectors, as opposed to parabolic reflection system.

Figure 1. Parabolic Trough Micro-CSP (courtesy www.solarlogic-csp.com)

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Power Tower System—In order to collect the thermal energy produced by the sun, power tower systems use a large field of flat mirrors, called heliostats, which surround a central tower. These heliostats are used to direct the suns rays onto a focal point within the tower. Similar to the parabolic system, this heat energy is collected using a heat-transfer fluid used to generate steam. The intensity of heat concentrated inside of a power tower, however, can reach 1,500 times that of the sun.[4]

Solar Dish System—Individual reflective dishes are used to track the sun's rays and focus them on an arrangement of fluid filled tubes. These tubes are directly connected to a Stirling engine that transforms the heat to electricity.[5]

An important element of concentrated solar thermal systems is the additional requirement of sun tracking.

In order to produce the extreme temperatures required in thermal concentration, systems must maximize efficiency and solar concentration by tracking the sun's course throughout the day. Unlike photovoltaic applications that are typically mounted on a solid frame, concentrated systems are mounted on axis, around which they rotate. In the case of power towers and solar dishes, elements of these systems are mounted on a double-axis frame to directly focus the sun. Alternatively, parabolic trough systems can be mounted on a single axis of rotation, typically aligned along a true North meridian, that follows the sun's course through the day. In order to achieve the rotation of concentrated solar technology, computers and advanced sun monitoring devices must be installed to control each element of these systems.[6]

Albeit less common, a hybrid technology also exists: concentrated photovoltaic (CPV). CPV uses the magnification principles of solar thermal and the energy production principles of photovoltaic cells. These systems utilize optics to intensify and direct inbound solar radiation into much smaller photovoltaic panels. Through this process, smaller amounts of expensive, high-efficiency photovoltaic materials can collect sunlight from a larger area covered by less expensive concentrating lenses, and overall costs are reduced. The concentrated photovoltaic sector represents less than one percent of the total solar industry, however.[7]

ENERGY STORAGE

ONE OF THE GREATEST OBSTACLES FACING SOLAR ENERGY IS THE PROCESS OF ENERGY STORAGE.

On bright days, the sun can provide approximately 1,000 watts of energy per square meter to the surface of the earth.[3] While the energy provided by the sun is beyond sufficient to power homes and provide the electricity that consumers demand, solar energy production halts during the night. Aside from supplementing solar utilities with fossil fuel or nuclear power sources, the only solution to this problem is to store solar energy throughout the day for use at night.

THE ISSUE OF ENERGY STORAGE IS ESPECIALLY DETRIMENTAL TO STANDALONE PHOTOVOLTAIC SOLAR APPLICATIONS.

Although panels can supply a steady electric current throughout the day, production stops immediately when sunlight intensity is insufficient to surpass the minimum cutoff voltage for the solar array. A regulator between the inverter and solar panel determines when this cutoff occurs; the cutoff voltage is often as high as 90 to 300 watts, but varies with size, configuration, and the type of inverter. At a small scale, the current best solution to the problem of storing photovoltaic energy is found in traditional chemical batteries. These batteries, such as lead-acid and nickel-cadmium, can be used to store power from the panel throughout the daytime and be drawn upon when the sun goes down. Issues with efficiency and longevity of these batteries are substantial. Currently, research is taking place on the effectiveness of lithium-ion batteries as a more reliable alternative.[8]

At the utility scale, a vast majority of producers use pumped-storage hydropower technology (PSH). This technology uses excess energy to pump water from a low elevation to a higher reservoir, which can be used during off-peak production times to turn a hydroelectric turbine and balance the power load. PSH has significant infrastructure requirements, which make its continued use a challenge. Other new technologies are being developed using similar gravity-based principles to store energy at lower costs and reduced site requirements.[9]

Concentrated solar thermal systems, with the exception of solar dish systems, have the benefit of storing energy as heat. In this case, heat that is accumulated throughout the daytime can continue generating electricity when the sun goes down or clouds reduce exposure. In most cases, the same fluid used to capture thermal energy is used to store that energy in thermal storage tanks. These fluids are often thick oils or molten salts, which can reach temperatures of 500 to 1,000 degrees Fahrenheit. Heat-transfer fluids can retain thermal energy for 10-15 hours in storage, which can be drawn upon as needed to generate steam.[10]

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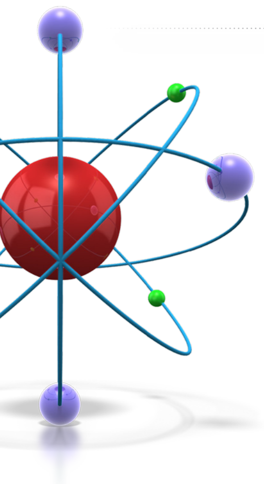
The barriers to higher photovoltaic efficiency lie within the science.

ENERGY EFFICIENCY

When photovoltaic technology was discovered in the 19th century, efficiency levels were too low to extract practical electrical current. As focus on photovoltaics grew, efficiency levels increased from 4 percent in 1954 to around 14 percent by 1960. Today, these levels hover around 15-19 percent for most commercially available solar panels. In laboratory-scale experiments, a record of approximately 40 percent efficiency has been achieved.[11]

As energy from the sun's rays beat down upon the earth's surface, a broad spectrum of frequencies exists. In the same sense that human eyes can only perceive a certain portion of this spectrum, which we call sunlight, solar panels can only convert a certain range of frequencies. Some photons that strike a solar panel have too much or too little energy to create an electrical current when reacting with semi-conductors.



In addition to a loss of energy in conversion, photovoltaic panels lose efficiency as they extract energy from the semi-conductors. Although silicon is one of the most efficient elements at converting solar radiation to energy current, it has a relatively high internal resistance. In order to resolve this issue, solar panels contain a thin metal grid across their surface. This grid redirects energy from the silicon cells and conducts it to contact points where energy is drawn from the panel. While the grid improves conduction, it covers a portion of the photons from incident sunlight, thus reducing the total efficiency.[3]

Concentrated solar thermal technologies, in turn, have barriers that also significantly diminish efficiency. Although the magnification and reflection of thermal radiation is relatively efficient, the process of converting such heat to steam and subsequently electricity brings these levels down.

Energy Losses in Concentrated Solar Thermal Systems

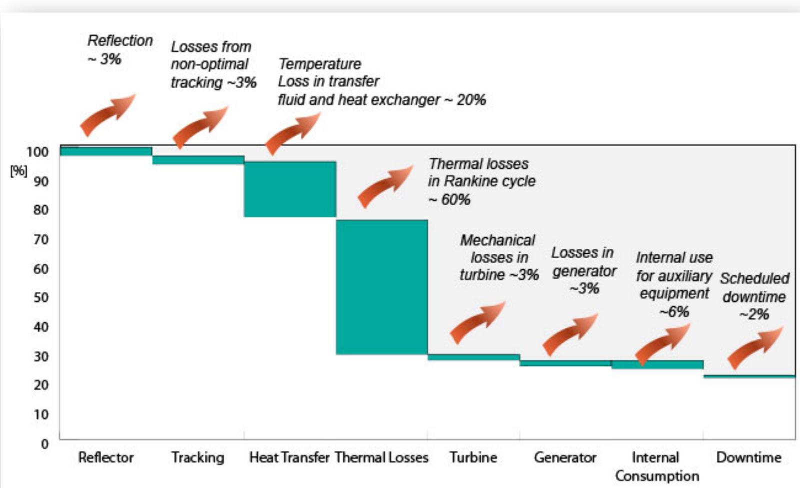


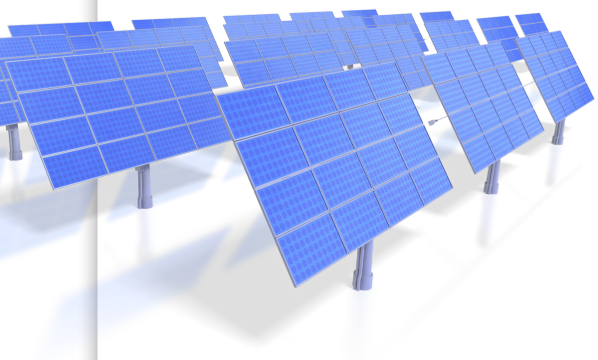
Figure 2. energy losses in concentrated solar thermal systems[6]

Even in perfect conditions, which are not truly achievable, the Carnot-efficiency model explains that steam turbines lose efficiency through thermodynamics. Accordingly, typical efficiency levels of steam turbine systems are around 43 percent or lower. Below, an approximation of energy losses in concentrated solar thermal systems demonstrates a realistic efficiency level of approximately 20 percent.[6]

While both concentrated thermal and photovoltaic solar technologies have made improvements in efficiency over time, their continued growth will benefit greatly from increased efficiency. It is apparent that sunlight contains ample energy to meet population demand. The ability to harvest greater amounts of that energy with each new solar development will allow solar technology to more broadly compete with traditional energy sources.

The Evolution of Solar Technology

Through a greater understanding of concentrated solar thermal and photovoltaics, it becomes evident that there are certain advantages and drawbacks associated with each technology. Much like biological evolution, modern solar technology has demonstrated trends of adaptation and development. Whereas species are said to meet the demands of their local environment, solar technology has done so in the renewable energy marketplace. Though both technologies began as somewhat of a novelty, solar applications have adapted to serve integral roles in power supply. Over the course of their development, each technology has found unique functions in the broader continuum of energy solutions.



In the market for utility scale solar projects, the functions of concentrated solar thermal and photovoltaics do overlap. Across the country, solar utilities have been developed, using both technologies with relative success. Of the 1,176 megawatts of utility scale solar energy being produced in the United States at the beginning of 2012, approximately 43 percent of this came from concentrated thermal technology, with the remaining 57 percent emanating from photovoltaic utilities. However, looking forward the role of photovoltaics grows, accounting for approximately 72 percent of solar utilities currently under construction (Source 11). In most other solar applications, however, solar technologies often complement each other more than they compete.

THE ROLE OF CONCENTRATED SOLAR THERMAL

One of the greatest assets for concentrated thermal technology is the most simple—*it utilizes the entire electromagnetic energy spectrum from the sun, rather than limited light wavelengths.*

In this sense, concentrated thermal has common ground with traditional utilities. The mutual ability to generate power with a steam turbine creates vast potential for concentrated solar to work as a supplement—or even replacement—to carbon-producing utilities, without sizable costs to significantly augment infrastructure.

Recently, the idea of supplementing traditional grid contributing utilities with solar power has seen solid growth. In 2011, General Electric paired with a California solar thermal developer to produce a hybrid natural gas and solar thermal technology, called solar combined-cycle plants. By accompanying a traditional natural gas facility with a power tower system to capture waste heat and power a steam cycle, efficiency in these facilities is increased up to 70 percent. Additionally, this process helps to significantly reduce the negative impact of emissions. GE's first of such facilities will include 50 megawatts of solar thermal technology, and will be operational by 2015.

General Electric Solar Combined Cycle Plant [26]

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"Integrating solar-thermal technology with gas plants means they can share the same steam turbines, generators, and switch gear, potentially cutting the cost of solar thermal in half…this is a natural fit"[12]

Though it has found a strong role as a complementary technology to fossil fuel-powered utilities, concentrated solar thermal is accomplished at the utility-scale in its own right.

IN THE UNITED STATES,

503 megawatts *of utility-scale concentrated solar energy* **currently exist**.

It is worth noting that **493 of these megawatts** *are produced in parabolic trough systems.*

An important consideration in the greater role of concentrated thermal technology is the location. Given that solar thermal requires extreme temperatures to produce electricity, it is no surprise that existing utility-scale projects are located in the hottest areas of the country, with the most temperate winters. Of the 503 megawatts in the United States, approximately 364 megawatts are located in parts of California; the remaining concentrated thermal utilities are in Nevada and Florida.[13]

Finally, concentrated solar thermal has found a stronghold through Combined Heat and Power (CHP) systems, also known as cogeneration. In these systems, thermal energy is used for both electricity production and heating or cooling applications. By capturing the waste heat or steam, heating and cooling units can be powered with no additional energy demand. While solar generation and heating/cooling systems are relatively inefficient on their own, CHP technologies allow for greater than 60 percent system efficiencies. CHP systems can be used in applications ranging from small residences to industrial facilities. This efficiency leads to lower operating costs, reduced greenhouse gas emissions, and fewer infrastructure requirements.[14]

Combined Heat and Power System Schematic

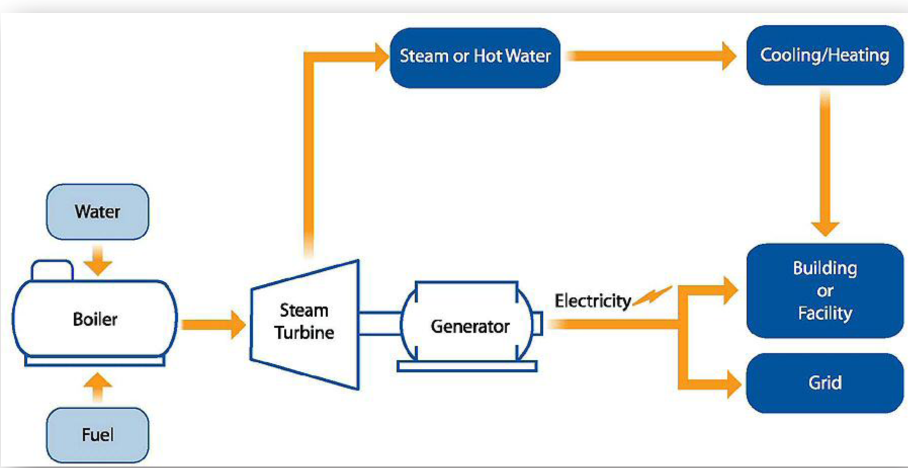
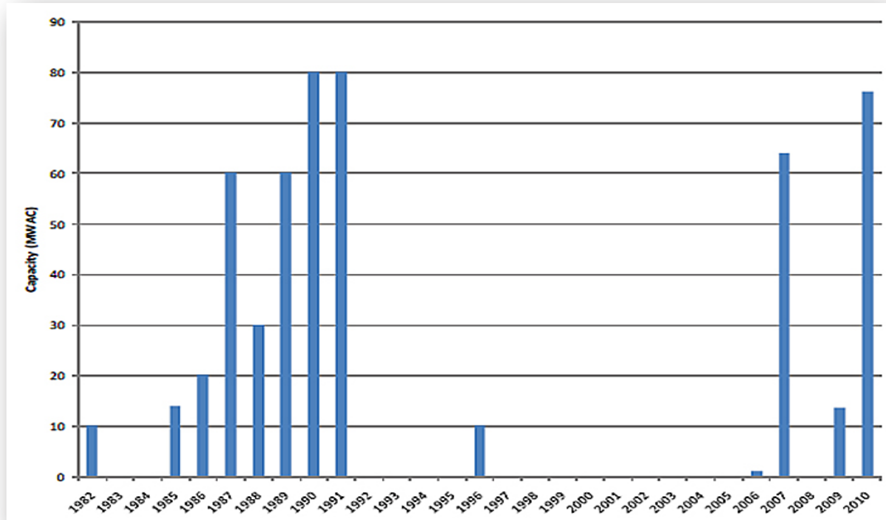


Figure 2: Combined Heat and Power System Schematic[15]

Concentrated solar thermal technology, despite having existed for thousands of years in some features, has continued to adapt and infiltrate new portions of the energy sector. While it has not yet found a place in smaller scale applications, solar thermal has successfully met a variety of unique demands at a larger scale. Crediting its likeness to traditional utilities, concentrated solar thermal has found an important role as an adaptable supplement or even replacement to many traditional energy players.

Concentrated Solar Capacity Installed By Year (1982-2010) [16]

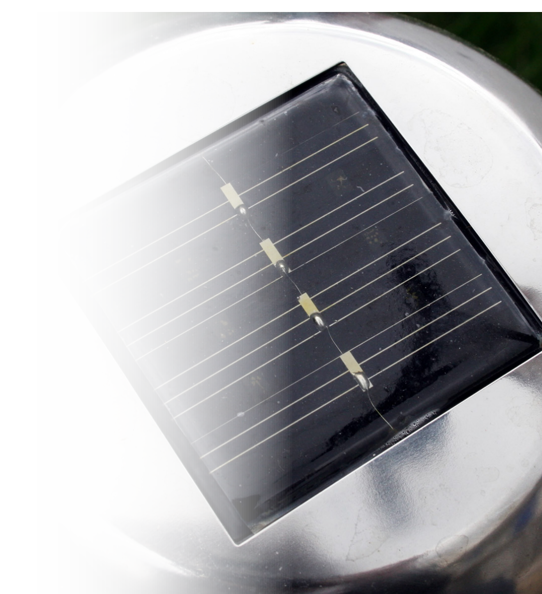


THE ROLE OF PHOTOVOLTAIC SOLAR TECHNOLOGY

Photovoltaic Solar Technology has seen great progress since its discovery. In contrast to the complicated science behind light to energy conversion that beset its early development, the simplicity of the solar panel can be credited for much of this growth. Photovoltaic solar applications are highly adaptable, and require relatively little maintenance over the 25+ year expected lifetime. Photovoltaic solar panels can be applied to nearly any energy requirement—from small, standalone panels to utility scale fields where thousands of panels are strung together to produce megawatts of electricity. Since the first application in small toys and calculators, photovoltaic technology has grown to power satellites, buildings and cars, among other things.

Aside from utility-scale contributions, photovoltaics have found a niche in standalone applications. This can be attributed to their low maintenance requirements and relatively low costs as compared to motors or grid extension. In these smaller applications, deep cycle batteries can easily be tied into the solar panel to provide steady, reliable energy. Some examples of these standalone applications are below: [17]

- Water Pumping
- Security Lighting
- Electric Fences
- Refrigeration
- Parking Meters
- Street Signals
- Communication
- Remote Monitoring
- Ancillary Power Needs



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In addition, photovoltaic solar panels have seen extensive growth in the market for residential power supply. Typically, a home will use around 10 to 20 solar panels, which can easily be mounted on a roof.[18] A study of photovoltaic installations in California reports that homeowners save an estimated $0.29 annually for every watt of photovoltaic energy installed.[19]

When installing photovoltaics, homeowners have the option of using batteries or connecting their panels to the grid. In the latter case, unused electricity can work to essentially reverse the electric meter, reducing the energy bill during the day to offset the cost of power required at night. As solar panel prices drop and consumers recognize these benefits, the residential market for photovoltaics has seen strong growth. According to the Interstate Renewable Energy council, photovoltaic capacity grew by 60 percent from 2009 to 2010 alone in non-utility applications.[20]

Grid-Connected PV Installation Growth by Sector

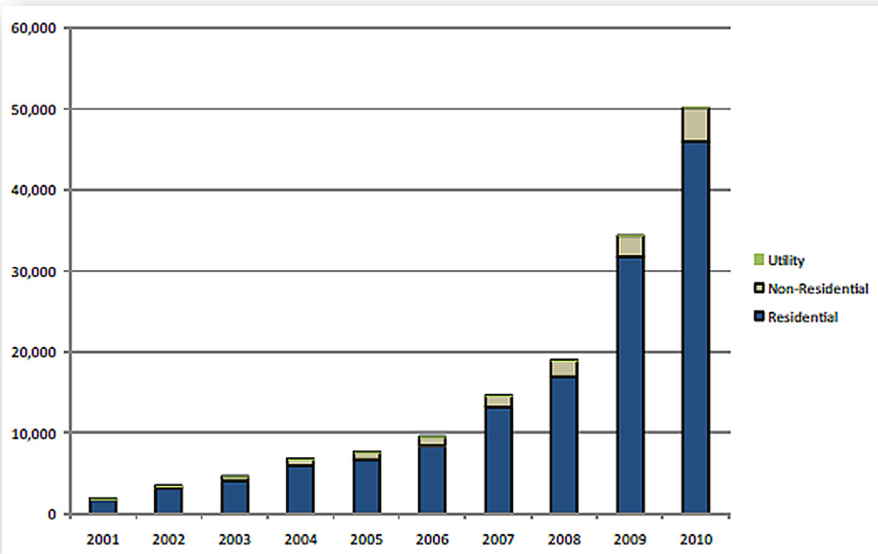

Figure 3: Grid-Connected PV Installation Growth by Sector [16]

"Thanks to increased Chinese production of photovoltaic panels, innovative financing techniques, investment from large institutional investors and a patchwork of semi-effective public-policy efforts, residential solar power has never been more affordable."[21]

Despite it's standing as one of the newest participants in the energy sector, photovoltaic technology has quickly found a place. In fact, photovoltaics have found a place meeting a broad spectrum of energy needs. While large-scale photovoltaic projects are competing with traditional utilities to meet consumer demand at one end of the spectrum, smaller residential projects are working to replace them at the other end. Photovoltaics are poised to continue expanding steadily in the energy market.

PHOTOVOLTAIC TECHNOLOGY IN DEVELOPING POPULATIONS

In the United States, rural energy demand poses a question: implement transmission infrastructure to access traditional utilities or invest in additional new utilities. The issue of rural electrification in developing countries is, however, a much more pressing one. Where vast portions of the population in some countries lack access to energy that they desperately need, solar applications have provided a promising solution. Recognizing the adaptability and scalability of photovoltaic solar, many rural populations around the globe are now able to accomplish things that were unthinkable only a few decades ago. Not only do photovoltaic applications provide a means for technological advancement, but they also generate immense health benefits to impoverished rural populations.

In India, the United Nations Environment Program (UNEP) helped to provide photovoltaic applications to 100,000 impoverished rural citizens. Traditionally, these citizens relied upon "dirty" energy sources to provide their basic needs. It is common that cheap fossil fuels or wood is burned to provide heating, cooking, and lighting needs. Not only does this practice create mass pollution, but it also accounts for 64 percent of deaths and 81percent of lifelong disabilities from indoor pollution in children five and under. In addition to the implied health benefit from using photovoltaic solar panels, this pilot program showed that even the most basic energy provision leads to drastically increased productivity, better grades for children in school, and better quality of life.[22]

> *"To provide even this little degree of electricity reliability and independence is to empower the poor in ways that can profoundly alter lives for the better."*
>
> – Timmothy Wirth, *UNF President*

THE FUTURE OF SOLAR EVOLUTION

Historically, the demand for solar technology has come only after its development. For example, scientists originally planned to equip the first orbital satellites with conventional batteries. Only after an exhaustive crusade to prove its viability was the solar panel considered for use by satellites. Today, both concentrated and photovoltaic solar technologies are seeing growing demand in their existing markets, and encountering new opportunities to challenge traditional energy sources.

In the case of solar thermal technology, one of the greatest challenges has been its scalability. Traditional concentrated thermal projects require many acres of heliostats to produce power. Often, these projects range from 10 to 50 megawatts or more. In addition, substantial infrastructure is needed for generators and thermal storage.

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Some companies are working on small-scale concentrated thermal technology. Solar-Logic (www.solar-logic.com), for example, has a patent-pending technology for a 10 kilowatt energy solution. By incorporating a small array of parabolic troughs with an innovative power turbine that efficiently extracts energy from low vapor quality thermal fluids, this technology allows for a new breed of smaller scale concentrated thermal projects at low cost. In addition, Sopogy (www.sopogy.com) is producing a group of "MicroCSP" products, which range from 200 kW to greater than 20 MW. MicroCSP products can be used to power heating/air-conditioning demand, as well as cogeneration applications.[24] Some of these applications could challenge the dominance of photovoltaics in the residential and standalone markets; however, their current greatest success is in combined heat and power applications.[23]

The next step for photovoltaic solar technology is simply in expansion. Despite seeing global growth of between 19-68 percent year over year from 1992 to 2010 in grid-connected use, photovoltaics have hardly reached their potential. Additionally, the aforementioned market in developing countries and rural applications has been largely overshadowed by grid-connected applications, despite seeing consistent growth of 8-24 percent from 1992 to 2010 across the globe. This off-grid market has seen very little funding as compared to its counterpart, but shows vast potential for the future of photovoltaics.

The growth of photovoltaic technology is largely a function of the cost of solar arrays, which is likely to continue dropping. Disregarding the tax incentives and government support that has facilitated great expansion of the market for solar energy, plummeting costs of production are helping photovoltaics to reach grid parity at a rapid pace. As a result, companies and governments worldwide are only beginning to recognize the potential of the already precipitously expanding photovoltaic market.[25]

One trend is clear: a growing preference for photovoltaic solar over concentrating solar power in pure-electric generation applications. Figure 3 below shows the relative market share of PV compared to CSP for electricity production in the United States (excluding all other technologies). From 2006-2012, the cumulative total of operating and under construction decreased from almost 40% CSP to 10% CSP.[27,28] This trend is expected to continue with recent cancellations of high-profile large scale CSP projects.[29]

Relative Market Share of Photovoltaic (PV) & Concentrating Solar Power (CSP) 2006-2011

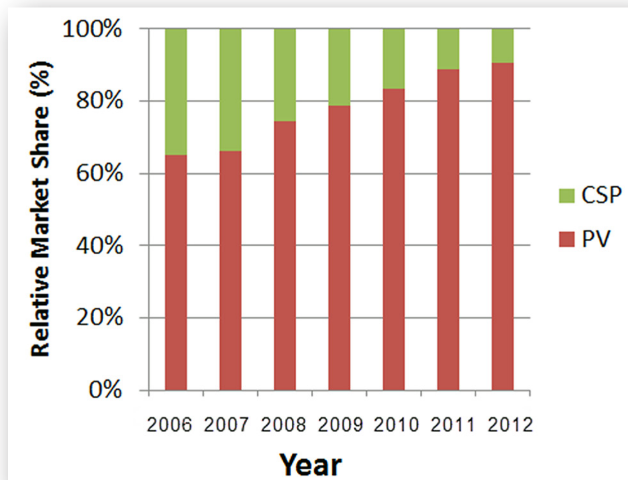


Figure 4. Relative Market Share of Photovoltaic (PV) and Concentrating Solar Power (CSP) 2006-2011 [27, 28]

CSP will not disappear from the power marketplace, but rather will move into technological niches outside of pure-electricity production, where it has inherent advantages. For example, the American Council for an Energy-Efficient Economy (ACEEE) promotes concentrating solar for Combined Heat and Power (CHP) to supplement power production and extend the operating life of retiring coal power plants.[30] Additionally, by 2032 Saudi Arabia plans to have 25 GW CSP operating (out of 41 GW total solar production). For the Saudis, a big driver in favor of CSP is the need for seawater desalination and other "hybrid CSP" opportunities, such as industrial heating and solar reforming in its oil and gas industry. Saudi Arabia wants CSP to help reduce reliance on groundwater for its growing population and save its hydrocarbon production for export.[31]

CONCLUSION

From their unique entrances into the energy marketplace to their current roles, concentrated thermal and photovoltaic solar technologies have seen great expansion.

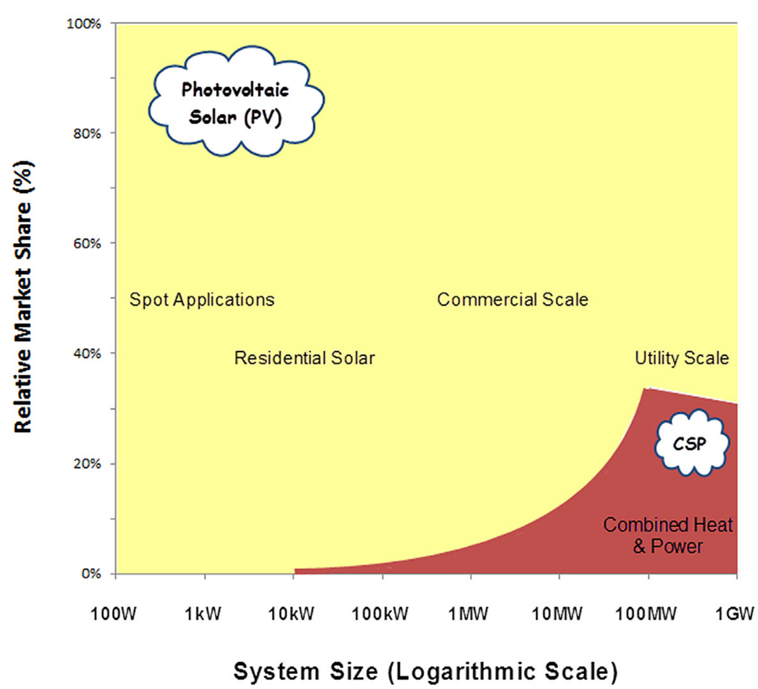
Especially over the past few decades, solar technologies have caught the eyes of consumers and providers alike as sustainable alternative to "dirty," conventional energy sources. Throughout the years, increased public interest has continually led to greater innovation and technological breakthroughs.

> *Today, as climate change and sustainability are becoming formidable issues in the public eye,* **solar presents itself as a PRIMARY SOLUTION**.

Throughout the history of solar technology, it has consistently demonstrated the ability to adapt. While innovation often precedes demand, each technological breakthrough has allowed solar technology to open the door to a new section of the energy market. To some degree, these innovations have led to overlap between concentrated thermal and photovoltaic applications. For the most part, however, each technology has found its own unique niche.

While both harness their energy from the sun, **concentrated thermal and photovoltaic solar** are in many respects diverse technologies with very different uses. *They differ in many of the most basic ways*. As a result, their co-existence becomes less of a competition and more of a joint effort to meet new demands and fill the void being created by public aversion to carbon combustion processes. To the right is a graph that shows the "**technological niches**" of Concentrating Solar Power compared to Photovoltaic Solar based on the total system power of each installation. As of 2012, PV has come to dominate all smaller-scale solar electricity applications, while retaining the majority market share even in commercial and utility-scale applications. CSP retains a strong niche at the utility-scale and in combined heat and power applications, where no amount of PV cost-reduction is expected to overcome its inherent technology advantages.

Figure 5. Technological Niche diagram showing the primary applications of PV compared to CSP based on the System Power Size



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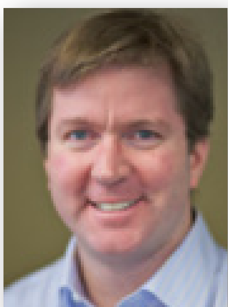
About the Authors

Brett Tyler Gage

Brett Tyler Gage is a talented researcher, financial analyst and business development advisor, with expertise in environmental science, economics and business. He brings keen insight and an inquisitive interest into the unique and rapidly changing intersection between the corporate world, climate change and sustainability. A graduate of the Lawrenceville School with high honors, he attends the Northwestern University.



Rick Borry, Ph.D.

Rick Borry joined Principal Solar as CTO in May 2011 with their acquisition of Capstone Solar Conferences and subsequent re-branding as the Principal Solar Institute. In addition to his role at Principal Solar, Dr. Borry serves as an advisor for Solar Logic at the University of North Texas in Denton.

Dr. Borry is a co-founder of Capstone Solar, where he produced a series of online conferences around the needs of solar professionals. While at Capstone Solar, Rick founded Webvent.tv, which is credited as the first platform to build communities around online conferences. Most recently, Rick was the Chief Software Architect for Certain Software beginning with their acquisition of his online event registration startup, Register123.com. At various stages during that tenure, Rick worked in every department while the company grew to over 150 employees around the world.

Rick earned his Doctorate in Chemical Engineering from the University of California at Berkeley and his B.S. from Clemson University. Rick has worked as a research associate for Dupont in Delaware and an environmental engineer for Hoechst Celanese in South Carolina.

layout | corporatebydesign@gmail.com