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Concentrating Solar Deployment System (CSDS) – A New Model for Estimating U.S. Concentrating Solar Power (CSP) Market Potential

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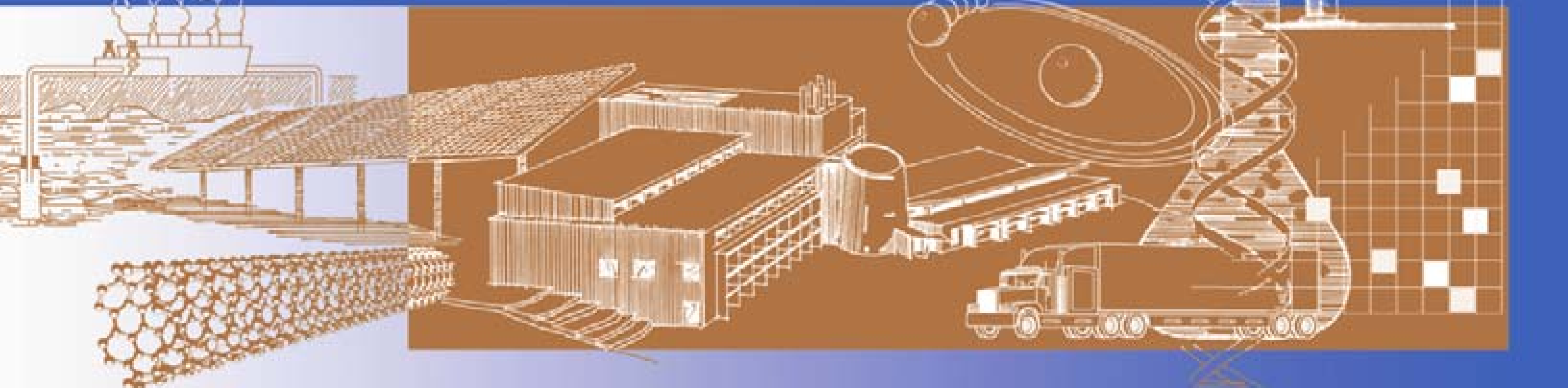

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Concentrating Solar Deployment System (CSDS) – A New Model for Estimating U.S. Concentrating Solar Power (CSP) Market Potential

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ABSTRACT

This paper presents the Concentrating Solar Deployment System Model (CSDS). CSDS is a multiregional, multitime-period, Geographic Information System (GIS), and linear programming model of capacity expansion in the electric sector of the U.S. CSDS is designed to address the principal market and policy issues related to the penetration of concentrating solar power (CSP) electric sector technologies. This paper discusses the current structure, capabilities, and assumptions of the model. Additionally, results are presented for the impact of continued research and development (R&D) spending, an extension to the investment tax credit (ITC), and use of a production tax credit (PTC).

CSDS is an extension of the Wind Deployment System (WinDS) model created at the National Renewable Energy Laboratory (NREL). While WinDS examines issues related to wind, CSDS is an extension to analyze similar issues for CSP applications. Specifically, a detailed representation of parabolic trough systems with thermal storage has been developed within the existing structure.

1. BACKGROUND and MODEL OVERVIEW

CSDS is a computer model of expansion of generation and transmission capacity in the U.S. electric sector spanning the next 50 years. It minimizes system-wide costs of meeting loads, reserve requirements, and emission constraints by building and operating new generators and transmission in each of 26 two-year periods from 2000 to 2050. CSDS is focused on addressing the market issues of greatest significance to renewables – specifically issues of transmission and resource variability.

CSDS attempts to examine these issues, primarily by using a much higher level of geographic disaggregation than other models. Other models – such as the National Energy Modeling System (NEMS) model used by the U.S. Energy Information Agency – have only a few regions in the U.S. (13 in the case of NEMS). Because of this, these models have to make assumptions about the cost of transmission and resource variability on the electric grid. With a high level of geographic disaggregation, we can model these geographic impacts more directly within the model. CSDS uses 358 different regions in the entire United States. Much of the data inputs to CSDS are tied to these regions and derived from a detailed GIS model/database of the renewable resources, transmission grid, and existing plant data. The geographic disaggregation of solar resources allows CSDS to calculate transmission distances and the benefits of dispersed solar plants supplying power to a demand region.

For CSP, a certain level of average radiation is needed before the resource can be considered to be viable. In the United States, those viable resource areas are located primarily within the southwestern states. Therefore, in the CSDS model, this subset of regions is the area in which CSP solar plants are allowed (Fig. 1). This reduction in the number of regions significantly reduces the run-time requirements of the CSDS additions to WinDS, as well as the amount of solar GIS inputs. The entire United States is still modeled, and wind power and conventional generation are built as needed throughout the country.

Similar to the model's existing breakdown of wind resource into five standard classes, the solar resource appropriate for CSP systems has also been divided into five classes that are defined by the annual average direct normal radiation. The breakdown by class is:

- Class 1 is 6.75 - 6.99 kW/m2/day
- Class 2 is 7.00 - 7.24 kW/m2/day
- Class 3 is 7.25 - 7.49 kW/m2/day
- Class 4 is 7.50 - 7.74 kW/m2/day
- Class 5 is 7.75 - 8.06 kW/m2/day

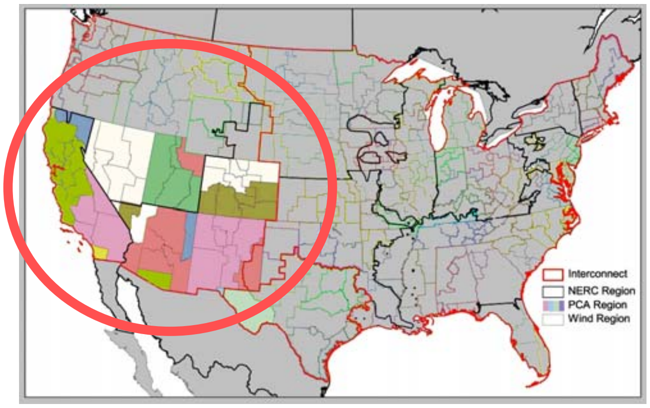

Fig. 1: CSDS Regions are in the southwestern United States

Additionally, there are a variety of exclusions applied to the solar resource if the slope exceeds 1%, average annual radiation is less than 6.75 kWh/m2/day, the area is a major urban or wetland area or a protected federal land. If the remaining resource lands are less than 5 contiguous sq. km, they are excluded.

Fig. 2 maps the location of the solar resource that is used within CSDS, and the CSDS regions are shown by the light gray boundaries.

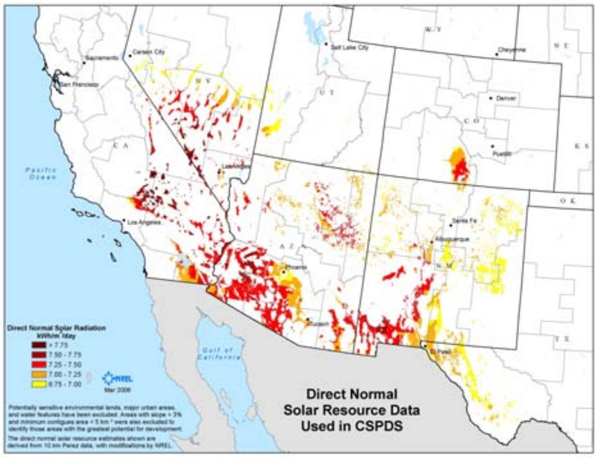

Fig. 2: Solar Resource in CSDS[1]

Linear programs, such as WinDS and CSDS, work by minimizing an objective function. The CSDS objective function is a minimization of all the costs of the U.S. electric sector including:

- the present value of the installation cost and anticipated operating and maintenance (O&M) costs of both generation and transmission capacity (conventional and renewable) installed in each period (each period represents 2 years), plus
- the cost of using the existing transmission grid as represented in the model, plus
- the cost of operating that capacity during the current period (fuel costs) to meet load, plus
- the cost of reserve capacity.

By minimizing these costs while meeting the system constraints (discussed below), the linear program determines (A) at which level to operate the currently installed capacity and (B) which types of new capacity and amount are the most economical to add in each period for each region in the country. Therefore, the capacity factor for each dispatchable technology in each region is an output of the model, and not exogenously defined. Note that hydropower, wind, and CSP are typically operated as much as possible, due to negligible variable cost. Therefore, these technologies operate at the maximum capacity factor possible, based on the resource class or hydro availability.

The cost minimization that occurs within CSDS is subject to more than 70 types of constraints, which result in thousands of equations in the model (due primarily to the large number of regions). These constraints fall into several main categories, including:

- *Resources*: The total amount of CSP installed in each region must be less than the solar resource potentially available – by region and resource class – as estimated by the NREL Resource and GIS teams.
- *Access to existing transmission lines*: The amount of new solar capacity that can be transmitted on existing lines is limited by the transmission capacity available on nearby lines. The GIS portion of CSDS determines which solar resources would be most cost-effective in using existing transmission capacity.
- *Load constraints*: The primary load constraint is that the electric load in each power control area (PCA) – there are 136 power control areas in CSDS for the entire country – must be met in each time slice (of which there are 16) throughout a year. The load and its rate of growth in each North American Electric Reliability Council (NERC) region are derived from the Reference Case of the U.S. Energy Information Agency's *Annual Energy Outlook*[3].
- *Reserve margin constraint*: There are two types of reserves constraints – planning reserve margin and operating reserve. For CSP, in the current version, the amount of storage is assumed to be adequate to provide capacity equal to nameplate capacity during the peak period. In other words, CSP is assumed to be dispatchable. Of course, the cost inputs reflect the larger cost associated with storage (discussed below). For comparison, capacity value for wind power is handled statistically. In each period, CSDS updates the estimate of the marginal capacity value of the next wind farm built in each region using a detailed statistical approach. The approach takes into account the

dispersion of the wind sites contributing to the load and the correlation in the output of those sites. When the ability to model solar-only CSP plants is added to CSDS, an approach similar to wind power's method of estimating capacity value will be used.

- *Operating reserve constraint*: Unlike wind, CSP is currently assumed to be fully dispatchable and, therefore, requires no additional operating reserve.

2. CURRENT CSP SYSTEM ASSUMPTIONS

This paper reports on the first stage of, hopefully, several in the implementation of CSP within the WinDS/CSDS framework. Ideally, the model would compete solar-only, trough with storage, dishes, solar towers, etc. in an economically optimum portfolio. However, this first stage of development limits the situation to a single technology (parabolic trough Rankine cycle, similar to the SEGS plants installed in California) with a preselected thermal storage level (six hours of thermal storage). These factors, combined with an assumed scale of 100 MW plant size, determine the initial cost and performance characteristics. The NREL CSP analysis tool, Excelergy[2], is a Microsoft Excel-based performance and financing tool for parabolic trough systems, with current costs and performance assumptions.

The storage assumption greatly simplifies the treatment of resource variability. Because the plant is assumed to be dispatchable, the capacity value for the plant is assumed to be equal to the capacity factor during the summer peak period, which is essentially the nameplate capacity. Additionally, no operating reserve is necessary for this plant, and surplus is assumed to be negligible due to the alignment of the solar resource and load.

TABLE 1: TIMESLICE PLANT CAPACITY FACTORS

Timeslice	**solar class 1**	**solar class 2**	**solar class 3**	**solar class 4**	**solar class 5**	**Hours**
H1	0.384	0.367	0.381	0.395	0.446	**1152**
H2	0.642	0.769	0.821	0.872	0.855	**462**
H3	0.989	0.974	1.020	1.065	1.066	**264**
H4	0.831	0.732	0.794	0.856	0.920	**330**
H5	0.274	0.199	0.229	0.259	0.276	**792**
H6	0.535	0.661	0.677	0.694	0.740	**315**
H7	0.900	0.894	0.890	0.887	0.978	**180**
H8	0.405	0.402	0.401	0.399	0.558	**225**
H9	0.115	0.111	0.106	0.102	0.122	**1496**
H10	0.259	0.326	0.326	0.326	0.327	**595**
H11	0.502	0.581	0.560	0.540	0.542	**340**
H12	0.035	0.047	0.040	0.034	0.031	**425**
H13	0.330	0.313	0.328	0.343	0.327	**1144**
H14	0.640	0.716	0.730	0.745	0.708	**455**
H15	0.947	0.935	0.973	1.010	0.950	**260**
H16	0.742	0.684	0.703	0.722	0.736	**325**
Average	**0.409**	**0.413**	**0.427**	**0.442**	**0.457**	

Excelergy was also used outside of CSDS to determine the performance of the assumed system for a variety of locations, representing all five solar classes. For each location, the hourly output of Excelergy was aggregated into the 16 timeslices within CSDS to determine the average capacity factor for each timeslice of the year, for each solar class (Table 1). For this analysis, it was conservatively assumed that these capacity factors (i.e. solar plant performance) were unchanged in the future. In reality, it is expected that these would improve through R&D and shared operational improvements.

3. BASE-CASE ASSUMPTIONS AND RESULTS

In this analysis, the Base Case is a business-as-usual case that relies heavily on the Reference Case scenario of the U.S. Energy Information Agency *Annual Energy Outloo*k (AEO) for 2005 for inputs that fall outside the scope of CSDS. The single deviation from the AEO 2005 is the price of natural gas going forward; which, for CSDS, is based instead on the California Market Price Reference (CA MPR).[4] Although partly based on the EIA projections, the CA MPR reference is significantly higher. It was determined that this reference was more reflective of the market in the southwestern United States. As with the U.S. EIA's AEO, this price trajectory will change each year.

Based on the 2005 DOE Solar Program Multiyear Technology Plan,[5] we assume that 54% of the cost improvements projected by DOE will occur through R&D (Table 2). In addition to the improvements over time shown in Table 2, CSDS also allows for "learning" improvements in the cost values. For each doubling of installed worldwide CSP capacity (a scenario of CSP installations outside the United States reaching 120 GW by 2040 is input), there is an 8% reduction in costs.

TABLE 2: R & D-DRIVEN COST AND PERFORMANCE

Solar class	Year	Capacity Factor	Capital cost	Fixed O&M	Var O&M
		-	1000$/MW	1000$/MW-	$/Mwh
1	2005	0.409	4865	5.83	2.54
1	2030	0.409	2832	5.83	0.55
1	2050	0.409	2554	5.83	0.50
2	2005	0.413	4865	5.83	2.52
2	2030	0.413	2832	5.83	0.55
2	2050	0.413	2554	5.83	0.50
3	2005	0.427	4865	5.84	2.46
3	2030	0.427	2832	5.84	0.53
3	2050	0.427	2554	5.84	0.48
4	2005	0.442	4865	5.84	2.39
4	2030	0.442	2832	5.84	0.52
4	2050	0.442	2554	5.84	0.47
5	2005	0.457	4865	5.84	2.33
5	2030	0.457	2832	5.84	0.51
5	2050	0.457	2554	5.84	0.46

With these Base Case inputs, CSDS projects that solar power will provide about 55 GW of capacity in 2050, far larger than today's 350 MW (see top slice of graph in Fig. 3). Although this growth is largely attributable to improvements in the cost and performance of solar power plants, there are many other drivers. By about 2014, the increase in natural gas prices (as forecast by the CA MPR) stalls the recent growth in new installations of combined-cycle, natural gas-fired power plants (fourth slice from the bottom). At about the same time, installations of advanced coal plants surge and dominate the new-build market until 2050 (seventh slice from the bottom – "Coal-new").

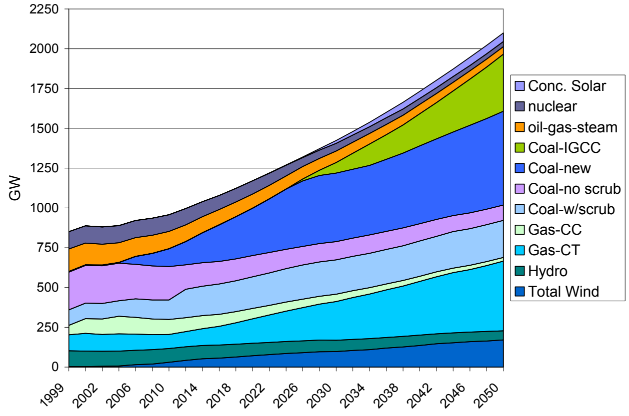

Fig. 3: National Capacity Projections for the Base Case

The dominance of new coal plants in the new capacity market of the second quarter of the 21st century is dramatic. Unlike natural gas power plants, the fuel for these coal plants is expected to remain relatively inexpensive, leaving no room for renewable energy to penetrate the market as a fuel saver. Likewise, sulfur dioxide and NOx emissions from new advanced coal plants are almost an order-of-magnitude less than today's average existing coal plant, limiting the advantage of renewable energy for emission caps. However, a carbon tax or CO_2 limit would have a dramatic impact on the growth of renewable energy and energy efficiency.

Fig. 4 depicts the modeled growth in future CSP capacity by solar class. As expected, the best solar resource is used first and used the most by the model. However, the solar Class 5 resource is not completely deployed before solar Classes 4 and 3 (to a much lesser extent) begin to be deployed in the model. This is primarily due to transmission distance and load growth within the local region in which the solar resource exists. In other words, a lower-class solar resource close to the load is more economic, in some cases, than a better solar resource much farther from the load.

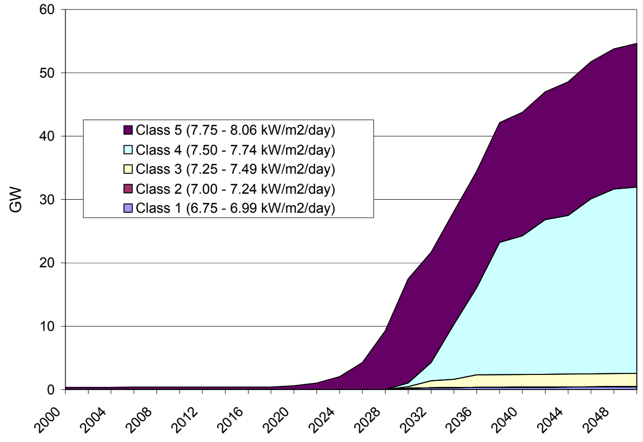

Fig. 4: CSP Base Case Penetration by Solar Class

Fig. 5 depicts the CSP capacity growth by the method of transmission. "Existing Grid between Regions" indicates that the model pays some price to build a line to the existing grid and uses some fraction of the existing grid capacity to get out of the region to satisfy load in another region or PCA. "Used for In-region Load" indicates that the power produced by the solar plant is used to satisfy load within the same region as the solar capacity, and only local distribution transmission is necessary. Finally, "New Grid Lines between Regions" indicates that a dedicated line only for that CSP capacity is built from one region to another (which might be quite some distance away). For the CSDS Base Case, the CSP solar power initially is used to satisfy load within the region. This is typically the cheapest method of transmission. Second, the existing grid is used to transmit the power. Often, this is just a short distance to adjoining regions with much larger load. For example, the solar region east of Los Angeles transmits power to be used in the Los Angeles region itself.

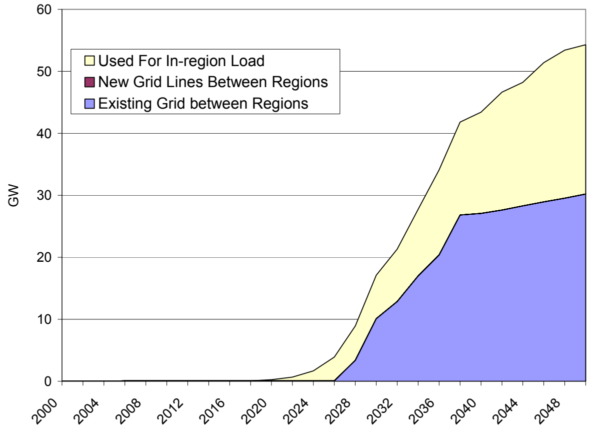

Fig. 5: CSP Capacity Growth by Transmission Type

Another interesting question of deployment, which can be answered by CSDS, is where the future CSP capacity will be located. Based on the GIS inputs to CSDS, transmission, siting issues, and load location and load growth, the model selects the economically best sites for each period to add new capacity. Fig. 6 shows the location of CSP capacity in 2050. As expected, the regions with the greatest deployment level have excellent solar resource or are close to large electric-load growth (such as in southern California).

Fig. 6: CSP Capacity deployment by region in 2050

4. SENSITIVITY CASES FOR FEDERAL POLICIES

We examined three federal policies including continued research and development (R&D), extension of the current 30% investment tax credit and switching to use of a production tax credit. We present results from each below.

4.1 Continued R&D for Concentrating Solar Power

As stated above, the primary reason for the surge in CSP capacity in the Base Case is the anticipated improvements in costs and performance. Fig. 7 compares the projected deployment of CSP in the Base Case with a case in which there are no R&D-driven improvements in solar plant costs – the costs are the same costs as today throughout time. By 2050, the total CSP deployed in this no-R&D case is only 831 MW, or less than 2% of the Base Case installations. Although both cases include improvements due to learning, the absence of the R&D improvements precludes the installations that could lead to significant learning-based cost/performance improvements.

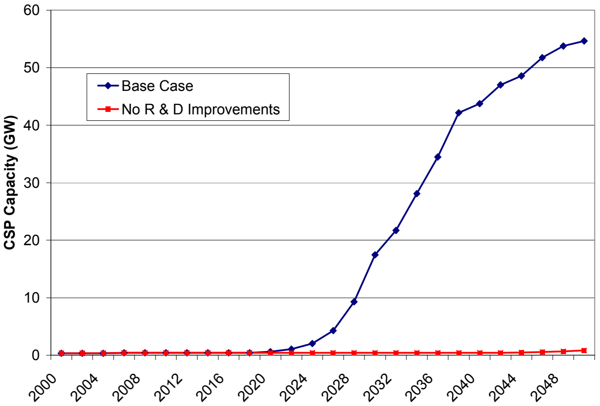

Fig. 7: CSP Capacity Expansion with and without technological improvements

Research and development improvements are just one method for lowering the cost of CSP. There are other policy and engineering methods for lowering these costs. Instead of trying to model each of these cost-reduction techniques, another methodology is to simply lower the total “cost trajectory” through time. In other words, we can take the Base Case solar cost trajectory and lower it by a certain percentage. Fig. 8 demonstrates the impact of lowering the cost incrementally up to 40% of the Base Case cost trajectory. This shows that a reduction in cost of 50% throughout time causes the initial penetration of CSP to move forward in time by roughly 10 years. If the cost trajectory is reduced by 50%, roughly 32 GW of CSP capacity are installed by 2020 vs. less than 1 GW for the Base Case.

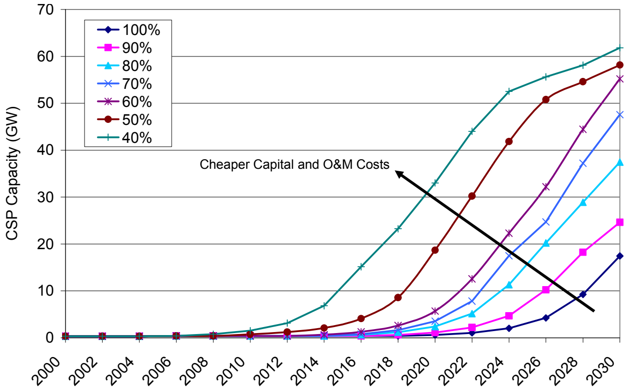

Fig. 8: Cost Reduction Impact on Capacity Penetration

4.2 Extension of the Investment Tax Credit

The Energy Policy Act of 2005 added a 30% investment tax credit until 2007 on top of the existing permanent 10% investment tax credit for solar power. There are several reasons for extending the 30% ITC far past the current 2007 expiration date. The lead time for a CSP plant is long enough that a 2-year window on the ITC does not allow enough project development time to take full advantage of the ITC. Therefore, to provide financial stability in the industry and adequate development time to keep costs low and the supply chain efficient, we examined what the impact would be on extending the investment tax credit to a timeframe commensurate with utility-scale power.

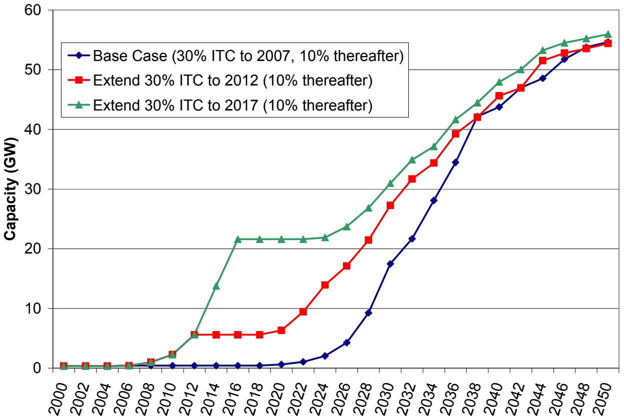

Fig. 9: Impact of Investment Tax Credit Extension

As shown in Fig. 9, continuing the ITC to 2017, as recommended by the Western Governors' Association solar taskforce, will significantly increase CSP capacity through the end of the simulation period. However, as might be expected, with continued R&D-driven improvements in solar power plants and increasing fossil fuel prices, after 30 years, the amount of CSP capacity installed is less dependent on the ITC extension, and that effect starts to be damped out. Two counteracting forces lead to this result. The first, and more obvious, is that increased deployment leads to improved CSP cost/performance through learning. The second is that the best solar sites are used quickly in the ITC extension cases, leaving only lower-quality sites once the ITC has expired. However, in the Base Case, the better sites are not used until later, allowing the installations in the Base Case to start bridging the gap with those of the ITC-extension cases.

These results might lead one to question the rate of growth in the CSP industry during the ITC period. These growth rates seem extreme in comparison to the current capacity. The CSDS model does contain a growth penalty such that if the growth is greater than 20% in any year from the prior year, a penalty is paid by the model to build this capacity. However, this level of capacity growth is not without precedent. The growth in the recent upsurge in natural gas-combustion turbine power plants was more extreme with the addition of 62 GW in 2002 alone, and significantly less since that year.

4.3 Impact of a Production Tax Credit

Another federal policy that is available to CSP is the production tax credit (PTC). This policy tool has been a major driver for wind industry growth in the United States in recent years. In WinDS, a PTC extension greatly increases the amount of wind deployment during the intervening years. However, as Fig. 10 shows, this is not the case with CSP – at least at the current federal PTC level of 1.8 cents/kWh. Because the current costs of CSP are considerably higher than wind, this PTC is inadequate to generate significant growth in excess of the Base Case in the near term. In fact, having a PTC only – and losing the permanent 10% ITC – significantly reduces the amount of CSP throughout time. If the PTC is extended to the end of the simulation period (2050), the amount of installed capacity is initially lower than the Base Case, but then higher than the Base Case after 2038. This increase is because the costs for CSP have decreased significantly through R&D and learning, such that the PTC is more valuable in those years than the ITC.

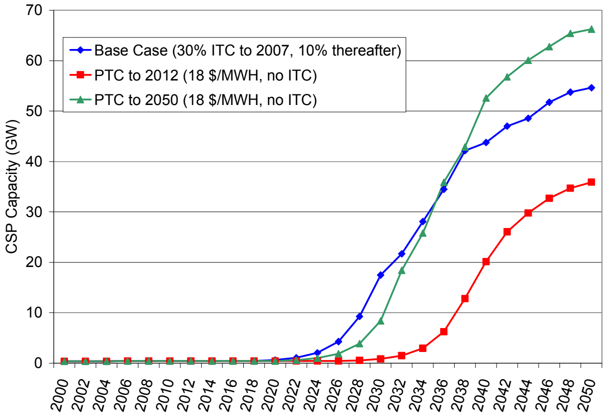

Fig. 10: Impact of a Production Tax Credit instead of an Investment Tax Credit

5. CONCLUSIONS

- A tool has been developed to model the future capacity growth of CSP trough systems that can be used to examine various cost and policy scenarios, while more accurately accounting for transmission needs.
- CSP will contribute a significant share of future U.S. electric generation in our Base Case scenario.
- Increased research and development leading to further reductions in cost are vital to the eventual penetration of CSP into the electric sector.
- CSP deployment is very sensitive to cost, because the resource is concentrated and relatively close to load centers. Appropriate incentives are necessary to help ensure a more sustained technology expansion.

- Extending the investment tax credit past 2007 will dramatically increase the generation from solar power, and should help to ensure a growing U.S. solar power industry, as well as support local economies and job markets.
- Implementing a production tax credit for CSP similar to the PTC for wind power has a minimal or negative impact on CSP deployment, until costs have come down to make the PTC a major portion of the cost.

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14. ABSTRACT *(Maximum 200 Words)*

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15. SUBJECT TERMS
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