GRID-CONNECTED RENEWABLE ENERGY:

SOLAR ELECTRIC TECHNOLOGIES

Slide 1

Grid-Connected Renewable Energy: Solar Electric Technologies

Solar Electric Technologies

- **Large Solar Electric Technologies**
- Technology Economics
- Barriers & Solutions
- Technology – PV
- Technology – CSP

Slide 2

Presentation

This Solar Electric Technologies Module provides information on large grid-connected solar generating systems including large photovoltaic (PV) systems and large concentrating solar power (CSP) systems – e.g., parabolic trough, power tower, Fresnel, concentrating dish, and concentrating photovoltaic (CPV) systems.

Section One – The first section of this presentation discusses the resource, its availability, and use for large solar electric technologies.

Section Two – The second section looks at the economics of large solar electric systems.

Section Three – This section discusses barriers and solutions to the deployment of large solar generating systems.

Section Four – This section specifically deals with large grid-connected flat-plate PV systems and describes both the technology as well as issues specific to this technology.

Section Five – This section specifically deals with concentrating solar power systems, what they are, how they are used, and issues specific to these technologies.

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THE TECHNOLOGIES

- Flat Plate Photovoltaic (PV)

- Concentrating Solar Power (CSP)

Slide 3

The Technologies

Flat Plate Photovoltaic (PV)

Photovoltaic or PV – (also called solar cells) are semiconductor devices that directly convert sunlight into electricity. The technology may be used for applications of all sizes: remote home power; village power; and large grid-connected systems. The physics of PV was first discovered in the 1800s, but remained a scientific curiosity until the discovery of silicon semiconductor materials during the 1950s. While the markets for transistors and, later, integrated circuits provided the impetus for the semiconductor revolution, the early inventors at Bell Laboratories were well aware of the potential for power generation. The first application of PV came with the development of satellites in the early 1960s and the need to generate power to operate their sensors and communication devices in space.

The first terrestrial (as opposed to space) applications enabled similar sensing and communications in remote locations where PV could cost-effectively compete with disposable batteries providing only a small amount of electric power. Over time, larger remote PV applications were able to compete in situations where more power was needed and onsite generators proved expensive to install, maintain, and supply with fuel. Mountain-top radio repeaters/transmitters are a good example.

During the late 1970s, largely in response to the 1973 oil embargos, US, European, and Japanese programs were started to accelerate the development of terrestrial solar PV power. These programs, particularly in the United States, Japan, and Germany, launched an industry that has reduced the cost of manufacturing PV panels and installing and operating complete PV systems.

Today the PV industry's annual manufacturing output is ˜10 GW of solar panels and has been growing at a rate of ˜30% annually since the late 1990s. About 2-5 kW is needed to provide the lighting and general household electricity use of a typical household (not electrically heated, not electric hot water) in the United States. Thus, to put 10 GW in context, the annual worldwide production of solar PV panels is about enough to meet the needs of 2-4 million US homes.

The United States, however, uses only a fraction of the worldwide production, as the largest recent markets for PV are in locations where public policy provides incentives to own and operate PV systems. Since 2000, the solar PV markets have been strongest in Germany, Spain, Japan, and the state of California. Today there are between 4,000 and 6,000 MW of grid-connected solar projects world-wide.

Concentrating Solar Power (CSP)

Concentrating Solar Power or CSP – (also called solar thermal electric) are power plants that produce electricity from steam created from a fluid heated by the sun's energy. Although the CSP concept has been around for decades, it was not considered economic and was virtually ignored as a feasible electricity technology through the late 1990s. This may be due to the fact that CSP has no small-scale applicability, making it more difficult to ramp up production. Recently, however, several factors have caused a resurgence of interest in CSP:

- The high cost of fossil fuels

- Environmental concerns about conventional power sources
- Technological advances in CSP
- Government incentives and mandates for renewable energy sources, such as:
- Renewable portfolio standards (RPS), which require electricity suppliers to source a certain percentage of electricity from renewable energy and sometimes specify a percentage from solar energy; and
- Feed-in tariffs (mostly in Europe) that set a good price to be paid for each kWh of power from a CSP plant.

Since the last Solar Energy Generating Station (SEGS) unit was completed in California in 1990, CSP technologies have been quietly attracting new attention. Today there are almost 5,000 MW of CSP plants operating globally.

References

- 95. NREL – Assessment of Parabolic Trough and Power Tower Solar Technology Costs and Performance Forecasts

THE RESOURCE

- Solar energy comes in two forms
  - **Diffuse** (skylight)
  - **Direct** (beam sunlight)
- Photovoltaic (PV) can use **both**
- Concentrating Solar Power (CSP) can use **only the direct**
- CSP must track the sun

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The Resource

Sunlight reaches the earth's surface as either a direct beam coming on a path directly from the sun, or it is scattered by clouds and molecules in the atmosphere. The clear blue sky results from molecular scattering. Remember the Apollo moon pictures with the black sky? The sky appeared black because there is no atmosphere on the moon.

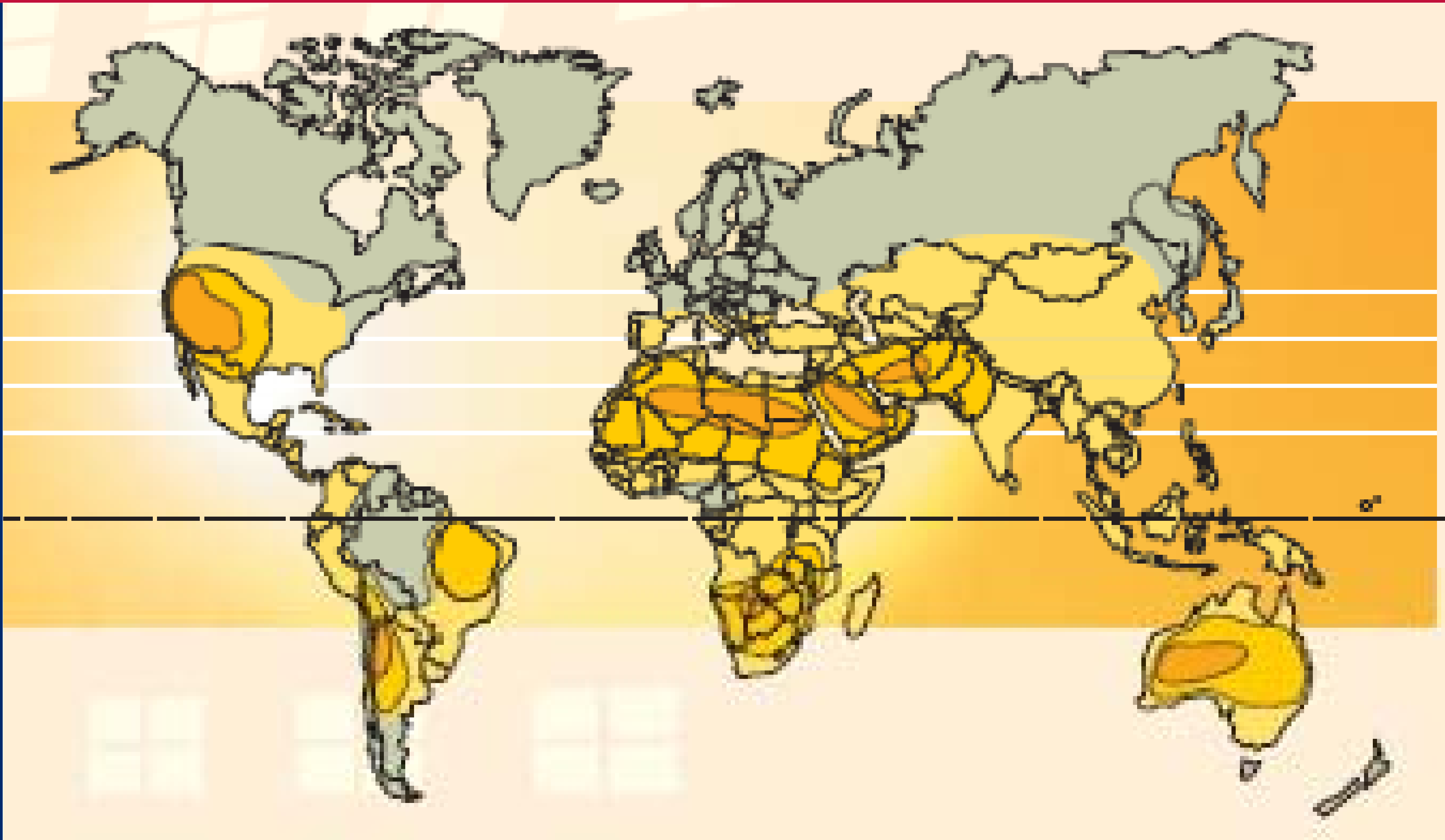
Photovoltaic (PV) can use both forms – Most PV is the flat-panel kind that can receive solar energy both directly from the sun and indirectly from scattered (diffuse) light. By far the largest contributor on a clear day is the direct beam part, but on overcast and cloudy days the diffuse sunlight increases and the direct beam sunlight is reduced.

CSP can only use direct beam sunlight – Concentrating solar power (CSP), however, takes advantage of the greater amount of direct beam sunlight available in very sunny locations, such as desert areas in the American Southwest, western China, northeastern India, North Africa and the Mideast. Because the sun follows a path across the sky during the day, *concentrating solar power receivers must track its motion from morning to afternoon*. It is just like following a moving object with a pair of binoculars. Focused solar energy is extremely powerful, which is why CSP is so effective.

References

- 95. NREL – Assessment of Parabolic Trough and Power Tower Solar Technology Costs and Performance Forecasts
- 204. NASA – Surface Meteorology and Solar Energy: Methodology

GLOBAL SOLAR RADIATION



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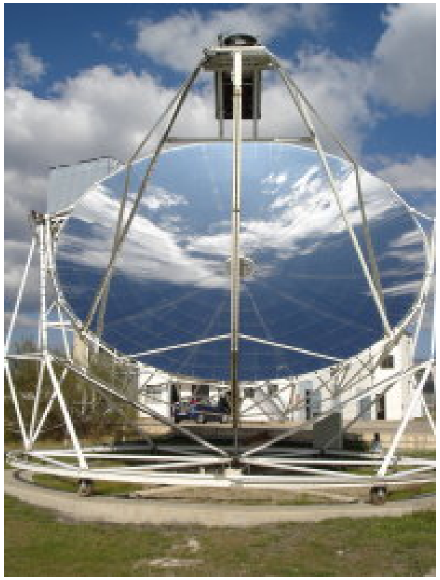
Global Solar Radiation

Solar energy resources are greatest either (a) near the equator where the sun’s daily path tracks high overhead and direct beam sunlight passes straight down through the atmosphere; or (b) at high desert locations with thin air, since most of the atmospheric interference occurs at lower elevations. However, clouds are a strong mitigating factor for many equatorial locations, so many of the areas with the most abundant solar resources for CSP use are in desert areas with less cloudy and overcast weather. Unlike CSP, PV can be used anywhere, though the economics will be different in different geographic locations due to the interaction between the amount of solar radiation and the cost of competing electricity sources.

TRACKING THE SUN

- Single Axis Tracker
  - Collects 20% more energy than fixed PV
  - Costs less than double axis
  - Commonly used for CSP plants; attain 80-90% solar capture
- Double Axis Tracker
  - Collects 40% more energy than fixed PV
  - Used for point focusing technologies; attain 100% solar capture
  - Require twice the land of single axis



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Two Common Tracking Configurations

Tracking mechanisms are used to increase the capture of the direct beam sunlight by orienting solar collectors, either flat plate or concentrators, toward the sun. There are two types of concentrators used for tracking the sun, those that focus sunlight to a point or small circle and those that focus light onto a line or thin strip. Flat plate collectors can capture both direct and scattered (diffuse light or skylight) whereas concentrating collectors capture only the direct beam sunlight. Relative to a fixed, south-facing (north-facing in the southern hemisphere) flat panel system, a horizontal single-axis tracked flat panel can collect about 20% more energy annually. A two-axis flat plate tracker can collect up to 40% more than a fixed array. For concentrating systems a two-axis tracker can capture 100% of the direct resource while a single-axis concentrator captures 80-90%.

Single Axis – “Line focusing” concentrators need only track on a single axis and are less expensive than double-axis systems, but do not capture as much energy. They are used extensively for CSP plants, such as the solar trough plants. Single-axis tracking is the most common system, mostly because it costs less and is simpler to maintain. The relative performance of single versus two-axis tracking improves with proximity to the equator. On the equator, during the spring and fall equinox the sun rises in the east, passes directly overhead, and sets in the west; on these days the sun can be tracked perfectly using only a single axis. Horizontal one-axis tracker frames are structurally similar to those for fixed arrays, so the additional cost is for a relatively simple tracking mechanism. Their simplicity also makes them easy to operate and maintain. Single-axis systems are the standard commercial solution for both concentrating solar and tracking PV installations.

Double Axis – “Point focusing” concentrators need to align directly with the sun and need to rotate on two axes. Two-axis or point focusing concentrators achieve the highest level of concentration and are used primarily for concentrating PV collectors using high efficiency and high-cost solar cells, and dish engine CSP systems (see CSP section). The cost for achieving the additional performance gain from a double-axis tracking system has not yet been demonstrated commercially.

Collector Shading – Installers must be careful to avoid a set-up where one collector will shade another, as happens in any collector field that is not on a completely level surface. Panel-to-panel shading is a challenge for double-axis tracking and about twice as much land is needed relative to single-axis tracking configurations. To avoid self-shading in array fields, two-axis trackers must be set farther apart, reducing the collector area to about 20% of the land area. Single-axis trackers can be installed more densely, achieving collector areas using up to 40% of the available land.

Solar Electric Technologies

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- **Technology Economics**
- Barriers & Solutions
- Technology – PV
- Technology – CSP

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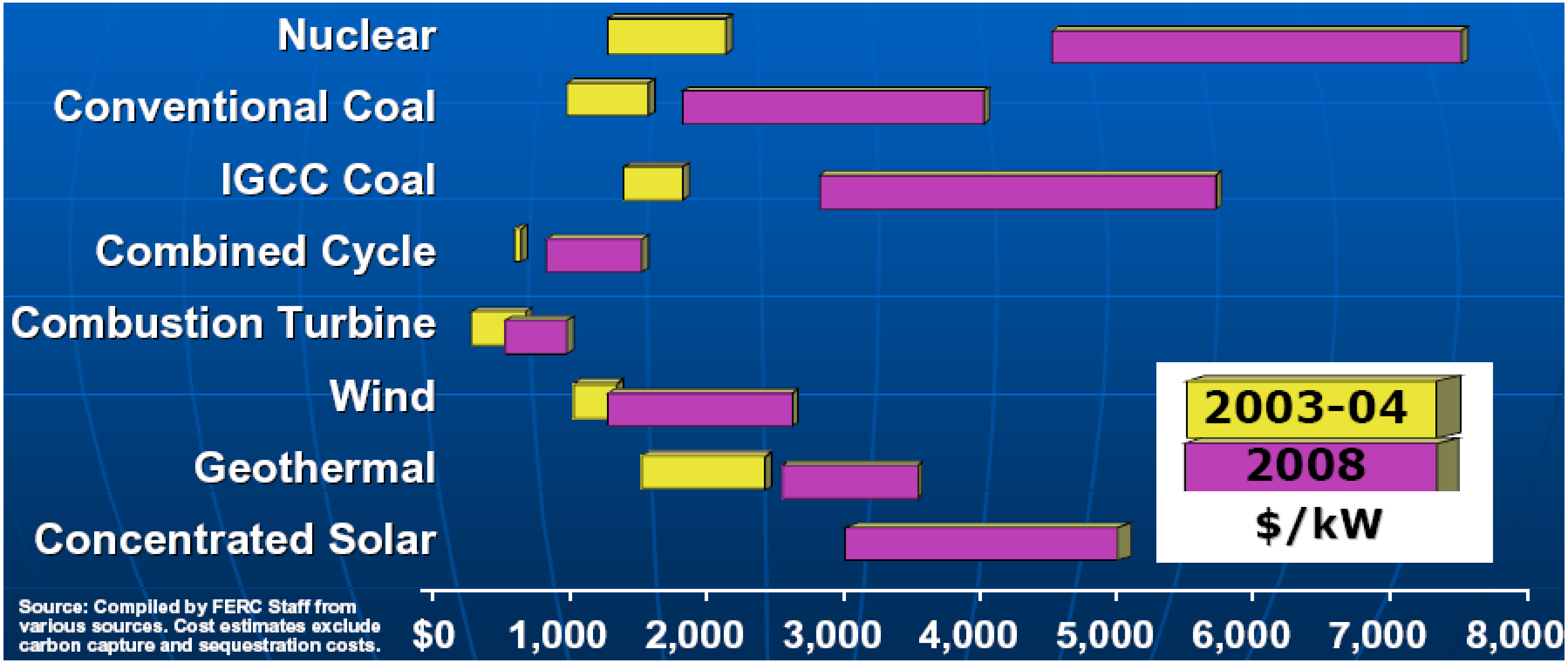
Technology Economics

ESTIMATED COST OF NEW GENERATION



Source: FERC – 6.08

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Estimated Cost of New Generation in the United States

This table was published in June 2008 by the US Federal Energy Regulatory Commission (FERC). The bars represent the cost spread between generation technologies due to different siting requirements and, for renewables, different resource quality. They reflect capital costs and do not include fuel costs, decommissioning, or waste fuel disposal. From this chart you can see the CSP (and large grid-connected PV is in the same cost band) are at the upper range of capital costs, exceeded only by nuclear and IGCC coal plants. These figures reflect the capital costs without subsidies of any kind. Though these are US costs, the relationships hold true elsewhere (i.e., the actual numbers might be different, but the relative costs would be similar).

References

- 37. DOE – Increasing Costs in Electric Markets

LARGE SOLAR PLANT INSTALLED COSTS

- **Large PV** – 12 to 20¢/kWh
- **Trough/power tower** – 13 to 17¢/kWh
- **Dish engine/Fresnel** – 10 to 13¢/kWh
- **Integrated Solar Combined Cycle System** – 10.5¢/kWh
  (if CC = 10¢/kWh)

Source: Technology Proponents

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Large PV and CSP Plant Installed Costs

Large grid-connected, flat-plate solar technologies are in the same cost range as concentrating solar technologies though the two have different characteristics. To the extent that tax credits or tax benefits are available, they affect both types of technologies in the same way (e.g., a 30% investment tax credit reduces the costs by one to two cents – around 12 to 15¢/kWh. However, the global economic situation has had different impacts on the two types of technologies. The spread in the prices listed for large PV and trough/power tower systems reflect those potential policy impacts.

The global economic downturn in 2008 hit just as the global PV manufacturing industry was ramping up production. In early 2008 there was greater demand than supply, while in early 2009 there was excess PV manufacturing capacity compared to PV demand. As a result, a new large (10 MW) grid-connected PV project proposed by First Solar in Southern California in January 2009 is estimated to cost just under 10¢/kWh. This is the lowest historic price for a large PV project and is considered to be an unusual opportunity. However, that window of opportunity for these bargain prices will be very short because excess production is being snapped up rapidly for a few large projects in California and Europe. After that experts believe either demand will rise again or manufacturers will adjust production to match reduced demand.

Costs for both dish engine and linear Fresnel plants (see slides #45-46) are highly speculative right now since neither has been built yet at commercial scale. However, proponents are claiming a cost of around 10 to 13¢/kWh. For an integrated solar combined-cycle system (ISCCS), the solar portion will generally add less than 10% to the per kWh cost of the combined-cycle plant.

It is difficult to compare these costs since many of them are speculative. A higher price is justified where the technology includes storage that makes a facility dispatchable and available on peak. Moreover, investment in large solar is driven by a number of non-cost factors such as competing clean generation resources, international incentive programs, site availability, and the desire for new and innovative technologies.

There are significant policies contained in the economic stimulus packages of most large economies that are intended to stimulate demand for solar and reduce the current excess in manufacturing capacity.

CURRENT SOLAR INSTALLED CAPACITY

	Pending (MW)	Operational (MW)
Large PV	6,000-8,000	7,800
Parabolic trough	1,790	1,019
Power tower	1,137	48
Dish engine	1,750	0
Linear Fresnel	177	5
ISCCS	105	60
Total:	**9,959**	**8,932**

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Current Market Trends

The global PV industry increased six-fold between 2004 and 2008. The 2008 global PV market was 90% higher in 2008 than in 2007. The CSP market remained stagnant from the early 1990s until 2004 when investments in new commercial-scale plants resumed. The pipeline for new projects increased dramatically from 2.7 GW in 2007 to 6 or 8 GW (depending upon the source) in 2008. This growth was stimulated by market promotion policies, particularly FIT policies, as well as the World Bank CSP promotion program. Before the 2008 global recession, many investors in solar power were entities that could benefit from both feed-in tariff incentives and also shield current income from taxes through accelerated depreciation of solar power system assets. Recent economic changes have dampened investment enthusiasm, but significant amounts of government stimulus money are now available in Japan, the United States, and Europe for investment in renewable energy.

Current PV Markets

Over 7.8 GW of grid-connected PV are currently operating worldwide, with the largest concentrations in markets driven by incentives, including Japan, Germany, Spain, and the United States. In 2007, Germany accounted for about 50% of the market, Spain about 25%, and Japan and the United States about 10% each. In the largest markets, Germany and Spain, this growth has been almost exclusively through the installation of centralized grid-connected installations driven by those countries feed-in tariffs. The 2008 global economic downturn cast uncertainty about PV markets, but action by many governments in 2009 to invest stimulus funds into green technologies including renewables has increased confidence within the industry. Though renewable generation projects face competition primarily from plants dependent on coal and natural, particularly in OECD countries, a resurgence in oil prices will likely motivate public opinion in favor of solar power. Global energy security and climate change concerns suggest continued public policy support for the development and increased use of renewable energy. In response to somewhat softer near-term markets, PV prices have dropped over 5% in the first half of 2009. The cost of capital, which has a major impact on the cost of solar electricity, continues its downward trend from its peak in the early 1980s, as measured by 10-year US Treasury bill rates.

Current CSP Markets

There are over 1,000 MW of CSP power currently operating world-wide and almost 5,000 MW of projects that have already been awarded utility contracts plan to be in operation no later than 2015. More than 4,700 MW of those projects are planned to be built in California alone. In addition, there are another 2,800 MW of projects under negotiation (where the specific CSP technology has not yet been identified) in China, Israel, South Africa, and Spain. Virtually all of these contracts have been awarded through a tendering process.

The concentrating solar industry saw many new entrants and new manufacturing facilities in 2008. Ausra opened a manufacturing facility in the US state of Nevada that will begin to produce 700 MW per year of CSP components by mid-2009. Schott Solar of Germany opened a manufacturing plant in Spain and is constructing a similar plant in New Mexico to make receiver tubes. Rio Glass Solar opened a manufacturing plant in Spain for trough mirrors, and Flabeg of Germany announced plans to build a parabolic mirror factory in the United States.

Off-takers

The most common off-taker for a large grid-connected PV project is the local utility. However, for large PV systems located behind the meter at a customer's site, the off-taker is the customer himself. Almost the only off-taker for large CSP projects is the local utility. In some locations (e.g., Arizona, New Mexico, and Algeria) utility CSP plants are seeking to export some of their power to neighboring states (e.g., California) or countries (e.g., across the Mediterranean to Europe) to the extent that such exports are eligible for FIT tariffs in Spain or RPS eligibility in California.

References

- 56. NREL – Learning – Photovotaics
- 57. IEA – PV Performance, Reliability and Analysis
- 65. Solarbuzz – World PV Report 2009
- 84. Photovoltaic Market Sees 17% Growth Rate

BUSINESS MODELS

- **Utility ownership** – Turnkey
- **IPP ownership**
  - Partnership
  - Lease
- **Other structure** – e.g., multilateral-funded project

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Business Models

The two most common business models for large grid-connected solar plants are utility ownership and ownership by an independent power producer (IPP). A country's energy laws and its tax structure may favor one of these business models over another, as indicated in the next two slides. Most of the presently operating projects were contracted through a tendering process except in countries with a feed-in tariff (e.g., Spain), in which case the projects simply sign an agreement to sell power at the appropriate tariff rate.

Turnkey Model – In the turnkey model the facility is constructed for the utility, which then takes ownership and operation of the project. This model has minimal risks for both the contractor and the utility since the utility's economic resources backstop the initial financing of the project and the technical and operational specifications contained in the contract serve to guarantee that the project will perform as specified.

IPP Ownership – Under this model the facility is owned by a private sector entity (independent power producer – IPP) that designs, builds, finances, and operates the project and recovers the costs over time through a power purchase agreement with the utility. The project may be financed through private sector debt and equity or there could be a public/ private partnership. Or the facility could be owned by a private company and leased to the utility. Where there is a feed-in tariff the projects must be IPP-owned to be eligible.

- **A public/private partnership** is a financial arrangement wherein a private lender (i.e., commercial bank) may provide part of the capital through a 14-year term loan at market rates. The other part of the capital is provided by a public lender (possibly through government bond issue) that may offer a 30-year term loan at market rates but interest-only payments required through year 15.
- **A lease/purchase arrangement** is beneficial to the utility in that the developer recovers its costs over time rather than in a lump sum as it would for a turnkey project. Once the debt is paid, the utility purchases the project for a nominal amount and benefits from the debt-free power production. However, depending upon the financial arrangement, this may not be as beneficial for developers who tend to make their profit at the back end once the debt has been retired.

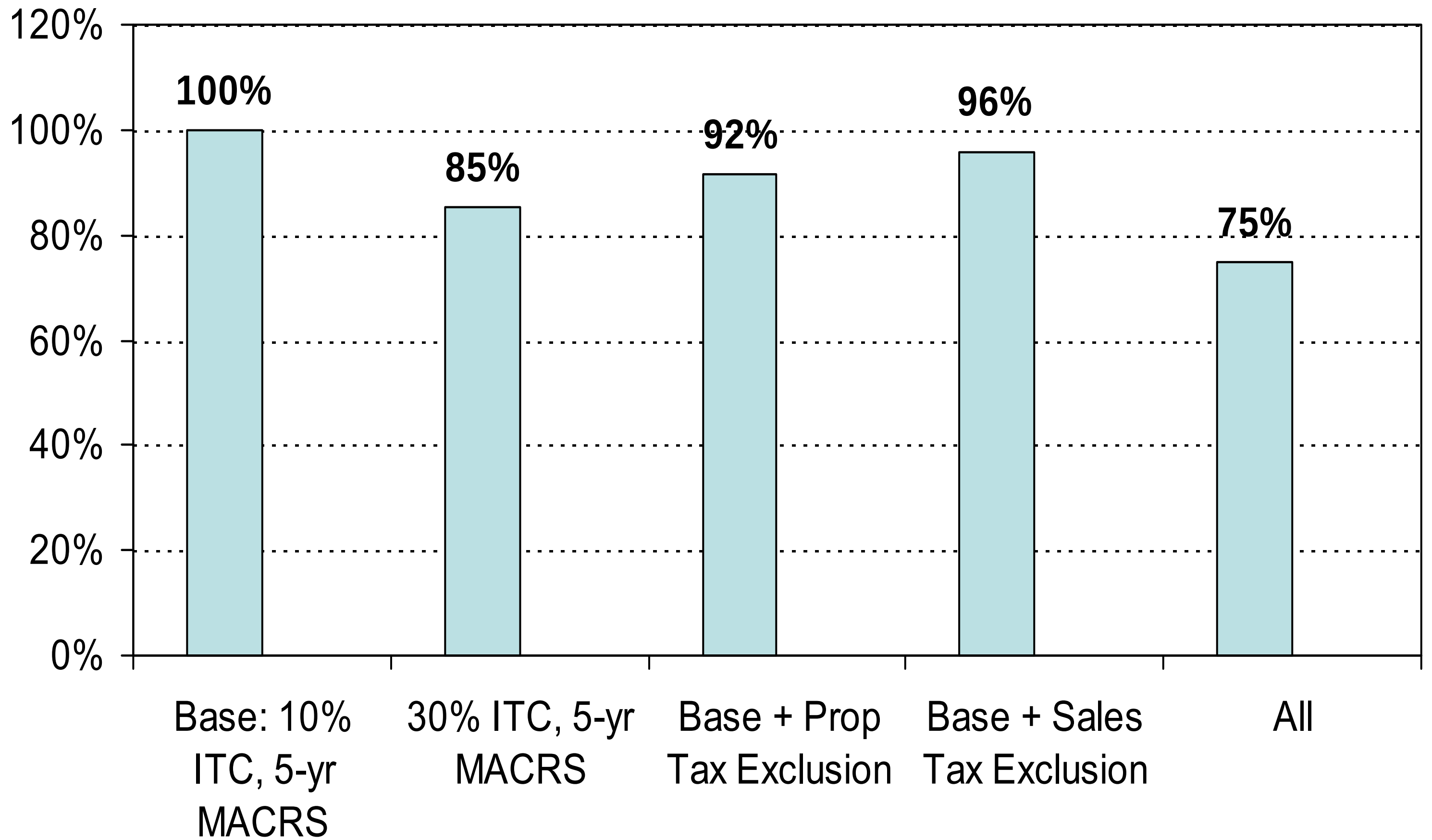
Other Structures – Recently a third business model has emerged due to global interest in CSP project development. Though a few CSP projects were constructed in the late 1980s, the industry then languished due to CSP's relatively high cost. Various projections indicate that unit costs could be greatly reduced if production ramped up, but the industry has been unable to overcome the initial inertia. The World Bank (WB) developed a special program to provide funding to overcome the initial financial gap that prevented new CSP plants from being constructed.

In this model, the World Bank (or some other multilateral lending institution) provides funds for solar project development (i. e., the WB/GEF has provided Egypt, Morocco, India, and Mexico $50 million each to build a CSP project). In this business model, the government is given the money for the project that is then purchased from the developer by or on behalf of the utility (typically using a tender to select the developer). Since there is no project finance risk or risk premium, this is a much lower-cost business model for both the utility and the developer compared to the turnkey or IPP models. However, it is also an uncommon business model – the World Bank-funded CSP projects to date are small 20 MW pilot projects, which is all the level of funding would support. It is too early to know whether this model has set the stage for widespread CSP expansion.

References

- 96. WB – Assessment of the World Bank/GEF Strategy for the Market Development of Concentrating Solar Thermal Power

Effect of Incentives (IPP Financing)



Source: NREL – Sargent & Lundy Report

Slide 12

Tax Incentives and Investment Costs

Modified Accelerated Cost Recovery System – MACRS

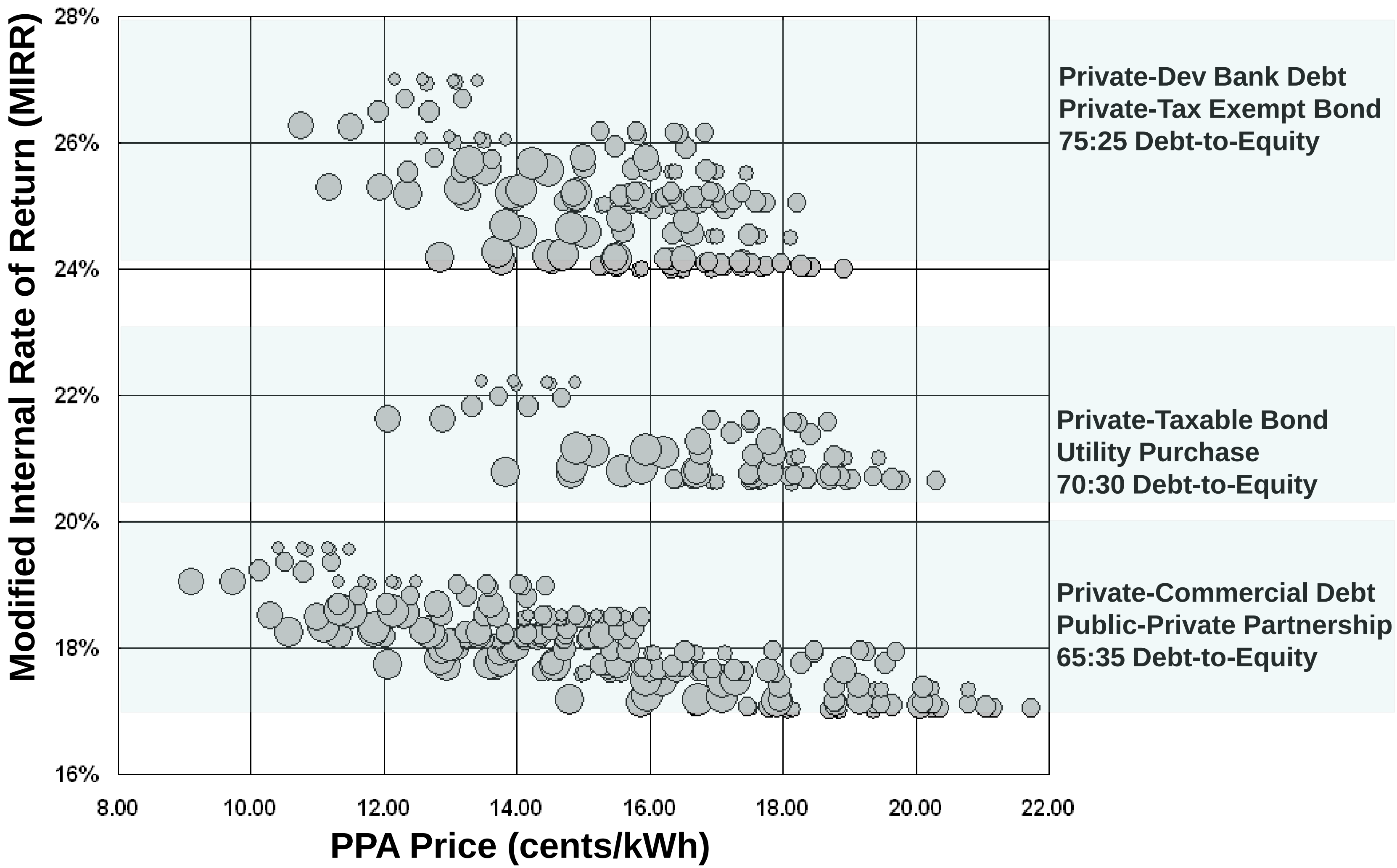
Government tax policies can have a significant impact on the capital costs of solar projects. The tax policies that most directly affect the cost of large solar facilities include the investment tax credit (ITC), property tax exclusions, and sales tax exclusions. (See Overview Module for more detail on tax incentive policies.)

Effect of Tax Policy Incentives for Large Solar Projects – This analysis, done by the US National Renewable Energy Laboratory (NREL) in Golden, Colorado, indicates the impact of various tax incentives on the overall cost of a large solar plant that is financed through private sector investment. The analysis used the costs of an existing CSP plant (though the analysis is applicable to large PV facilities as well) and shows what the effect on cost would be if the investment tax credit – ITC – went from 10% to 30% (i.e., a savings of 15%, as shown in bar 1 and bar 2) under a modified accelerated cost recovery system (MACRS). This analysis also shows the effect if the plant was given a property tax exclusion (8% reduction in the plant cost); or if the plant was given a sales tax exclusion (4% cost reduction). If the plant received a 30% ITC and tax exclusions from both property and sales taxes, that would result in a 25% overall reduction in the project cost. Of course the actual incentive and tax levels will vary from country to country. However, this table provides a good indication of the impact of altering tax policy on the cost of a large solar generating facility by altering three common tax policies.

References

- 95. NREL – Assessment of Parabolic Trough and Power Tower Solar Technology Costs and Performance Forecasts

IMPACT OF FINANCIAL VARIABLES



Source: Black & Veatch

Slide 13

Financial Analysis Results

This graph by Black & Veatch illustrates what happens if you modify the financial parameters of a solar project including ownership, debt-to-equity ratios, and the internal rate of return.

In developing this graph, two CSP project ownership options were modeled: a utility ownership case in which a private entity develops the power plant and then sells it to a utility that subsequently owns and operates the facility (middle cluster); and a private ownership case, in which the plant is developed and operated by a private entity that finances project construction with a combination of equity and debt from a commercial or development bank, or from a taxable bond issuance.

The results show that for the same plant the price of energy can vary from 9 ¢/kWh to almost 22 ¢/kWh depending upon the debt-equity ratios, the internal rate of return, how long the debt is carried, who owns the plant, who owns the debt, and a variety of other financing contract variables. In each of the three cases the entity holding the debt and the debt-equity ratio were held constant while other contract issues were varied. Each bubble represents a separate computer run varying **one** financial input parameter. The size of the bubble represents the magnitude of the impact.

The point of this exercise is to show the sensitivity of the energy price to financing details. It is not possible to know what the price of energy will actually be from a solar plant until the detailed assumptions that will go into the final financial agreement have been examined. These financial details can have an 8-12¢ effect on the ultimate cost of energy from that plant.

Though this study was applied to CSP projects the same results can be expected for any type of large solar generation plant.

References

- 97. Black & Veatch – New Mexico Concentrating Solar Plant Feasibility Study

Solar Electric Technologies

- Large Solar Electric Technologies
- Technology Economics
- **Barriers & Solutions**
- Technology – PV
- Technology – CSP

Slide 14

Barriers & Solutions

LEGAL & REGULATORY FRAMEWORKS

- Private sector market for large PV
- Utility market for CSP
- Market-making policies:
  - Feed-in tariffs
  - Renewable portfolio standards with solar set-aside
  - Net metering for grid-connected on-site use
- Market stability & long-term contracts essential

Slide 15

Legal & Regulatory Framework

The electric power sectors of most countries were built during the 20th century and consisted of fully integrated generation, transmission and distribution companies with publicly regulated monopolies to serve franchise areas. This framework was based on early power system technology that did not include long-distance transmission capabilities or sophisticated technology to control large regional electric networks. During the 1990s this paradigm shifted to one of larger area control and in many places the break up of fully integrated power systems. Today, in many countries there are independent generation, transmission and distribution companies, where only the local distribution (“wires”) companies remain a monopoly. (See Overview Module for more discussion of legal structures of utilities.)

The interconnection of large renewable plants into the generation mix in such systems is based on competitive wholesale markets for electricity that are operated under clear and specific rules to ensure they remain competitive. In many cases there are market promotion policies that provide incentives for different renewable power generators, such as solar operators. The main promotion policies are either feed-in-tariffs (FIT) through which a solar power plant is paid a specific tariff for supplying solar power to the network or a mandatory target (renewable portfolio standards – RPS) which requires all retail suppliers of power to include a certain percentage of renewable energy in their portfolio. In both cases, the effect is to create competitive markets for renewable power and opportunities for large scale solar development.

Private Sector Market for Large PV

For distributed solar PV (such as on rooftops) another incentive approach is to permit “net metering,” in which a customer’s revenue meter is programmed to calculate the net flow of power to a customer. The logic of this arrangement is that the PV looks to the utility like energy conservation, reducing the PV owner’s demand and allowing any excess power to be banked against the customer’s future power purchases (usually calculated on an annual basis).

For rooftop systems where there are feed-in tariffs, there are two meters, one for selling power into the grid at the feed-in tariff and one for buying power from the grid at the approved consumer rates. Different net-metering and feed-in tariff policies may have specific size limitations for eligibility to participate. In some US states, commercial scale PV arrays (e.g. > 200 kW to 1 MW) may participate in net-metering schemes. All sizes of PV arrays are eligible to participate in the Germany and Spanish FIT programs, though utility-scale PV plants (e.g., > 200 kW) in Spain represent 1.9 GW out of 3.0 GW of utility-scale PV systems worldwide. By the end of 2008, an estimated 1,800 utility-scale PV plants existed worldwide, up from 1,000 at the end of 2007.

More and more frequently in the United States and Europe, private-sector companies site, build, and operate utility-scale PV facilities on their own property. Many commercial and industrial facilities in the United States and elsewhere are interested in having large grid-connected PV generation on-site to provide electricity to their businesses because it will improve the reliability of their electricity supply and/or because they believe it offers them a competitive advantage in the marketplace. Many of these commercial or industrial businesses have large expanses of flat roofs perfectly suited for large solar arrays. Google has a 1.6 MW PV facility at its head office in California and Nellis Air Force base in the United States has a 14 MW array. The primary barrier to the private sector market for large PV is its high capital costs.

Utility Market for Large PV & CSP

Market Making Policies – As described in the Overview Module, a feed-in tariff or a mandatory target policy, like a renewable portfolio standard with a solar set-aside (e.g., a sub-target for solar), are the two most influential types of market-making policies for encouraging large grid-connected solar. Most FIT programs have solar specific tariffs and many RPS programs (e.g., Arizona 4.5%, China 3,000 MW, New Mexico 4%) have specific solar targets. As an example, a high feed-in tariff for large solar projects in Spain has been a key element driving private sector investments in solar in that country. (See Overview Module)

Utilities in Egypt, Morocco and Algeria are building or have built CSP projects encouraged by the World Bank program. However, these small (20 MW) projects have produced only a preliminary increase in utility interest in countries without market promotion policies. The primary factors that support large grid-connected solar are the same factors needed by all renewable energy technologies: favorable policies, market stability, long-term contracts, and supportive incentive policies. To be really effective in stimulating new large solar projects, multilateral lending institutions must provide funds for incentive policies, or provide loan guarantees. These policies and guarantees can result in a strong local and international policy framework partnership that goes beyond an individual project.

Solar rebate programs, investment tax credits, and production tax credits have stimulated the rapid growth of large PV in the United States and in many other large economies in Europe and Asia. Where the quality of the solar resource is sufficient for solar power generation, it is the legal and regulatory framework that determines the feasibility of large grid-connected solar facilities.

Market Stability and Long-term Contracts – Regardless of the specific policies selected, for solar projects to receive financing it is critical that energy policies be stable, predictable and properly enforced. Any changes should be prospective only with sufficient lead-time to allow business to adjust accordingly. Finally, long-term purchase power agreements – PPAs (of at least 15 to 20 years duration) are necessary to support the financing of these capital intensive projects.

(See Overview Module Financing and PPA sections)

A carefully crafted net-metering law is important for encouraging large, grid-connected, on-site solar facilities. However, even for this fairly simple market stimulation policy the details matter. For example in California there is a cap on the number of megawatts of customer-sited large PV projects that will be allowed to interconnect with the grid. Obviously this limits the potential impact of the policy. However, there is no limit on the size or number of large grid-connected utility PV projects that can be interconnected. (See Overview Module on Net Metering.)

TARIFF STRUCTURE

- Energy payments
  - Time of delivery
  - Premium for peak
- Capacity payments
  - Firm capacity or
  - As available capacity

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Tariff Structure

Energy – The most direct way to provide incentives for a large grid-connected solar project is to develop a PPA that provides sufficient revenue to cover costs, service debt, pay taxes, and provide an acceptable rate of return to project sponsors. Most solar technologies benefit from time of delivery (TOD) energy prices. CSP plants with storage capability may provide other grid services like peaking power and dispatchability. If so, these benefits should be compensated for in the PPA beyond the value of the base-load power itself. (See the PPA and Transmission sections of the Overview Module)

Capacity – It is appropriate for all renewables to receive some capacity payments: non-firm capacity (e.g., kWh capacity payments based on actual performance); or firm capacity payments if the technology incorporates storage capabilities. (See PPA capacity discussion in Overview Module).

OTHER BARRIERS & ISSUES

- **Land rights & siting**
  - Location
  - Environmental regulations
  - Alternative land uses
- **Transmission costs**
  - Large projects located in remote areas
  - New transmission lines important

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Other Barriers & Issues

Land Rights and Siting

Because large solar arrays of any type require significant amounts of land, land acquisition and siting have both economic and environmental implications for the project's success. However, land rights and siting may or may not be an issue depending upon the proposed location of the solar facility, the applicable environmental regulations, and the alternative uses for the land. It is really not practical for large-scale PV and CPS plants to be used simultaneously for animal grazing or other agricultural uses due to operation and maintenance considerations and the fact that in many cases the best locations for solar power are in arid areas where agricultural use is limited. Solar sites can share the land with other renewable power generators such as wind or geothermal, assuming both of the resources are of sufficient quality and there is sufficient space for siting and maintaining both facilities.

Transmission Costs

By their very nature, large solar systems tend to be located away from electricity load centers. This means that new transmission lines to carry the power to where it will be used is an integral part of any large solar project. The need for new transmission lines is an issue for most all large grid-connected renewables but can be a particularly important issue for large solar systems located a great distance from utility load centers.

The planning, expansion, and cost sharing of transmission facilities are discussed in greater detail in the Overview Module Transmission section.

LARGE-SCALE GRID-CONNECTED PV

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Large-Scale Grid-Connected PV

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PRESENTATION TECHNOLOGY – PV

- **Technology Overview**
- PV Market Trends
- Technology Issues & Solutions
- PV Project Economics
- Best Practices

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Technology Overview

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PV CELLS AND MATERIALS

- **Crystalline silicon solar cells**
  - Most widespread use, most field experience
  - Single and multi-crystalline manufacturing processes
  - Mature with limited potential for cost reduction

- **Thin-film solar cells**
  - Silicon and other semiconductor materials
  - Lower efficiency, but also lower cost
  - More potential for cost reduction

Slide 20

PV Cells and Materials

Crystalline silicon solar cells – Crystalline silicon solar cells are and have been the workhorse of the PV industry. They are made with the same materials as semiconductor devices such as transistors and microchips. In 2000 the solar industry used less than 10% of the industrial semiconductor feedstock. Rapid growth in solar manufacturing demand in the next five years created shortages and increased prices for the feedstock material, semiconductor-grade polysilicon. Currently, the solar industry uses well over 50% of the world supply of this material and continued growth has driven up silicon prices. Partly in response to silicon prices, and partly owing to the promise of lower manufacturing costs for thin-film solar cells, there has been a huge investment in new ventures exploring thin-film amorphous silicon solar cells that use less of this material and other more exotic semiconductor materials. In part responding to demand, manufacturers have also increased the capacity of polysilicon manufacturing, which has helped bring prices down.

Thin-film solar cells – A thin-film solar cell (TFSC), also called a thin-film photovoltaic cell (TFPV), is a solar cell made by depositing one or more thin layers (thin film) of photovoltaic material on a substrate. The thickness range of such a layer varies from a few nanometers to tens of micrometers. Thin-film PV technologies became a larger share of total PV installations in 2008 (of the 8 GW of PV manufacturing capacity by the end of 2008, 1 GW of that was thin film). Thin film has gained acceptance as a mainstream technology, due partly to manufacturing maturity and lower production costs, and partly to its advantage in terms of silicon feedstock – it requires just one-hundredth as much silicon as conventional cells.

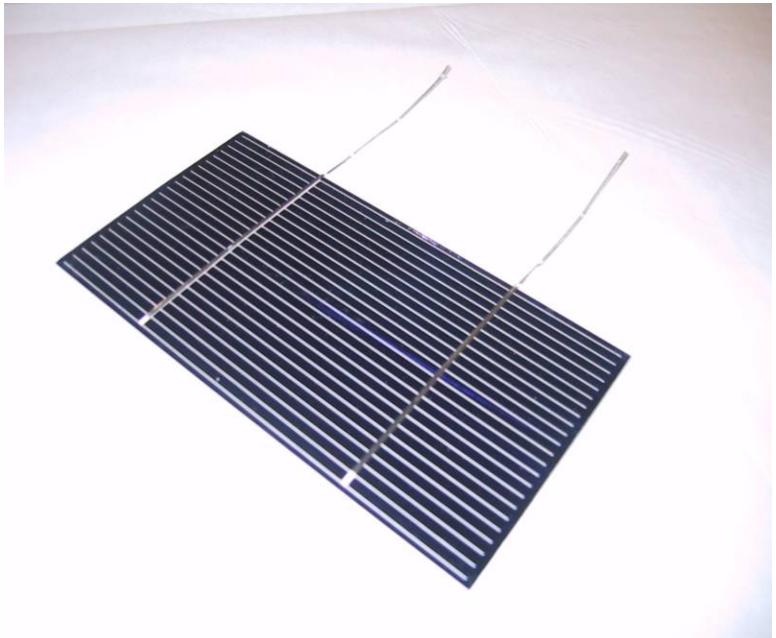
Many different photovoltaic materials are deposited with various deposition methods on a variety of substrates. Thin-film solar cells are usually categorized according to the photovoltaic material used. The following categories exist:

- **Cadmium Telluride (CdTe)**
- **Copper indium gallium selenide (CIS or CIGS)**
- Dye-sensitized solar cell (DSC)
- Organic solar cell
- **Thin-film silicon (TF-Si)**

The TFSC types that appear in bold letters are currently in mass production while the rest are still in the development or pilot-plant phase. In most cases the TFSC are named after the photovoltaic material that they use, although there seems to be some confusion regarding some TFSC types because manufacturers and researchers use different names to describe the same technologies.

PV CELLS & MODULES (PANELS)

- PV modules are assemblies of
  - PV cells
  - Structural frames
  - Transparent (usually glass) covers
  - Provisions for wiring them together to form arrays
- Modules are connected to form **high voltage "strings"**



PV cell

Slide 21

PV Cells and PV Modules

PV Cells

Common solar cells range up to eight inches square (64 sq inches). The cell pictured on this slide is about two by five inches and produces about 1 watt of DC electricity when exposed to bright sunlight. The thin lines on the top of the cell are metal conductors to gather electricity from the cell. The two thicker lines conduct the electricity from one cell to another during the manufacturing process. PV cells are linked together into a solar module or panel.

Some solar cell manufacturers sell solar cells to factories that assemble them into solar panels. This business model has often been used in situations where local value added is sought by governments providing incentives for solar deployment. For example, Sharp has an assembly facility in Thailand that assembles some small televisions and solar panels for the Thai market. In such facilities assembly lines can be developed in several months with levels of automation depending upon the needed plant throughput and cost of local labor. Typically such a facility would assemble from 100 kW up to 2-3 MW of PV modules in a year. The only process that requires specialized equipment is vacuum lamination, during which special chambers are used to bond the glass, encapsulants, and solar cells.

PV Modules (Panels)

The solar industry periodically explores downstream business models that integrate solar panels into larger array structures and systems. For example, the size of typical modules are limited by the size of available laminating chambers, the largest of which are in the 3 to 5 m^3 range. Such modules can be packaged, shipped, and handled with general purpose equipment (trucks, rail cars, forklifts) and individual panels can be picked up and installed by one or two laborers. For initial installations in new markets this is likely the best approach. For very large-scale systems in large local markets there can be an additional assembly plant step, mechanically and electrically connecting tens of modules into panel assemblies for field installation using specialized handling equipment to reduce field labor steps and improve quality control. This model is expected to be used to a greater extent in the future since streamlining the array structures, materials, and installation process can result in significant cost reductions.

Photo credit: Ascension Technology

GRID-CONNECTED PV PLANT

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A Sample Grid-Connected PV Plant

This slide shows a 1 MW solar array built in the Philippines in 2004, with modules assembled in groups of 45 panels (three high by 15 wide). Note the security wall and lighting around the perimeter of the array field. Also note the treatment of the ground with crushed rock to prevent vegetation from growing and potentially shading the array. Solar panels require no routine maintenance, and cleaning is usually not cost effective. One exception was a 100 kW system operating in a very humid region of India, where green algae grows on all surfaces during the monsoon season and must be cleaned off at the end of the wet season. For more information on the Philippines plant, see the Philippines Utility-Scale PV Case Study.

Photo credit: Irradiance, Inc

- Technology Overview
- **PV Market Trends**
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- PV Project Economics
- Best Practices

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PV Market Trends

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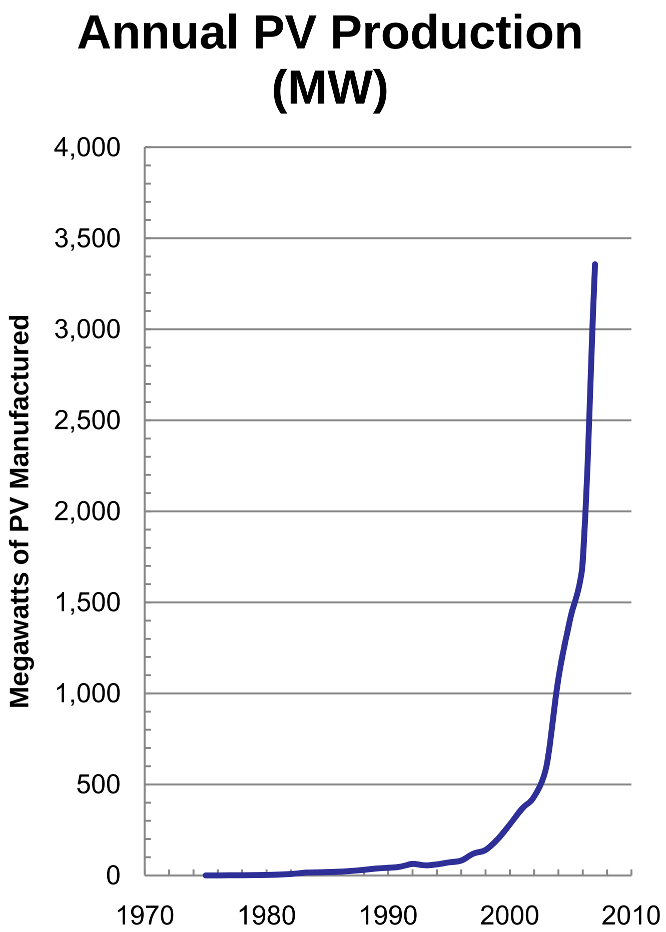
PV INDUSTRY GROWTH

- The PV industry has grown dramatically in the last decade

- Cumulative production to date is approximately 10 GW



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PV Industry Growth

The PV industry has been growing since the mid 1970s; during the late 1990s this growth began to accelerate rapidly owning to the introduction of incentives first in Japan, then Germany and the USA. These incentives have been influenced by economic development aspirations (first in Japan), energy security issues (in Germany following the Chernobyl accident), and by climate change concerns. Growth has continued in the new millenium and has been spurred by instability in the Mideast, fuel oil price spikes in 2008, and most recently by economic stimulus policies related to the economic downturn taking into consideration sustainability concerns regarding conventional fossil fuels.

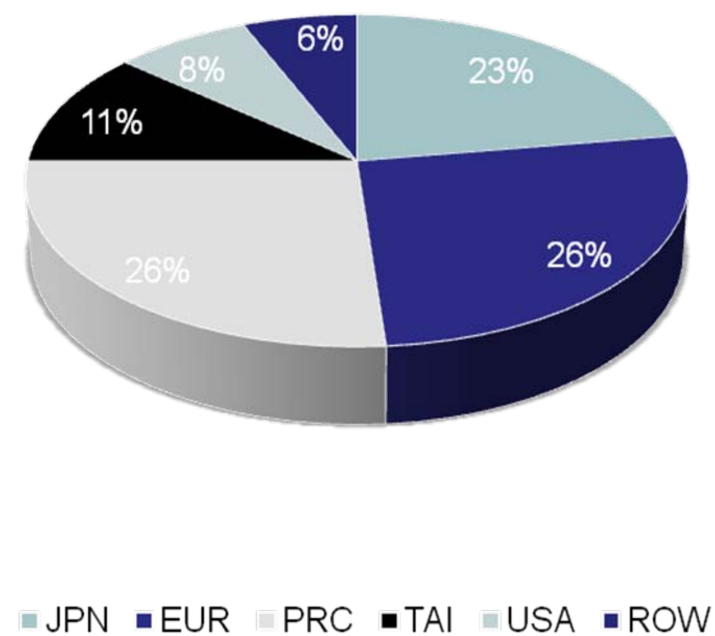
References:

- 243. Renewables Global Status Report Update 2009
- 268. Trends in Photovoltaic Applications Survey Report of Selected IEA Countries Between 1992 and 2007
- 269. PV Status Report 2008: Research, Solar Cell Production and Market Implementation of Photovoltaics

DISTRIBUTION OF PV PRODUCTION

- China has rapidly advanced to lead manufacturing
- Europe and Japan currently have about the same market share
- United States and rest of world are losing market share

Global PV Production 2007



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Distribution of PV Production

The PV industry grew out of space programs in the United States, Europe, and Japan in the early 1970s. It was first considered seriously for terrestrial applications following the oil shocks in the late 1970s. The United States initially led the development of PV manufacturing, but Japan quickly overcame the US lead by introducing the first large national incentive program in the early 1990s. Germany followed suit in the mid-1990s and boosted the European market share. More recently, the Chinese manufacturing share has been the fastest growing, and has been supplying US and EU markets. Recent Chinese policies have added incentives to mitigate climate issues related to China's rapidly increasing electric power demand.

PV PANEL PRICES

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PV Panel Prices

Most PV modules are less than 300 watts. The cost of solar panels in wholesale quantities is measured in terms of cost per unit of power rating, with a downward trend in the past decade from $5 to about $3 per watt in 2009. (Note: these are expressed in current year dollars; given currency inflation, the drop in “real” prices is greater.) The size of solar panels relates to their efficiency in converting sunlight to electricity. A panel with the same power in watts as another, but with half the efficiency would be twice as large. This is the fundamental difference between thin-film and crystalline silicon modules.

Photo credit: Irradiance, Inc

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PV MARKET PERFORMANCE TRENDS

- High market volatility
- Investors over-respond to short-term events
- Uncertain long-term finance slows investment plants and solar manufacturing

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PV Market Performance Trends

There is still a great deal of volatility in PV markets and since these markets are global, the volatility affects everyone. First Solar is selling most of its product in Europe, where it commands higher prices than in the United States. The situation might change on a moment's notice, based on changes in public opinion leading to curtailment of government incentive programs. The referenced article points out in stark terms the financial reality of PV project development: Investors are fickle, short sighted and over-respond to immediate, short-term events. Uncertain long-term finance slows long-term investments in solar power plants and solar module manufacturing facilities.

References

- 238. Shinkle – First Solar Stumbles

- Technology Overview
- PV Market Trends
- **Technology Issues & Solutions**
- PV Project Economics
- Best Practices

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Technology Issues & Solutions

TECHNOLOGY ISSUES: PV POWER PRODUCTION

- PV modules produce DC power
- Must be converted to AC for transmission and distribution
- Inverters convert DC to AC power and provide additional functions to assure proper interconnection with utility systems

Slide 29

PV Systems

Early PV systems charged batteries and no conversion to AC was needed. These systems helped build the industry, and interestingly established the voltage size of solar panels that continues today. Many solar panels still have 36 solar cells connected in series so that they can effectively charge a 12-volt lead acid battery. These early systems often had only a single pole or roof mounted module. They are still widely used where only a small amount of electricity can make a significant contribution for remote habitation or remote sensing and communications.

PV modules produce DC power that must be converted to AC for transmission and distribution. Inverters convert DC to AC power and provide additional functions to assure proper interconnection with utility systems: Synchronization with utility voltage reference, and isolation from the utility system when utility service is interrupted or abnormal. In most industrial nations with incentives creating large PV markets, consensus has been reached regarding technical standards for interconnection and policies for inspection and enforcement. Recommended sources are the IEEE standards in the US and the IFC standards internationally.

One issue concerning large PV systems in remote regions is that they could be the target of theft, since there is a big demand for solar panels in remote areas. High voltages in PV systems could provide a hazard to such thieves, similar to the hazards experienced by the theft of electricity or copper wire from distribution companies. However, the potential for electric shock has not seemed to slow electricity and copper wire theft.

References

- 271. CB Scheme and CB-FCS Scheme PV Standards

TECHNOLOGY ISSUES: MODULARITY AND SCALABILITY

PV system building-block components:

- Modules ranging from 50 to 500 watts, 16 to 50 volts, and ½ to 5 square meters
- Array fields ranging from 50 watts to 50 MW
- DC-to-AC inverters ranging from 500 watts to more than 500 KW

Slide 30

Modularity and Scalability

PV systems are constructed by connecting modules in series (like multiple batteries in a flashlight) to increase voltage or in parallel to increase electrical current. The serial interconnection of modules creates what is called a "series string" that in most cases develops voltage at a level needed by the system. For both grid- and non-connected systems, a range of operating voltages results since PV voltage decreases with increasing PV cell temperature, which in turn depends on air temperature and the intensity of sunlight. Strings are then connected in parallel to increase the electrical current output, again matched to the needs of the inverter and the electric system to which it connects. Maximum system voltages under US standards are limited to 600 volts; European standards permit 1,000 volt systems.

PV modules have very high reliability, with failure rates of 1 in 1,000 or less. PV's modularity allows for fitting PV into available parcels of land, expanding PV systems over time as demand increases or budgets become available. Building blocks for very large PV systems are the DC-AC inverters. For MW scale systems the typical building block is 100 kW and for multi-megawatt systems the building blocks are limited by the power ratings of commercially available inverters, now about 500 kW. The wire size needed to collect relatively low voltage DC current is another natural limit to the scale of a building block. For a 500 kW array about 2 hectares of land are needed, necessitating long (100 meter plus) wire runs to collect all the DC current to a central point where an inverter might be placed.

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TECHNOLOGY ISSUES: INVERTERS—THE WEAK LINK

- Multiple inverters are the norm
- Most in the 100 to 500kW range

Note: Fans are needed to cool inverter spaces since 5% DC power is lost to heat (or use for process heat)

This picture shows cabinets for 2 inverters & switches

Slide 31

DC and AC Inverters

Multiple inverters are usually used for large systems for several reasons:

- **Availability**: Few if any companies make inverters 1 MW or higher, but rather steer customers toward multiple smaller ones used in creating building blocks in the 100 to 500 kW range.
- **Reliability**: Inverters have traditionally been the “weak link” in PV systems, so having multiple inverters reduces lost power generation when a problem arises since only a fraction of the overall system suffers downtime if an inverter fails.
- **Size**: Small inverters are more easily transported across bad roads to remote areas and can be more easily installed.
- **Reduced wire-run distances and power losses**: Since dc power must be collected and carried to the inverters, multiple inverters can reduce the average wire run length since in MW+ scale systems can be distributed throughout the array field.
- **Cost**: Inverter manufacturers can reduce cost through standardization and mass production of fewer products.

The “limiting multiple inverter” scenario is an inverter on every module, or what is referred to as an AC module. These are just being introduced, however, and have yet to develop a substantial track record. Around 1999 some of the first large-scale systems in Germany were equipped with multiple 5 kW “string inverters.” There are several advantages to using multiple small inverters on every module:

- They reduce or eliminate the amount of dc wiring and the building space for inverters.
- DC electricity at high voltages is more expensive to collect from a large array field than is AC power, which can easily be boosted later to higher voltages for grid transmission.

There is an analogy to electric transmission and distribution systems: As power is delivered to consumers, the voltage is stepped down from high to low voltages because high voltages are better for moving power long distances and low voltages are better for use in homes and businesses. PV modules are like appliances and are safer and simpler at lower voltages. Today there is considerably more flexibility on the part of system designers, but it appears that most megawatt and larger systems are using inverters in the 100 to 500 kW range.

Photo credit: Irradiance, Inc

References

- 56. NREL – Learning – Photovotaics
- 57. IEA – PV Performance, Reliability and Analysis

PRESENTATION TECHNOLOGY – PV

- Technology Overview
- PV Market Trends
- Technology Issues & Solutions
- **PV Project Economics**
- Best Practices

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PV Project Economics

NON-TECHNOLOGY COSTS

- **Installation costs**: 5% of total system cost
- **O&M costs**: .5% of total system cost/year
- **Labor needs (1MW plant)**: guard, 2 on-site laborers

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Non-Technology Costs

Field assembling the structural steel and modules can also be labor intensive in developing countries when PV systems are first introduced. For the CEPALCO project in the Philippines (*/ See PV Case Study) about 100 watts of array were installed per man-day of unskilled labor. In more developed countries assembly activities might be done in a factory setting then transported to the field. As PV grows in an area, project construction logistics will evolve with experience, and with sufficient volume begin to develop more permanent local jobs in factory settings. PV systems operate automatically but any site will require on-site personal to maintain the equipment and grounds, as well as respond to any emergency and provide site security. The labor required for a 4 hectare 1-MW system is a 24-hour guard/operator, and two 8-10 hour/day unskilled laborers. O&M costs are about 0.5% and installation costs are about 5% of the total system cost.

Photo credit: Irradiance, Inc

PV PROJECT DEVELOPMENT FLOW

- Develop a simple financial model
- Define size and candidate locations
- Estimate solar resources and land cost/availability at candidate locations
- Develop options for cell technology, tracking, concentration, land, and project finance
- Use financial model to seek best solution

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PV Project Development Flow

Fluctuations in the solar resource can be 5-10% annually (year to year) and 15-20% monthly (month to same month in a different year). A financial model should have long-term average resource information. Usually this is done with a year or more of data from a specific location compared with same year data and long-term data obtained from a reasonably nearby weather station.

It is always a challenge to make PV economically feasible. It is best to start with a simple financial model that includes:

- capital and construction costs
- anticipated power production
- financing costs
- electricity sale revenues

A simple spreadsheet model can identify threshold capital costs, power purchase prices, and financing terms that will make a project financially attractive. The next two slides provide an example of the type of system cost and performance models useful for this purpose.

There are economies of scale associated with large PV systems, though not of the magnitude associated with concentrating solar power (CSP) discussed in the next section of this presentation. Scale affects fixed engineering and site development costs as well as construction management. The incremental return as the project grows above 5 MW is likely to be small since at that scale the management cost is a very small percentage of the overall project cost.

Finally, having a champion who is willing to work very hard to make the finances work is critical to project success.

SAMPLE PV SYSTEM COST MODEL

Design and Construction $/Watt(DC)	
PV module unit price	$ 2.75
Array structure and wiring	$ 0.20
Power inverters	$ 0.20
Plant planning costs, fees, permits	$ 0.15
System construction	$ 0.20
Total Capital Cost $/Watt (DC)	**$ 3.50**

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PV System Cost Model

This slide illustrates the basic cost elements of a large-scale PV power plant, except the cost of land. The biggest single cost is for the PV modules themselves. The historic decrease in world module prices has slowed and held stable in the $3 to $4 per watt (DC) range for several years. In 2009 the downward trend is poised to renew with the softening of demand in some large incentive-based markets and with the continued manufacturing capacity expansion.

Other PV system components such as array structure and wiring materials, as well as labor costs, are similar to other engineered projects and already have a mature market. With more experience in building PV systems, these costs have the potential for additional reductions, but incrementally rather than substantially.

Power inverters specific to the PV market are also a relatively small part of the overall system cost, but do have the potential over time to drop by a significant percentage. In the future, inverters could cost as little as $0.10 per watt.

The planning and construction costs sited here are for teams experienced in the construction of PV plants. New entrants in the business will likely experience higher costs owing to a steep, but short, learning curve. Long term these costs will abate somewhat as more experience and simpler regulatory policies (fees, permits, etc.) are applied to project developers. Typical fees include traditional land acquisition costs and the fees and permits associated with that (title, construction permits, environmental studies) and utility interconnection studies and any others that might be mandated by regulators.

In 2009 the $3.50 total cost illustrated here represents very low margins, and a low profit scenario for all sectors in the PV value chain. This model only includes the cost of money and does not assume other financing costs that could arise since those are so project specific.

References

- 132. PV Financial Analysis Model

PV SYSTEM PERFORMANCE MODEL

Finance and Operation	
Cost of money (%/yr)	5%
Annual O&M (% of capital cost)	0.5%
Plant module DC to inverter AC losses	80%
Generation capacity factor	20.0%
Annual production (kWh/W)	1.40
Annual plant cost ($/Watt DC)	$0.28
Average kWh cost ($/kWh)	**$0.20**

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PV System Performance Model

A PV system's annual performance depends on solar energy resources that result in a "Generation Capacity Factor" typically in the range from 15% to 25%, with higher percentages in sunnier locations. PV power plants are rated on an AC basis; that is the amount of AC power produced by an inverter when the sun's energy incident on the array field is at its nominal maximum value of 1,000 W/m^2. Arrays of PV modules are rated on a DC basis at standard module temperatures (usually 25°C) and incident sunlight levels (usually 1,000 W/m^2).

The two principal physical factors that cause losses are the heating of modules to temperatures greater than 25°C and the ensuing drop in voltage and the resistive losses in the array field wiring, inverters, and output voltage transformers. Each of these factors claims about 10% of the DC module rating, so that the peak AC capacity is only about 80% of the total of the module ratings.

A system's peak-rated generation is reached only during clear, sunny conditions. Rather than running at a steady rate, the system follows a daily cycle with production starting soon after sunrise, ramping up in the morning, peaking around noon when the sun is highest in the sky, and then ramping down in the afternoon and stopping at sunset. On days with heavy clouds the sunlight level may reach only 10% of its peak, clear sky value. On days with scattered clouds, the sunlight level measured at a point can rapidly cycle between 10% and 100% as clouds shade and un-shade an array. Rather than deal with the details of the minute-to-minute variations of plant performance to determine the annual sum total generation, an equivalency is made by asserting an annual generation capacity factor. The 20% capacity factor cited means that the plant's actual production over a year will be equivalent to the plant running at its full rated capacity for 20% of the time (1,752 hours) over the 8,760 hours in a year.

Thus, the annual production is the product of the DC rating (here we are dealing on a per watt DC rating of one watt), times the 80% derating going from DC to AC, times 20% of 8,760 hours, which gives the 1.4 kilowatt-hours of AC power production per DC watt rating per year. The operator would only know the amount of power that would be available on a clear day. Over time the operator will learn to predict performance based on weather forecasts. This is practiced by all system operators for estimating future demand and PV forecasting models are being developed and tested in California and some other places.

The corresponding annual sum of the cost of capital (5% interest computed as a constant payment amount over an assumed 20-year plant life) and 0.5% annual O&M assumptions, works out to 28¢, so by dividing the cost of electricity from such a plant would be 20¢. At 20 ¢/kWh, this power would be hard to sell in today's wholesale electricity markets, where prices are typically half or less of this cost.

Parity between wholesale electricity markets and PV systems will be achieved by some combination of reduced costs in building PV systems, lower-cost financing, and higher wholesale prices for electricity. For now this gap is being filled by the policies and incentives mentioned in the first part of this module. This model can be used to explore alternative routes toward making a project viable.

- Technology Overview
- PV Market Trends
- Technology Issues & Solutions
- PV Project Economics
- **Best Practices**

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Best Practices

BEST PRACTICES: POLICY

- **Renewable energy policy framework**
  - Feed-in tariff, or
  - Mandatory target

  (Need either specific price/ target for solar)

- **Enthusiastic utility partner**

- **Tax incentives**
  - Investment tax credit
  - Production tax credit

- **Strong loan guarantee program**

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Best Practices: Policy

Best practices, from the perspective of enabling private investment in large grid-connected PV are summarized as follows:

- Have a well-designed, stable, and predictable policy framework that incorporates either a Feed-in Tariff with a specific PV price or a mandatory target type market policy (RPS/RES) that includes a specific target for solar.
- An enthusiastic utility partner is very important for any technology but particularly for solar PV plants where the utility is the exclusive off taker.
- In addition to a solid market policy, supplemental tax incentives and a reformed tax structure (e.g. property taxes, VAT, import duties) will improve the ability to finance and develop large PV projects.
- A related supporting policy is a loan guarantee program that can be provided by either the local government or may be created and supported by a multilateral lending institution.

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BEST PRACTICES: TECHNOLOGY

- **Avoid novel technology, be conservative**
  - Use proven solar and inverter technology
  - Stress importance of long-term goals
- **Initial projects lay foundations for future**
  - Track and report metrics for multiple goals
  - Outreach to policymakers and power sector

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Project Considerations

Large, grid-connected PV is not common because it is new and expensive relative to conventional power plants and even compared to some other renewable generating technologies. New large PV systems in developing countries represent an important learning experience for industry, policymakers, electric power companies, and the public. Much rides on the success of the first installations in a region, so it is usually prudent to be conservative. One should avoid introducing novel, unproven modules or inverters and focus on the broader long-term goals and benefits of preliminary ventures into this field of technology. These long-term goals may include the wish to gain experience with large grid-connected PV systems, developing a group of trained technicians to maintain systems, and promoting local economic development through local manufacturing and/or assembly.

BEST PRACTICES: PROMOTING LOCAL VALUE-ADDED

- Use local labor
- Seek local steel and concrete
- Local manufacturing for:
  – combiner boxes
  – assembly of solar modules
  – foundation construction

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Local Value Added

Although PV systems are very new and involve advanced technology (for the manufacture of solar cells and power electronics needed to convert dc into ac power), there are many stages in the supply chain that can be tailored to support local job creation at the site of the project. The trade-offs involve the relative costs between an approach featuring centralized, mechanized, high-volume manufacturing and associated packing, shipping and import tariff costs, versus one utilizing distributed, local, lower-volume and less-mechanized manufacturing. Civil works for PV plants, for example, can be built by many relatively low-skilled laborers or through a more mechanized process relying primarily on heavy diesel-powered earthmoving and grading equipment rather than human labor.

Structural supports for PV projects are similar to those used in many infrastructure construction projects, such as for bridges, pipelines, and electric power transmission lines and could be manufactured at the same factories. Electrical wire and conduit for the field interconnection of modules and connections between array fields and inverters are also similar to many common wiring needs and could be manufactured in-country and cut to standardized lengths and fitted with terminal connectors locally.

Perhaps the most sophisticated of the potential local manufacturing opportunities are the enclosures used to combine strings of PV panels together in the collection of dc power from the array field to the inverters. For example, in the CEPALCO project in the Philippines (*/ See PV Case Study), the junction boxes were assembled in Vietnam.

The larger the scale of the local generation PV planned (not necessarily at one very large single plant), the more likely it will be to create more sophisticated local manufacturing opportunities.

CONCENTRATING SOLAR POWER (CSP)

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Concentrating Solar Power

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PRESENTATION TECHNOLOGY – CSP

- **Technology Overview**
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- Best Practices

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CSP Presentation

The name concentrating solar power (CSP) was coined a few years ago by the National Renewable Energy Laboratory (NREL) and refers to solar systems that use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. The concentrated light is then used as a heat source for a conventional power plant or is concentrated onto photovoltaic surfaces which produce energy directly. A number of concentrating technologies exist today and more are still in the research phase.

CONCENTRATING SOLAR TECHNOLOGIES

- **Concentrating photovoltaic**
- **Concentrating solar thermal (CSP)**

  – Concentrate sunlight by 80-3,000 times to produce high-temperature heat

  –Heat converted to electricity

Slide 43

Concentrating Solar Power Technologies

CSP technologies may be divided into two types: concentrating solar thermal technologies, and concentrating solar photovoltaic technologies. In many places, CSP has become synonymous with solar thermal technologies, and the acronym CSP in the rest of this presentation will refer to solar thermal technologies.

Solar thermal CSP plants produce electricity by converting direct sunlight into high-temperature heat using various types and arrangements of mirrors. The heat is then used in a conventional generator. These plants are comprised of two major subsystems: one that collects solar energy and converts it to heat; and another that converts heat energy to electricity. The heat can be converted to electricity in three ways: (1) steam turbine; (2) gas turbine; or (3) use of a Stirling engine. Using commercial steam turbines or gas turbines in conjunction with CSP requires the CSP systems to be very large since the smallest widely available commercial turbines and generators are 50 MW or larger.

Concentrating solar PV (CPV) plants provide power by focusing solar radiation onto special photovoltaic (PV) receivers (not traditional flat-plate panels) that convert the concentrated radiation directly to electricity. Either mirrors or lenses can be used to concentrate the solar energy. CPV plants are typically modular at sizes up to about 100 square meters and 20 kW ratings and can be used in smaller installations than CSP since the DC-to-AC conversion equipment used is modular at that power level.

CSP solar thermal technologies are unique from many other forms of renewables in that they have the option to incorporate thermal storage in their design. The addition of storage makes power from CSP plants dispatchable. Dispatchability adds tremendously to the usefulness of CSP from the perspective of electric system operators. Thermal systems can either use fossil fuel to supplement solar thermal energy, or they can use thermal storage to store solar-generated energy for use at a later time. For example, high-temperature thermal energy stored during the day can be used during peak hours in the evening to generate electricity. These attributes, along with very high solar-to-electric conversion efficiencies, make CSP a potential renewable energy option in sunbelt regions worldwide.

References

- 270. NREL – Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts

Characteristics of Concentrating Solar Thermal Power

- Best in large central station arrays for economies of scale and O&M
- Limited modularity
- Integrated fossil fuel backup or thermal storage allows for dispatchable operation

Slide 44

Resource Availability

CSP with storage performs in a very similar manner to central station fossil plants (but with no or much lower emissions). With their familiar heat conversion systems, CSP can be attractive to utility planners. One square kilometer of CSP provides approximately the same energy output as a 50 MW coal or natural gas plant.

Photo credit: NREL Photographic Exchange

CONCENTRATED SOLAR ENERGY CONVERSION SYSTEMS


Parabolic trough


Power tower

Linear Fresnel



Dish engine


Concentrating PV

Slide 45

Concentrated Solar Energy Technology Conversion Systems

The primary attributes of CSP include: (1) Proven reliability with 100 plant-years of on-grid experience (from the 424 MW of operational troughs); (2) demonstrated dispatchability provides high-value power (for troughs & power tower); (3) high annual efficiencies; and (4) easy integration into a conventional grid. There are three main types of concentrating solar power technologies and two types of concentrating solar PV. Moving from the top left corner counter-clockwise they are: (1) parabolic trough; (2) dish engine; (3) power tower (center); (4) concentrating PV; and (5) linear Fresnel (type of concentrating solar PV). All of these technologies are concentrating technologies of one type or another.

Recently several factors have caused increased interest in concentrating solar technologies:

- High cost of fossil fuels
- Environmental and climate change concerns
- Government renewable energy policies and incentives
- Technical advances
- Relatively short construction lead times

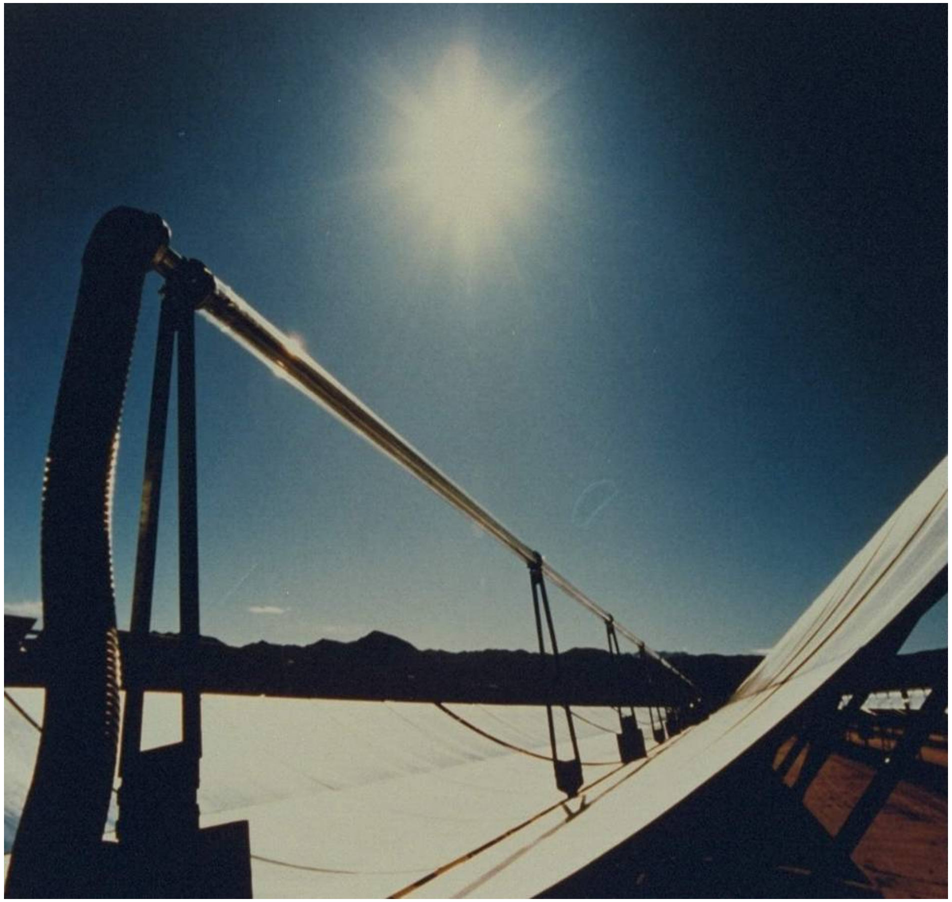
References

- 36. DOE – Renewable Energy Trends in Consumption and Electricity 2006, pp. 23-32.

CSP TECHNOLOGIES: TROUGH SYSTEMS

Components

- Trough collectors (single-axis tracking)
- Heat-collection elements
- Heat-transfer oil
- Oil-to-water steam generator
- Oil-to-salt thermal storage
- Conventional steam Rankine-cycle power block



Slide 46

Parabolic Trough Systems

A parabolic trough system uses parabolic mirrors that line up in long rows to concentrate sunlight onto an absorber tube (receiver). The receiver contains a heat transfer fluid (the simplest being mineral oils used in early plants, eutectic fluids, and the most challenging molten salts) that is heated and circulated, and the heat is released to generate steam. The steam powers a conventional steam generator to produce electricity. The mirrors use a single-axis tracker to ensure that the sun is continuously focused on the receiver. Parabolic trough systems require siting on flat land.

Electricity generation by solar trough plants in California has been consistently strong over the almost 20 years since the Kramer Junction plants began operation. Advanced development of components and subsystems have also contributed to performance gains over the last decade.

References

- 95. NREL – Assessment of Parabolic Trough and Power Tower Solar Technology Costs and Performance Forecasts
- 135. American Energy: The Renewable Path to Energy Security
- 237. NREL:TroughNet – Parabolic Trough Solar Field Technology

CSP TECHNOLOGIES: POWER TOWER SYSTEMS

Components

- Heliostats (two-axis tracking)
- Air or molten-salt receiver
- Air or molten-salt working fluid
- Thermal storage
- Conventional steam cycle or combustion turbine

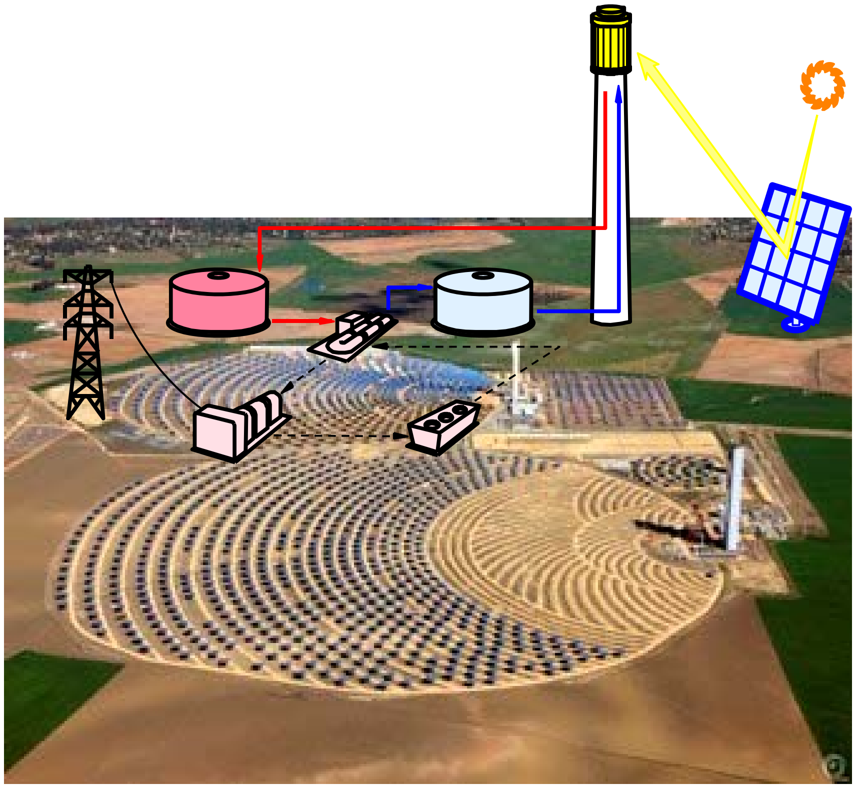


Diagram of molten-salt plant

Slide 47

Power Tower Systems

Solar power towers generate electric power by focusing concentrated solar radiation on a tower-mounted heat exchanger (the receiver). The system uses hundreds to thousands of sun-tracking mirrors called heliostats to reflect the sunlight onto the receiver. In a molten-salt solar power tower, liquid salt at 290°C (554°F) is pumped from a “cold” storage tank through the receiver where it is heated to 565°C (1,049°F) and then on to a “hot” tank for storage. When power is needed from the plant, hot salt is pumped to a steam generating system that produces superheated steam for a conventional Rankine-cycle turbine/generator system. From the steam generator, the salt is returned to the cold tank where it is stored and eventually reheated in the receiver. A heat transfer fluid heated in the receiver is used to generate steam that in turn is used in a conventional turbine generator to produce electricity. The molten-salt two-tank system is inherent to the power tower design and can feasibly provide up to 16 hours of high-efficiency storage. Power tower systems must be sited on flat land.

Early power towers used steam as the heat transfer fluid; the current designs use molten nitrate salt because of its superior heat transfer and energy storage capabilities. Systems with air as the working fluid in the receiver or power system have also been explored in international research and development programs.

Power towers are best suited for utility-scale applications in the 30 to 400 MW ranges. There are currently no commercial power tower plants in operation. Experimental and prototype systems have been placed in operation in Spain, France, Israel, and the United States (two 10 MW systems). There are 300 MW of power tower projects presently contracted or under consideration by California utilities, and the following international projects are also being considered:

- Eskom (South Africa), 100 MW molten-salt plant
- PS 10 (Spain), Abengoa Solar, 11 MW air receiver plant
- Solar Tres (Spain), Ghersa, Boeing, Nexant 17 MW molten-salt plant

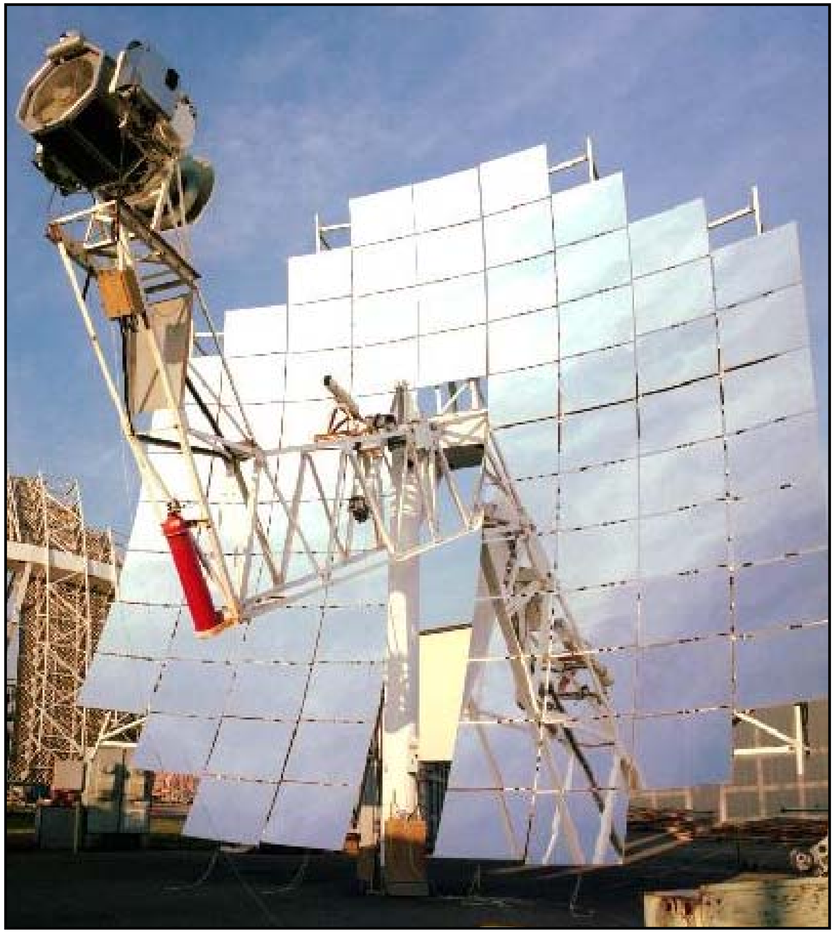
References

- 95. NREL – Assessment of Parabolic Trough and Power Tower Solar Technology Costs and Performance Forecasts

CSP TECHNOLOGIES: DISH ENGINE TECHNOLOGY

Components

- Two-axis tracking
- Modular 1-25 kW units
- Thermal receiver
- 8 different system configurations built and tested over the last 20 years



Slide 48

Dish Engine Technology

A dish engine system uses a mirrored dish to collect and concentrate sunlight onto a receiver. The resultant solar beam has all of the power of the sunlight hitting the dish, but is concentrated in a small area so that it can be more efficiently used. The dish structure must track the sun continuously to reflect the beam into the thermal receiver. The dish collects more solar energy than the trough system because it tracks in two axes, always pointing directly at the sun, in contrast to the trough system that tracks in a single axis. The receiver absorbs the sun's heat and transfers it to a gas or fluid in an engine. The heat causes the gas or fluid to expand and drive a piston that is connected to a generator that produces electricity.

Level land is preferable for construction and maintenance ease; however, siting requirements on slope are less significant than those for trough and tower systems. This technology does not include storage nor does it require water for cooling. The dish engine can be used in a hybrid configuration with combined cycle natural gas plants. There are no commercial dish engine power plants operating today, though the three California investor-owned utilities (PG&E, SCE, and SDG&E) have contracted for 1,250 MW of dish engine projects through the RPS tendering process.

References

- 95. NREL – Assessment of Parabolic Trough and Power Tower Solar Technology Costs and Performance Forecasts

CONCENTRATING PV TECHNOLOGY

Features

- 25 - 35 kW systems
- Two-axis tracking
- Acrylic lens concentrator or parabolic dish with PV at focal point
- Silicon solar cells
- Many companies are developing new designs

Slide 49

Concentrating PV Technology

Concentrating solar radiation can also be used for PV systems, because concentration reduces the cell area required to generate a particular level of electricity. Concentrating solar PV generally requires higher efficiency, and higher quality cells than for flat-plate systems as the best economic choice for this type system. Concentrating PV is a less complex system than other types of CSP and in some configurations doesn't require as much land. In addition, CPV systems do not require water for cooling. However, this system doesn't incorporate storage so it is not dispatchable. Also, unlike the trough or power tower technologies, CPV energy output is variable.

There are no commercial CPV power plants in operation. A series of pre-commercial development systems totaling 500 kW are operating in Arizona under the auspices of Arizona Public Service (APS), and a 200+ kW system is in operation in Australia. Planned deployments in the near future include an additional 5 MW by Arizona Public Service, 477 MW in California, several MW in Australia, and an undetermined level in Europe.

Similar to the dish systems, level land is preferable for construction and maintenance ease, although it is likely a less significant requirement for CPV sites than the siting requirements for trough and tower systems.

References

- 97. Black & Veatch – New Mexico Concentrating Solar Plant Feasibility Study

COMPARISON OF CONCENTRATING SOLAR TECHNOLOGIES

Technology	Commercial Status	Water Requirements	Thermal Storage	Land Required
Parabolic trough	Good commercial operational experience	Large if wet cooling is used Low w/dry cooling	Molten-salt 6 hrs	Flat
Dish engine	Lacks commercial operational experience	Low	NA	1%-3% slope
Power tower	10 MW prototype	Large if wet cooling is used Low w/dry cooling	Molten-salt 16 hrs	Flat
CPV	Lacks commercial operational experience >MW	Low	NA	1%-3% slope

Slide 50

Comparison of CSP Technologies

This table compares some of the characteristics of four of the CSP technologies.

Commercial Status: Only the parabolic trough is considered commercially available, though there have been several power tower experimental/pilot projects, and Eskom in South Africa has proposed building a 100 MW system. The majority of the trough projects are operated as IPPs.

Water Requirements: Both dish engine and CPV require water only for cleaning. Both parabolic trough and power tower technologies require significant quantities of water for cooling unless they use air-cooling. This reduces water requirements to low levels but also reduces efficiency and increases cost. (See Slides #64-66 for more information on cooling options)

Thermal Storage: Both parabolic trough and power tower technologies incorporate thermal storage (currently about six hours for trough and as much as 16 hours for power tower) allowing them to be dispatchable.

In addition, any of the CSP technologies could be put into a hybrid configuration with a combined-cycle natural gas plant that adds dispatchability but increases water requirements (see next slide).

Land Requirements: All of the CSP plants require fairly flat land though the dish engine and CPV can tolerate a slope of 1% to 3%.

Aside from water requirements, there is no discernible difference in the operation and maintenance costs between the various CSP technologies.

References

- 97. Black & Veatch – New Mexico Concentrating Solar Plant Feasibility Study

INTEGRATED SOLAR COMBINED CYCLE SYSTEM (ISCCS)

Features

- Adds solar field to combined cycle plant
- Produces saturated steam
- Allows for increased steam turbine capacity
- <10% to 25% solar electricity contribution

Slide 51

Solar-Fossil Hybrid Plants

Many solar-fossil hybrid options are possible with natural gas combined-cycle and coal-fired or oil-fired Rankine plants. These hybrid plants have the potential to accelerate near-term opportunities for project development due to improved economics and reduced overall project risk. These hybrids are called integrated solar combined cycle systems (ISCCS). Two commercial ISCCS plants are being installed in Algeria and Morocco and are expected to begin operation shortly.

The solar-fossil hybrids add a solar field of some type (parabolic trough, power tower, dish engine, or CPV) to a combined-cycle plant in order to generate saturated steam. The steam is fed to the heat recovery steam generator (HRSG), which raises the temperature higher, and then is sent to the steam turbine. A typical combined-cycle plant has a steam turbine about half the capacity of a combustion turbine. In an ISCCS design, the steam turbine capacity is increased to accept steam created by the solar components.

If operated in a baseload mode the solar contribution to electricity generation is generally less than 10%, depending upon the solar technology paired with the combined-cycle generator. When hybridizing a solar power tower and a fossil-fired plant, solar can contribute up to 25% of the peak power output from the plant and between 10% and 25% of the annual electricity output. (The higher annual solar fraction can be achieved with 13 hours of thermal storage and the lower solar fraction with just a few hours of storage.)

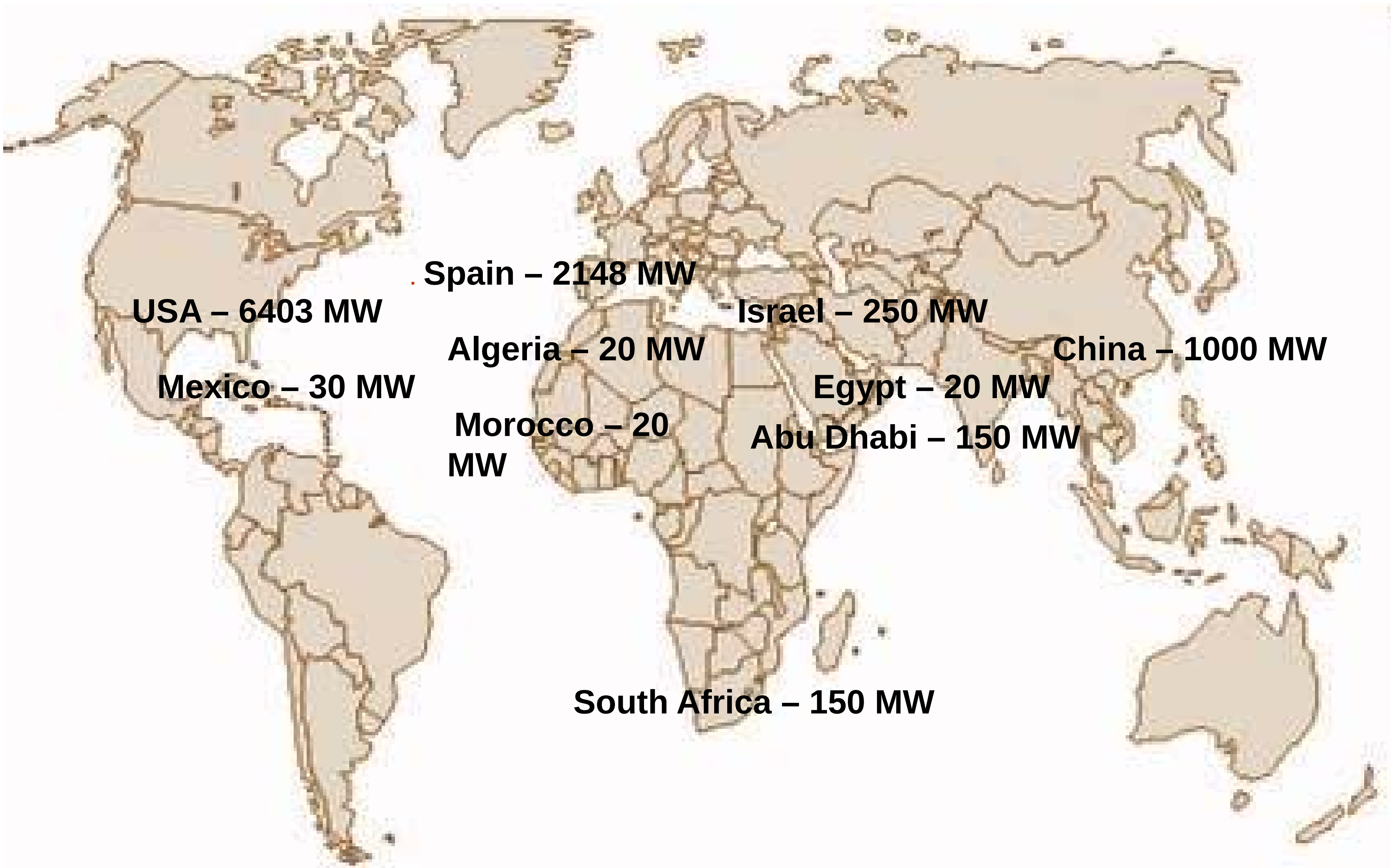
In an ISCCS plant, additional electricity is produced by over-sizing the steam turbine, contained within a coal-fired Rankine plant, or the bottoming portion of a combined-cycle plant, so that it can operate on both full fossil and solar energy when solar is available. ISCCS designs have typically oversized the steam turbine from 25% to 50% beyond what the turbine can produce in the fossil-only mode. (Over-sizing of combined cycle turbines beyond this range is not recommended because the thermal-to-electric conversion efficiency degrades at the partial loads associated with operating in the fuel-only mode.)

ISCCS plants were considered for all four of the Global Environmental Facility (GEF) grant projects (India, Egypt, Morocco, and Mexico) though only the projects in Egypt and Morocco are being constructed. An ISCCS plant that was not funded by the GEF is just being completed in Algeria. Utilities in the United States and Europe have also been interested in this technology but as yet none have been contracted.

References

- 90. GreenPeace – Concentrating Solar Thermal Power Now
- 95. NREL – Assessment of Parabolic Trough and Power Tower Solar Technology Costs and Performance Forecasts
- 96. WB – Assessment of the World Bank/GEF Strategy for the Market Development of Concentrating Solar Thermal Power

EXISTING AND PROPOSED CSP PROJECTS



Slide 52

Existing and Proposed International CSP Projects

The five most promising regions (based on the resource availability and government interest) are the Mediterranean, especially Spain, the countries of the Middle East and North Africa, the southwestern parts of the United States and Australia.

For many developing countries CSP is a superb technology because many smaller countries import fuel and are also dependent upon power from hydroelectric facilities that are sometimes unavailable in the summer. Under these situations, CSP may be a viable option because it is not sensitive to drought or to fuel price fluctuations and it relies upon a secure, indigenous resource.

References

- 39. IEA – SolarPACES Library

US CSP PROJECTS (MARCH 2009)

Technology	State	Installed	Under Contract
Parabolic trough	Arizona	1 MW	
	Arizona		280 MW
Dish engine	California		800 MW
	California		950 MW
Linear Fresnel	California	5 MW	
	California		177 MW
Parabolic trough	California	354 MW	
	California		1,010 MW
Power tower	California		645 MW
	California		1,700 MW
Parabolic trough	Nevada	64 MW	
	Nevada		250 MW
Power tower	New Mexico		92 MW
	Column Totals	**424 MW**	**5,904 MW**
	US Total	**6,328 MW**	

Source: Morse Associates, Inc.

Slide 53

CSP Estimated Activity in the United States

Over the past few years there has been more CSP activity in the United States than in the rest of the world, due primarily to aggressive renewable energy policies implemented by US states. As of March 2009 there was significant utility and regulatory interest in constructing new CSP plants in the United States. Though there is only 424 MW of installed CSP capacity in the United States, currently there is an additional 5,904 MW of CSP under contract as a result of RPS tenders including:

- 1,540 MW parabolic rough projects (Plus 75 MW add-on to IGCC project in Florida)
- 2,437 MW of power tower projects
- 1,750 MW of dish engine projects
- 177 MW Fresnel (PV) projects

Of the 5,904 MW of proposed projects, most (5,282 MW) have been proposed in California primarily to help meet the California renewable portfolio standard requiring 20% renewable generation by 2012 and 33% by 2020. The other 622 MW are spread between Florida (75 MW), Arizona (280 MW), Nevada (250 MW), and New Mexico (92 MW). Arizona, Nevada, and New Mexico also have RPS targets, while Florida has RPS legislation pending.

References

- 58. Details of US and Global CSP Projects
- 95. NREL – Assessment of Parabolic Trough and Power Tower Solar Technology Costs and Performance Forecasts

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INTERNATIONAL CSP PROJECTS

(MARCH 2009)

Technology	Country	Active	Planned
ISCCS	Algeria	20 MW*	
	Egypt	20 MW*	
	Morocco	20 MW*	
Parabolic trough	Abu Dhabi		150 MW
	Spain	600 MW	
	Spain		100 MW
Power tower	Spain	48 MW	
Technology not yet chosen	China		1,000 MW
	Israel		250 MW
	Mexico		30 MW*
	South Africa		150 MW
	Spain		1,400 MW
	Column Totals	**708 MW**	**3,080 MW**
	International Total	**3,788 MW**	

Source: Morse Associates, Inc.

* Natural gas/CSP hybrid project; capacity shown is CSP portion only

Slide 54

CSP Activity Outside the United States

As can be seen from this table, the greatest amount of CSP activity outside the US has occurred in Spain, driven by its very generous CSP feed-in tariff (€0.32/kWh or roughly US$.50/kWh). As a result, all the projects are owned by independent energy producers. This tariff will be reduced in 2010 for any new projects, but projects are eligible for the tariff that is in effect at the time the project begins construction.

The Algerian project is a joint venture with Abengoa Solar. Algeria is hoping to sell excess power to Europe via a transmission line under the Mediterranean. The project in Morocco is a turnkey project being constructed by Abengoa for the utility that also hopes to make sales to Europe. A 12-company consortium has been formed – “Desertec” (including Abengoa) – to explore the expansion of the North African grid into Europe. The plan is expected to include a new underwater cable as well as strengthening the existing cable from Algeria to Spain, and strengthening the grid connecting the participating North African countries. The Algerian and Moroccan projects are both ISCCS projects that include 20MW solar trough contributions. Morocco is now interested in building a second plant to diversify its electric system and increase the amount of power coming from its indigenous resource.

The projects in Egypt, Morocco, and Mexico are all WB/GEF-funded projects, with the WB/GEF funds closing the gap between the project costs and retail electric rates. Israel has put out a request for proposals for 250 MW of CSP and is interested in encouraging one or more Israeli companies to get into the CSP business. The South African utility Eskom is considering building a CSP project in the northern area of that country as an alternative to brown coal, to diversify its electricity supply resources and to possibly create its own technology for export. China is also exploring opportunities for CSP projects in the western regions of China though actual projects are still only in the discussion stage.

A solar thermal plant was proposed for India but was never built due to design flaws and an inappropriate location (see WB/GEF document in references for more information).

References

- 58. Details of US and Global CSP Projects
- 96. WB – Assessment of the World Bank/GEF Strategy for the Market Development of Concentrating Solar Thermal Power
- 267. Clean Technology Fund: Concept Note for a Concentrated Solar Power Scale-Up Program in the Middle East and North Africa Region

PRESENTATION TECHNOLOGY – CSP

- Technology Overview
- **CSP Economics**
- Technical Issues & Solutions
- Project Development Flow
- Best Practices

Slide 55

CSP Economics

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CSP COSTS

$

- Higher cost than other renewables
- Relatively new technologies
- Costs coming down:
  - Plant size
  - Quantity of technology (learning curve & manufacturing volume)

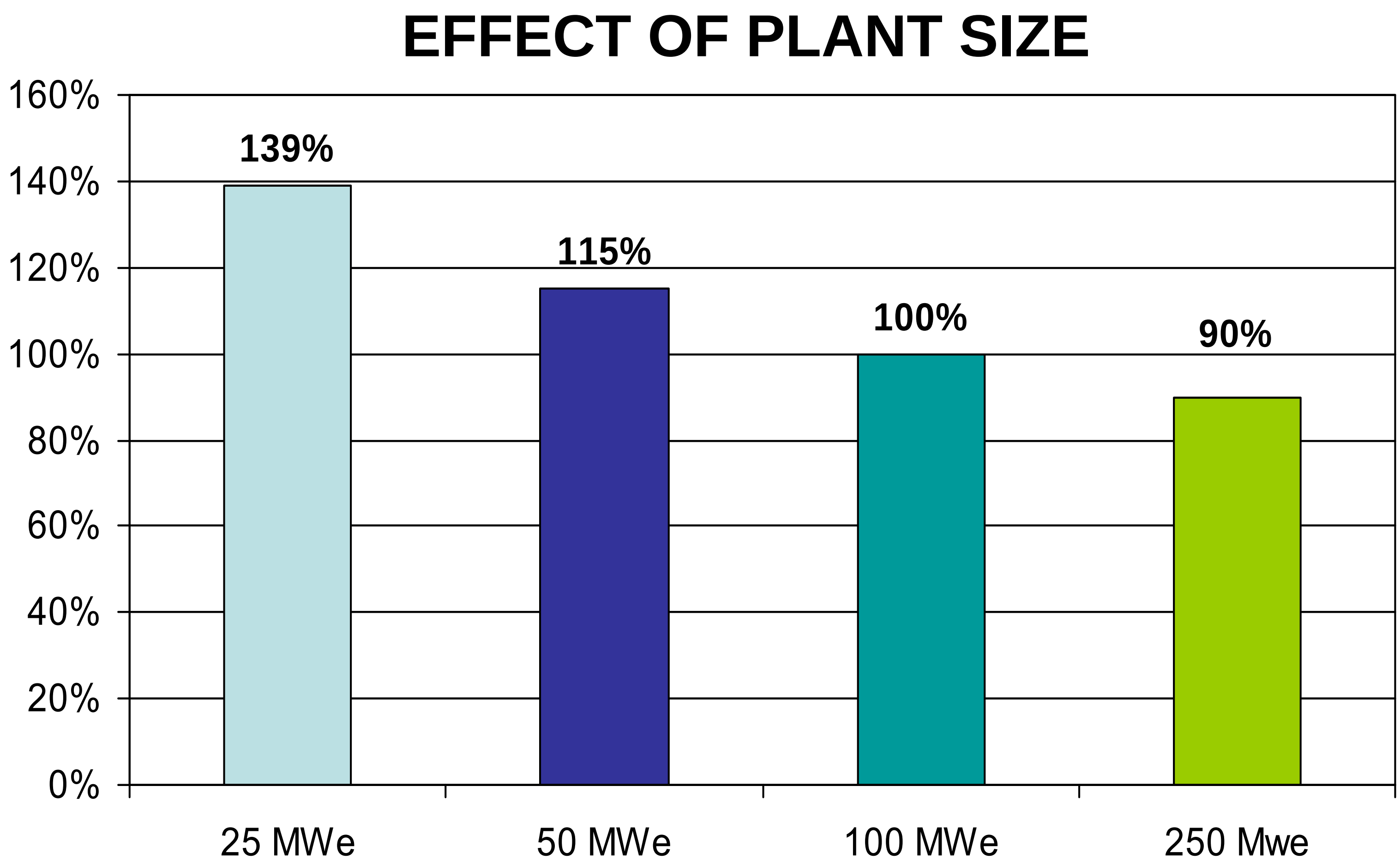
Slide 56

Issue: CSP Cost

Currently CSP projects have a higher cost than other renewable generating technologies or even conventional fossil generators, though they are lower in cost than nuclear generation. However, all of these technologies, with the exception of the parabolic trough, are relatively new and are just now gaining momentum in the marketplace. As seen in the previous slides, the number of CSP plants winning contracts has increased significantly, particularly those that incorporate storage. And the size of these plants is increasing also. Both these trends should translate to significant cost reductions over the next five years, assuming the economy improves and financing becomes more available.

Aside from the favorable enabling policies discussed earlier, two factors strongly influence the cost of these technologies: (1) the size of the individual plant; and (2) the total quantity of each technology that is under operation.

PLANT SIZE AND COST



Parabolic trough plant, 6-hour thermal energy storage, IPP financing, 10% ITC

Source: Nexant – NREL

Slide 57

Effect of Plant Size on Installation Cost

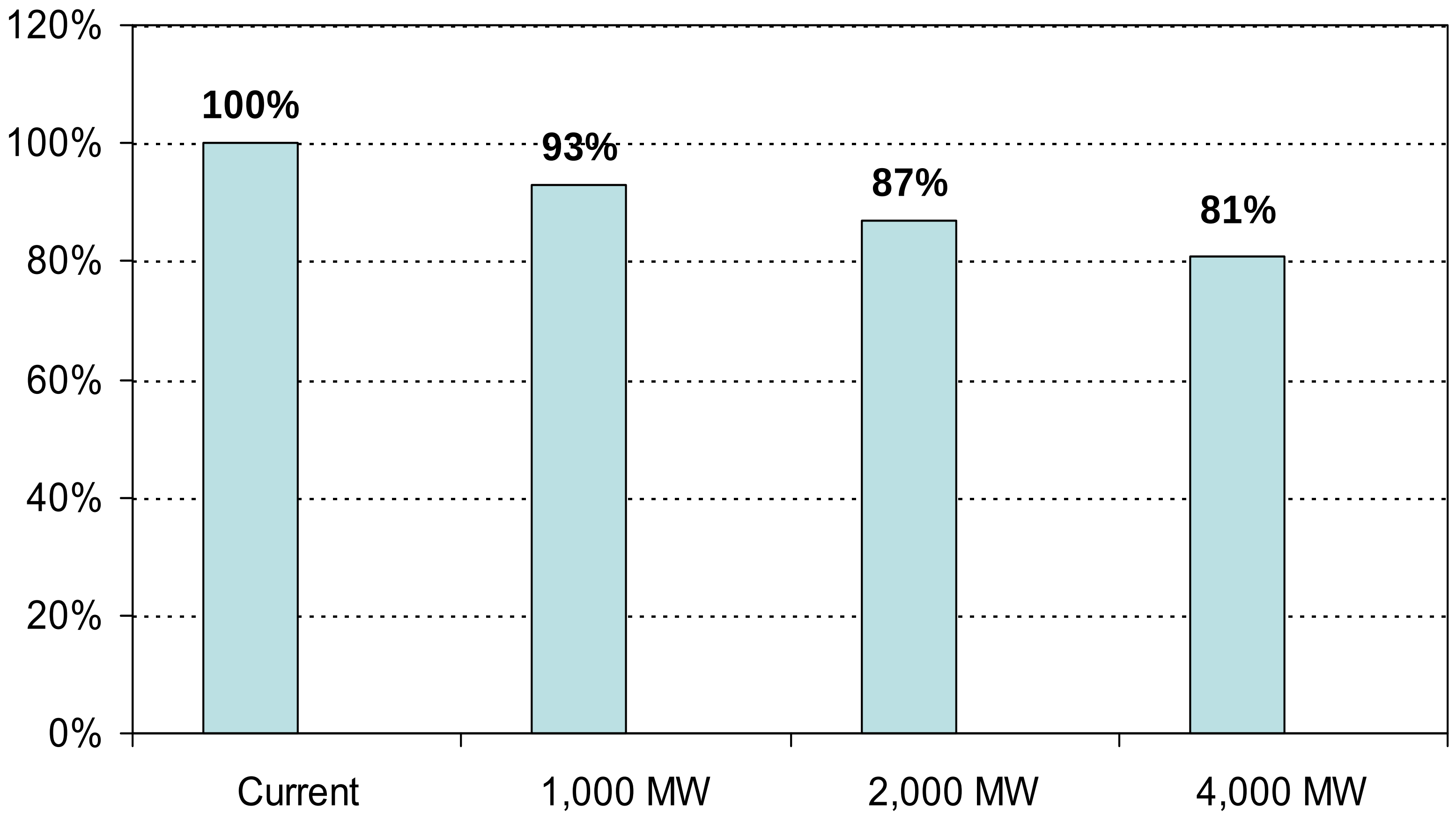
This graph shows the impact of individual plant size on the cost of a parabolic trough plant. Essentially, as the plants get smaller the price goes up due to economies of scale. If the base plant is 100 MW, then a 25 MW plant would cost 39% more per MW, a 50 MW plant would cost about 15% more, and a 250 MW plant would cost 90% less than a 100 MW plant. The lesson learned is to build the plant as large as possible while retaining compatibility with the location, and the size of load to be served.

References

- 131. Nexant Parabolic Trough Solar Power Plant System Size

ESTIMATED COST IMPACT OF MARKET SIZE

EFFECT OF DEPLOYMENT



Based on experience from existing plants (354 MW in California)

Source: NREL

Slide 58

Estimated Cost Impact of Market Size

This graph shows the effect on the cost of building more and more parabolic trough capacity. In 2003, when this analysis was done, only 354 MW of parabolic trough plants were operational. The analysis indicated that moving to 1,000 MW of operational trough plants would reduce costs of the next tranche of plants by 7%, while moving to 2,000 MW of trough plants would reduce costs by 13%. By the time there are 4,000 MW of operational trough plants, the technical learning and industry maturity should reduce costs by 19% compared to what it would be when there was only one-tenth that amount of capacity. This analysis assumed the same technology would be built in the same country by one or multiple companies. However, if the capacity is spread around 10 or more countries the level of benefit might vary. Since no one country or region has more than 700 MW of operational projects we have yet to see if these projections are accurate.

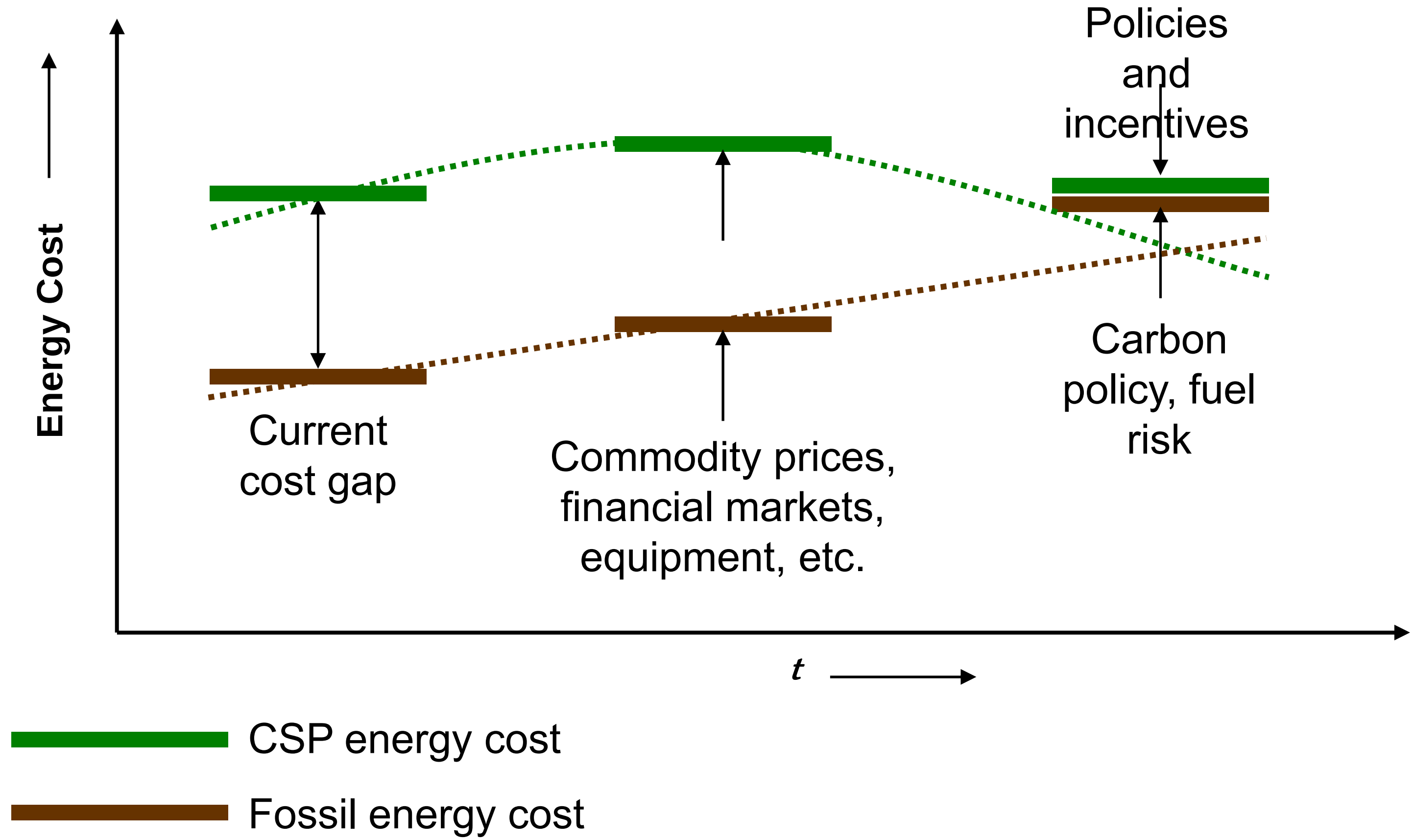
Historical trends in the solar power industry, however, suggest that as more plants (and larger plants) come into the pipeline, significant price benefits are likely to emerge.

References

- 95. NREL – Assessment of Parabolic Trough and Power Tower Solar Technology Costs and Performance Forecasts

IMPACT OF INCENTIVES AND POLICIES

Closing The Gap Between Fossil And CSP-Derived Energy



Source: Kate Maracas, Abengoa Solar

Slide 59

The Effect of Incentives and Policies

CSP-derived energy is approximately 25% more expensive than energy from a fossil plant. Over time, the costs of all generation will probably go up due to increased costs of steel, cement, copper, and other components. However, if you put a price on carbon emissions via a carbon tax or a greenhouse gas cap-and-trade program, the gap will be reduced. If you add an enabling renewable energy policy framework and incentives (like an ITC, PTC, and loan guarantees), the gap will be reduced. This is exactly the direction that energy policy is going in most large economies. Therefore, the cost gap is expected to close over the next decade, dependent on the rate of favorable policy implementation.

Because of the high capital costs of CSP projects, incentives and programs designed to reduce debt interest rates can reduce CSP project costs significantly. Tax incentives are also effective for improving the cost competitiveness of CSP projects. However, the effectiveness of tax incentives is limited by the potential “tax appetite” of investors unless incentives are transferable or refundable and do not interact unfavorably. The recent US stimulus package allows tax incentives like the ITC and PTC to be transferred or paid as grants. It also includes an improved Federal Loan Guarantee program for renewables. As a result, most of the CSP projects presently under contract in the United States are expected to complete construction and become operational due to these stimulus measures. The electricity consumer will still pay the cost for electricity from these plants but these tax incentives and policy measures help to reduce the effective cost. For example, the loan guarantees reduce the perception of risk at little cost to the government.

NARROWING THE COST GAP

CSP

- ✓ Large-scale projects
- ✓ Global uptake
- ✓ Strong developers
- ✓ Policies & incentives

GAP→

- ➢ Carbon policy
- ➢ Fuel risk

- ✓ Equipment and labor costs
- ✓ Increasing fuel prices
- ✓ Environmental costs

Traditional resources

Source: Barbara Lockwood, APS

Slide 60

Narrowing the Cost Gap

This diagram illustrates another way of looking at how the cost gap for CSP, along with other renewable technologies, is being reduced in the United States. The items listed on both sides of the arrows indicate cost changes that have already happened in the United States. Carbon policy and incorporation of fuel risk premiums are the last elements needed to close this gap.

CSP COSTS, TODAY AND TOMORROW

- Today firm, dispatchable CSP costs 15 to 18¢/kWh
- Could drop to 12 to 14¢/kWh in United States with existing incentives
- Current cost gap – 2 to 5¢/kWh
- Industry projections indicate CSP price could drop to 8¢/kWh (nominal) within the decade

Slide 61

CSP Costs, Today and Tomorrow

Existing incentives in the United States seem on track to bring CSP costs down from current levels, helping to close the 2-5¢/kWh cost gap. This would make CSP technologies more competitive. Over time, projections that CSP technologies could bring further price reductions to 8¢/kWh would help make these technologies attractive to utilities.

One potential unknown factor in these projections is the cost of commodities such as steel, cement, and copper. If those commodities continue to rise in price, that will raise the cost of all generating technologies accordingly.

- Technology Overview
- CSP Economics
- **Technical Issues & Solutions**
- Project Development Flow
- Best Practices

Slide 62

Technical Issues & Solutions

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ISSUE: LAND USE

Filters To Identify Prime Locations For CSP Development

All solar resources

Locations suitable for development

1. Start with solar resource
2. Eliminate locations with <6.75 kWh/m^2/day
3. Exclude sensitive lands
4. Remove land >1% - 3% slope
5. Eliminate areas < 1 km^2

Source: Fred Morse, Abengoa Solar

Slide 63

Issue: Land Use

The amount of land required for CSP projects may be an issue in some countries with very strong environmental laws and siting regulations, since CSP projects require about one square kilometer per 50 MW of output. However, in many equatorial countries with excellent direct solar resources and few other energy resources, land availability for CSP projects may not be an issue. Generally the land is either purchased or, particularly if government owned, leased. Private land could be leased with a royalty as it is for wind projects but to date this option has not been used for large solar facilities.

This slide indicates the basic criteria used to identify prime CSP locations.

- Start with direct normal solar resource estimates derived from 10 km satellite data.
- Eliminate locations with insolation of less than 6.75 kWh/m^2/day as these will have a higher cost of electricity. (Most of Spain does not meet this threshold, but its high feed-in tariff makes less than perfect locations feasible).
- Exclude environmentally sensitive lands, major urban areas, and water features.
- Remove land areas with greater than 3% average land slope.
- Eliminate areas with a minimum contiguous area of less than 1 square kilometer.

Access roads that can accommodate 40 foot-long ocean containers will be necessary for the construction of CSP projects. But given that the land is generally flat, access roads are not usually a significant issue for CSP projects, especially when compared to the requirements for large wind-turbine construction. However, access to high voltage transmission lines is desirable if at all possible (though typically CSP sites are not located close to transmission, which is why new transmission is such an important issue for these plants).

Source:

- Fred Morse, Abengoa Solar

ISSUE: WATER USE

Wet Cooling

- Uses 3.5 m^3 water per MWh
  - **~90%** for cooling
  - The rest used for the steam cycle and washing

One Solution: Dry Cooling

  - Reduces plant water consumption by ~90%
  - Increases the cost of electricity by ~10%

Slide 64

Issue: Water Consumption

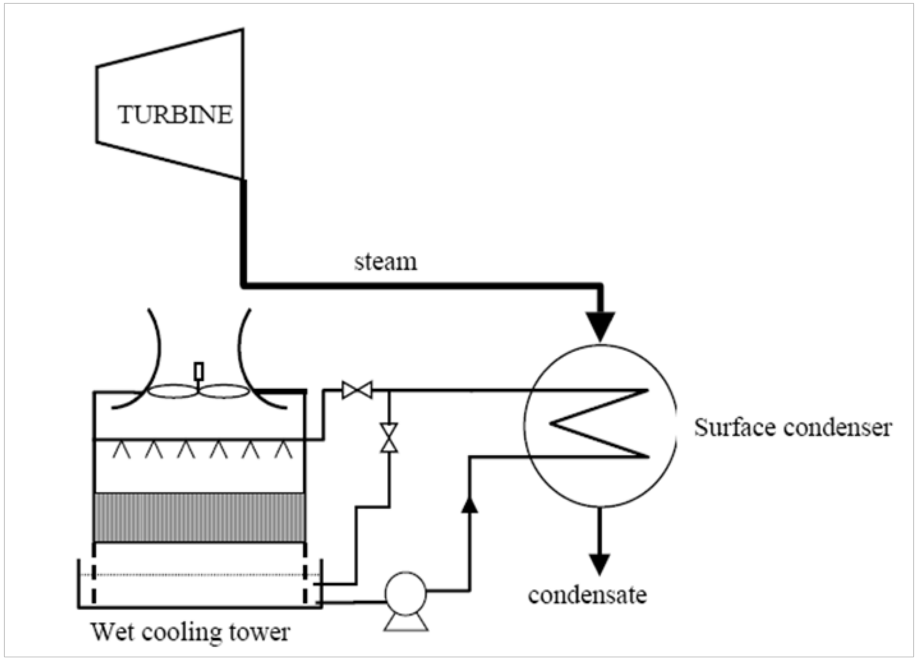
The availability of water to use for cooling parabolic trough or power tower facilities can be an issue in some geographic locations. One solution is to use a dry cooling system rather than a wet cooling system. This change can reduce plant water consumption by almost 90%.

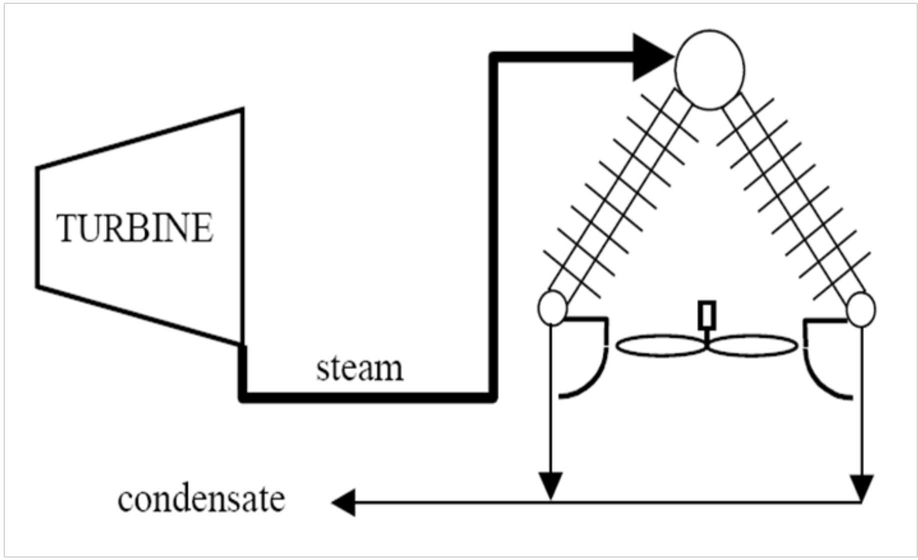
Using a dry cooling system, however, lowers the efficiency of the plant (e.g., its net output) by 5%, especially during hot periods, and also increases capital costs by 5%. As a result, the cost of electricity from dry-cooled plants is approximately 10% higher than for wet plants. The following slides discuss alternative cooling methods in greater detail.

References

- 133. CEC/EPRI – Comparison of Alternate Cooling Technologies

WET VS. DRY COOLING TECHNOLOGY





Wet cooling

Dry cooling

Source: EPRI

Slide 65

Wet vs. Dry Cooling Technology

For Rankine-cycle plants, cooling systems are required to condense the steam at the turbine exhaust and to maintain the desired turbine back pressure. For a given ambient temperature and humidity, the size and effectiveness of the cooling system determines how low a condensing temperature can be maintained for a specified water flow. Wet systems use ocean, river, or pumped aquifer water in a mechanical draft wet cooling tower to perform this function.

Water requirements for a trough system depend on the design and configuration. If wet cooling is used, water consumption is about 2.8 m^3/MWh, similar to conventional steam plants. In addition, about 0.14 m^3/MWh of water is needed for washing the solar field. Dry cooling reduces water consumption drastically, but also reduces performance and increases cost. *So the tradeoff is between water usage and the cost of power*.

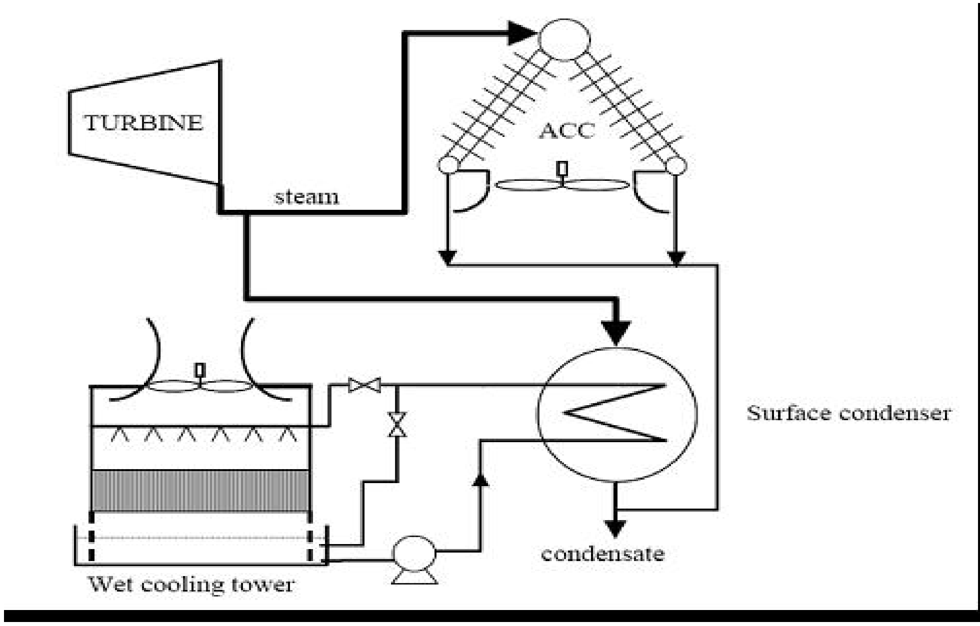
Dish engine systems are air cooled, with water required only for mirror washing and other services.

References

- 133. CEC/EPRI – Comparison of Alternate Cooling Technologies

2nd SOLUTION: HYBRID COOLING

- A “hybrid” mix of wet and dry cooling
- A number of approaches are possible
- Commercially available option
  - Includes both dry and wet cooling towers
  - Relative size of wet and dry cooling towers determines water use



Slide 66

Hybrid Cooling

A second alternative is a hybrid system that combines wet and dry cooling technologies. In hybrid wet-dry systems, both wet and dry components are included in the system, and they can be used separately or simultaneously for either water conservation or plume abatement purposes. The intent of this combination of wet and dry cooling technologies is to *reduce* the amount of water required for cooling, but not eliminate it entirely. Depending upon system configuration, water consumption can approach that of recirculating wet systems, or be much lower. Design studies have ranged from 20-80% reduction in water use when compared to all wet recirculating systems. Low capital cost hybrid systems have been considered for use during peak load periods of hot weather to provide short-term enhancement of primarily air-cooled systems.

References

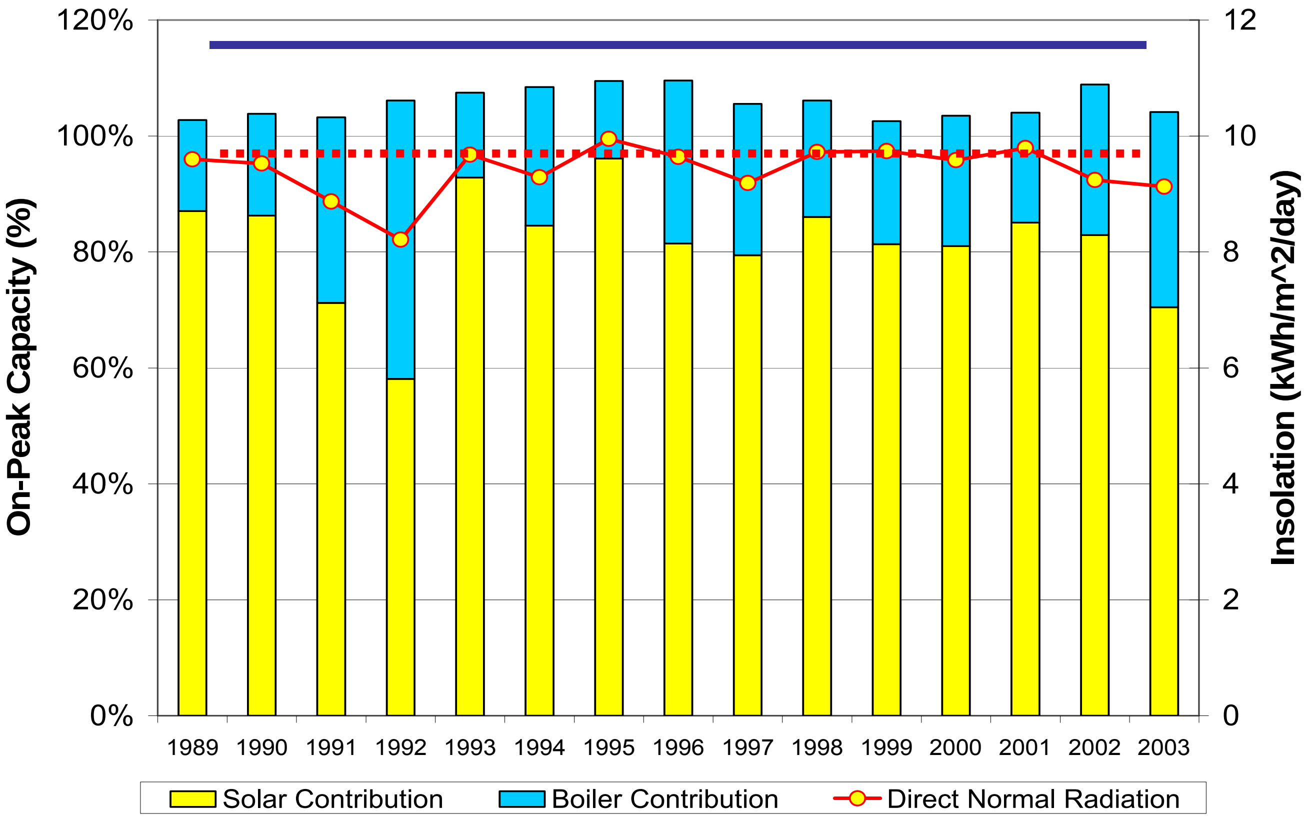
- 133. CEC/EPRI – Comparison of Alternate Cooling Technologies

ISSUE: SOLAR VARIABILITY

SOLUTION – STORAGE

Mount Pinatubo Volcano

CA Energy Crisis



– Averaged 80% on-peak capacity factor from solar
– Over 100% with fossil backup
– Could approach 100% from solar with the addition of thermal energy storage

SCE Summer On-Peak
Weekdays: June - September
12 noon - 6 pm

Source: KJC Operating Company

Slide 67

Issue: Solar Variability

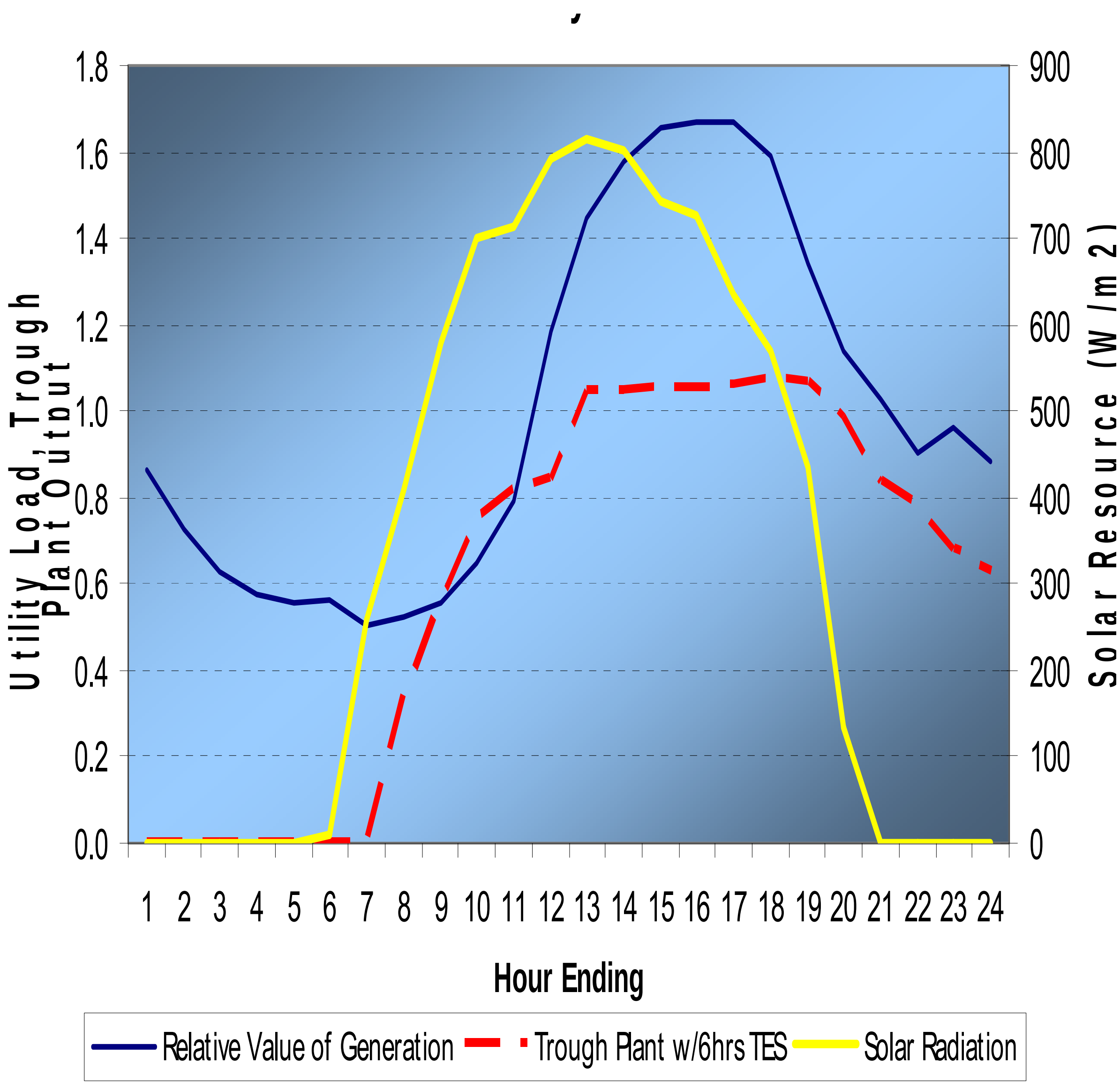
This table shows the summer performance of the solar trough plants located in Southern California and operating since 1989. These plants with 20% natural gas assistance (this is not an ISCCS plant but just a solar assist) averaged 80% on-peak capacity factors from solar and 100% using the fossil backup. However, with the addition of thermal energy storage, the plants could approach 100% from solar operation. (Production went down considerably in 1991 and 1992 due to the eruption of Mount Pinatubo.)

Solar system output in California tends to match the morning and afternoon demand but falls off in late afternoon when demand peaks. Thermal storage permits the collection of solar energy during one period for use at a later time. For example, energy collected in the afternoon could be used to generate electricity in the evening. If the solar field size is enlarged as well, the addition of thermal storage results in a large solar electrical capacity factor for the plant as well.

For thermal storage with trough systems, the preferred technology is a molten-salt two-tank system that provides a feasible storage capacity of 6-12 hours, though currently 6 hours is more common. The molten-salt two-tank system is inherent to the power tower design and can feasibly provide up to 16 hours of high-efficiency storage.

There are no thermal storage options currently available for dish engine systems.

DISPATCHING SOLAR POWER



Generation from solar plant with storage can be shifted to match the utility system load profile

Source: Black & Veatch

Slide 68

Dispatching Solar Power

This slide with data from a New Mexico feasibility report shows graphically how the use of storage can shift the system output to better match the utility's load profile. The load profile is shown by the blue line and the anticipated solar generation by the yellow line. The red line shows how adding storage to the generation output from the CSP plant can shift the output to better match the demand curve. (Note: Other generating units will also be operating at this time so the CSP project does not need to meet the full demand but just match its fluctuations.)

Reference

- 97. Black & Veatch – New Mexico Concentrating Solar Plant Feasibility Study

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ISSUE: NEW TECHNOLOGY RISK

Risk offsetting factors

- Large, multinational corporations are involved in every part of chain
  - Project and technology developers
  - Utilities and independent power producers
  - Engineering and construction companies
- These quality counterparties reduce overall CSP project risk due to their:
  - Large balance sheets
  - Power and construction expertise
  - Strategic technology deployment

Slide 69

Issue: New Technology Risk

CSP technologies are very new. Parabolic trough technology is the oldest with 20 years of operating experience. The other technologies have had no operating experience or on a pilot plant basis only. This lack of a track record can make financing a new technology difficult. However, the hundreds of megawatts of CSP projects that have now been contracted in California, Europe, and elsewhere will soon provide much-needed operational experience. Moreover, participation by large multinational corporations as counterparties to CSP development helps reduce the overall CSP project risk due to their large balance sheets and related power and construction expertise. For example, some current companies active in CSP development include:

Parabolic trough – The primary developers of this technology include Solargenix Energy (USA), Solel Solar Systems (Israel), and Solar Millennium (Germany). Suppliers of components for trough systems include reflector supplier Flabeg (Germany) and receiver suppliers Schott Glass (Germany) and Solel Solar Systems. [Note: For parabolic troughs up to half of the equipment needed for the project can be locally sourced. Primarily the prime mover and receiver tubes need to be imported. See the next slide.]

Dish engine – System developers include SES (USA) for 25 kW units, and SBP (Germany) for 10 kW units.

CSP ADVANTAGES FOR UTILITIES

- Steam technology is well understood
- Utility-scale installations
- Decreasing component costs
- Zero carbon emissions
- Can provide firm dispatchable output

Slide 70

CSP in the Eyes of Utilities

Today, utilities that are adding renewable power are generally favorable toward including CSP technologies in their supply portfolio for a number of reasons:

- The steam portion of these CSP plants is exactly like the steam generation they have worked with for decades; this familiarity is comforting.
- CSP installations can be 100 MW or more per facility, thereby providing a sizeable chunk of power when that is needed by the utility.
- The component costs are generally known and decreasing over time.
- With the exception of ISCCS, CSP plants have zero carbon emissions or emissions of any kind.
- Trough and power tower technologies can provide firm dispatchable energy output prized by most utilities (which means system integration is not a problem).
- With the exception of ISCCS plants, CSP can provide a hedge against natural gas price volatility and carbon caps using an indigenous and reliable resource – the sun.

The negative attributes of CSP projects in the eyes of a utility are:

- Cost – they are more expensive than fossil options if fuel cost volatility and environmental impacts are not taken into consideration.
- Short-term ratepayer impacts (due to high investment costs; long-term, CSP projects should be very beneficial to ratepayers).
- These projects tend to be owned and operated by IPPs, though utilities generally prefer to own and operate all generation facilities themselves.

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ADVANTAGES OF CSP FOR INVESTORS

- Scalable
- Return on investment can support favorable equity & debt financing
- Long-term source of clean power

Slide 71

CSP in the Eyes of Investors

Private sector investors are attracted to CSP projects for three main reasons:

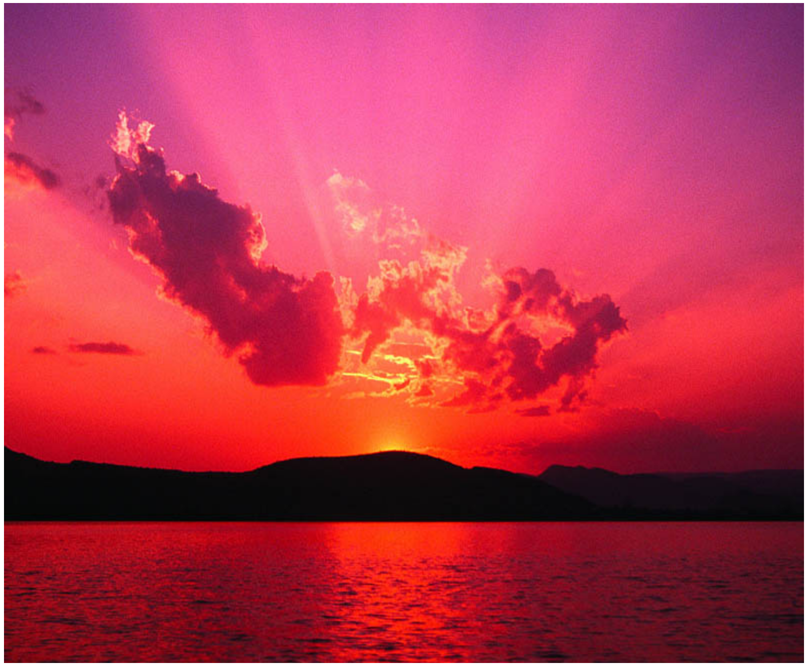
- CSP plants are scalable, meaning that they can be built in a wide range of sizes, expanding the market opportunities for their use.
- With a good PPA, the return on investment is adequate to encourage main-stream equity and favorable debt financing terms.
- Once debt is paid, with the exception of ISCCS projects, CSP plants operate with no fuel and a relatively long plant life offering the potential of becoming a “clean cash cow.”

The primary negative aspect of CSP plants in the eyes of investors is risk:

- The new technology risk
- Not understanding how these technologies work and therefore discounting their benefits
- Resource forecasting risk ±5%

AREAS OF CSP R&D

- Improved thermal storage medium
- Move parabolic troughs to one-tank storage system (improves efficiency)
- Higher temperatures for power towers (results in greater power output)



Slide 72

Areas of CSP R&D

The following three items indicate the evolutionary changes likely to take place over the next five years that could improve the performance of CSP projects. Research is presently underway on all of these technology changes.

- Thermal storage is likely to move from molten salt to an improved media, several of which are presently under investigation.
- Parabolic troughs are likely to move from a two-tank system to a one-tank system, improving efficiency and reducing cost.
- The power tower is likely to move to higher temperatures that could result in greater output at lower costs.

- Technology Overview
- CSP Economics
- Technical Issues & Solutions
- **Project Development Flow**
- Best Practices

Slide 73

Project Development Flow

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CSP PROJECT DEVELOPMENT FLOW

- Resource assessment
- Siting and project feasibility
- Transmission needs assessment
- Secure land rights
- Secure market off-taker
- Secure construction financing
- Determine equipment suppliers
- Finalize O&M agreements
- Finalize economic assessment
- Project construction
- Performance testing
- Convert to long-term financing
- Commence commercial operation

Slide 74

Project Flow

This slide illustrates a sample solar energy project development flow. Resource assessment is a key element for any renewable energy project but is more straightforward and easier for solar projects than for some other types of renewables. Site insolation data can validate the satellite/weather data and makes lenders more comfortable. Transmission needs may be greater for CSP projects because ideal sites are often located long distances from transmission lines. Transmission needs should be carefully studied and evaluated since they can significantly impact the economics of a project.

CSP PROJECT DEVELOPMENT TIME

- Initial activities, some in parallel – 12-34 months
  - Site control
  - PPA negotiation
  - Regulatory approval
  - Interconnection agreement
  - Financial closing – 12-24 months

- Permitting and engineering (in parallel) – 18-24 months
- Construction – 18-24 months

Total time: 4-6 years

Slide 75

CSP Project Development Time

This slide presents a list of the tasks required to bring a CSP plant into operation. The timeframe is based on a CSP plant located in the United States. Some of these activities, such as permitting, may require less time in one country than another. Other activities, like financial closing, will vary dramatically between projects as well. Nonetheless, this slide presents a fairly realistic picture of the time required to bring a new CSP project on-line.

The long project development time for CSP projects, four to six years, rivals that of geothermal projects for several reasons:

- Financing of an international project may take longer than for a domestic project – if the regulatory environment is not stable, financing may never be secured
- The need for specialized mirrors and other equipment that may not yet be commercially manufactured, and must often be shipped long distances, adding to the time requirements
- The time required to permit and construct new transmission lines to deliver the power to load centers can delay plant operation
- Permitting, site control, and regulatory approval may be increased for an international project

A couple of mitigating factors, including a stable regulatory/policy climate and the use of local component manufacturing, can shorten this timeline.

A stable regulatory/policy climate is absolutely necessary to enable the development of generating projects with long construction lead-times. Utilities and project developers must be confident that the regulatory environment critical to the legal status and financial health of the project will not have changed between the initial activities and commercial operation.

Local component manufacturing is another potential way to both reduce cost as well as project development time. If there are a number of CSP projects planned for construction in the same geographic region a local mirror manufacturing facility could be established that could serve the needs of projects in that immediate area, as well as export mirrors to adjacent areas. Steel for frames, metal bending, welding, piping, civil engineering, and labor can all be supplied locally, thus improving the efficiency of the construction process as well as reducing costs and contributing to local economic development. Note that the receiver tubes and power blocks will still probably be imported but they are more easily available and transportable than large mirrors.

CSP COMPARISON CRITERIA

Solar Attributes:	Large PV	CPV	Parabolic Trough	Dish Engine	Power Tower
Quality of solar resource					
Water for cooling					
Thermal momentum					
Storage capability					
Location/demand/size					
Cost					

Slide 76

Criteria for Comparing Large Solar Technologies

The following criteria can be used to evaluate the best solar technology fit for a particular geographic region. It is possible that all five technologies will be applicable, or possibly only one or two. Evaluating the circumstances of a particular location will help narrow the field.

Quality of the Solar Resource – As mentioned earlier, PV facilities can use diffuse sunlight while CSP projects require direct sun. The quality of the solar resource will determine what types of solar technologies are appropriate.

Availability of Water – Is water available for cooling or is water scarce? PV systems (including concentrating PV and Fresnel lens) do not need cooling water, they only need water to occasionally clean the panels. Parabolic trough and power tower CSP systems require significant quantities of water for cooling. However, they can use dry (or hybrid) cooling though this will add about 10% to the cost of the system.

Thermal Momentum – This refers to the ability of the facility to continue generating even when a cloud passes over the sun. Most CSP plants have this ability though PV does not. However, this attribute is only important if cloud cover is a regular issue at the proposed project's location.

Storage Capability – Storage capability is a definite advantage to many utilities. The parabolic trough and power tower technologies both have six or more hours of storage capability. However, the value of this storage depends partly upon the hours of peak demand and the other generation resources on the system. PV systems generally produce their peak output at solar noon while peak output for CSP plants may vary depending upon their design configuration and storage capability. Storage also allows for some dispatchability, which is also considered by many utilities to be a benefit.

Location vis-à-vis Demand – How close is the proposed solar project to demand centers and how large is the proposed solar project compared to the peak load? Small CSP projects in particular cost more. However if a country/utility does not have a load large enough to justify an efficient solar plant the options are to either build transmission so excess power can be exported to another country/utility, or build a smaller project that might cost more/kWh than another type of solar technology.

Cost – The different solar technologies have similar cost structures though they do not all have the same attributes. Therefore, it is important first to identify the attributes you want from the system before looking at the cost.

Once the type of solar technology(ies) appropriate for the quality of a given resource have been assessed, and a suitable plant size determined vis-à-vis demand and other generation resources, other types of attributes can be considered.

PRESENTATION TECHNOLOGY – CSP

- Technology Overview
- CSP Economics
- Technical Issues & Solutions
- Project Development Flow
- **Best Practices**

Slide 77

Best Practices

BEST PRACTICES

- RE policy framework
  - Feed-in tariff, or
  - Mandatory target

  (Need either specific price or target for CSP)
- Enthusiastic utility partner
- Tax incentives
  - Investment tax credit
  - Production tax credit
- Strong loan guarantee program

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Best Practices – CSP

Best practices, from the perspective of enabling CSP, include:

- A well-designed, stable, and predictable policy framework that incorporates either a feed-in tariff with a specific CSP price (such as the one in Spain) or a mandatory target type market policy (RPS/RES) that includes a specific target for solar (such as in New Mexico and Arizona).
- An enthusiastic utility partner is very important for any technology, but particularly for CSP plants, where the utility is the exclusive off-taker.
- In addition to a solid market policy, supplemental tax incentives and a favorable tax structure (e.g., related to property taxes, VAT, import duties) will improve the ability to finance and develop CSP projects.
- An important supporting policy is a loan guarantee program that can be provided either by the local government or can be created and supported by a multilateral lending institution. Loan guarantee programs can make the difference between obtaining financing or not obtaining financing for a CSP project. It will also reduce or eliminate the risk premium for that financing.