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MODELING THE IMPACT OF STATE AND FEDERAL INCENTIVES ON CONCENTRATING SOLAR POWER MARKET PENETRATION

Nate Blair,[*] **Walter Short, Mark Mehos**

Senior Energy Analyst, Principal Researcher, CSP Program Manager

National Renewable Energy Laboratory, 1617 Cole Boulevard, Golden CO 80401
303-384-7426, nate_blair@nrel.gov

ABSTRACT

This paper presents methodology and results from the **Re**gional **E**nergy **D**eployment **S**ystem Model (**ReEDS**) examining the ability of concentrating solar power (CSP), other renewables, and electricity storage to contribute to the U.S. electric sector.

ReEDS is a multiregional, multi-time-period, geographic information system (GIS), and linear programming model, designed to address the principal market issues related to the penetration of renewable energy technologies into the electric sector over the next 50 years. These issues include transmission cost/access and the intermittency of solar and wind power. ReEDS examines these issues using a highly discrete regional structure, renewable resource variability, and consideration of ancillary services requirements and costs.

The model was exercised in a business-as-usual scenario that doesn't require any renewable deployment, a second scenario that represents an implementation of current state renewable portfolio standard (RPS) requirements, and a third scenario with a federal renewables requirement. For the years to 2050, the amounts of national generation capacity by technology as well as the emission levels in each scenario are presented. Additionally, the regional deployment of CSP is also examined and presented.

1. Background and Model Overview

The Regional Energy Deployment System (ReEDS)[1] 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. ReEDS is focused on addressing the market issues of greatest significance to renewables.

ReEDS attempts to examine these issues primarily by using a much higher level of geographic disaggregation than other models. Most other models – such as the National Energy Modeling System (NEMS) used by the U.S. Energy Information Agency – have only a few regions in the United States (13 in the case of the NEMS electric sector). Because of this, these models cannot adequately represent transmission and renewable energy resource spatial diversity. With a high level of geographic disaggregation, we can model these distance effects directly within the model. ReEDS uses 358 different regions in the entire United States. Much of the data inputs to ReEDS 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 ReEDS to calculate transmission distances and the benefits of dispersed solar plants supplying power to a demand region.

Concentrating solar power troughs (the technology currently included in ReEDS) are most economic in those regions with a high level of direct beam radiation. In the United States, viable resource areas are located primarily within the southwestern part of the United States. Therefore, to minimize model complexity. GIS data requirements,

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[1] ReEDS is an extension and compilation of the Wind Deployment System (WinDS), Concentrating Solar Deployment System (CSDS), and Hydrogen Deployment System (HyDS) models developed at NREL.

and run time, CSP installations in ReEDS are limited to the Southwest as shown in Figure 1. Figure 1 also shows that the electric grid for the entire country is modeled, and wind power and conventional generation are built as needed throughout the country.

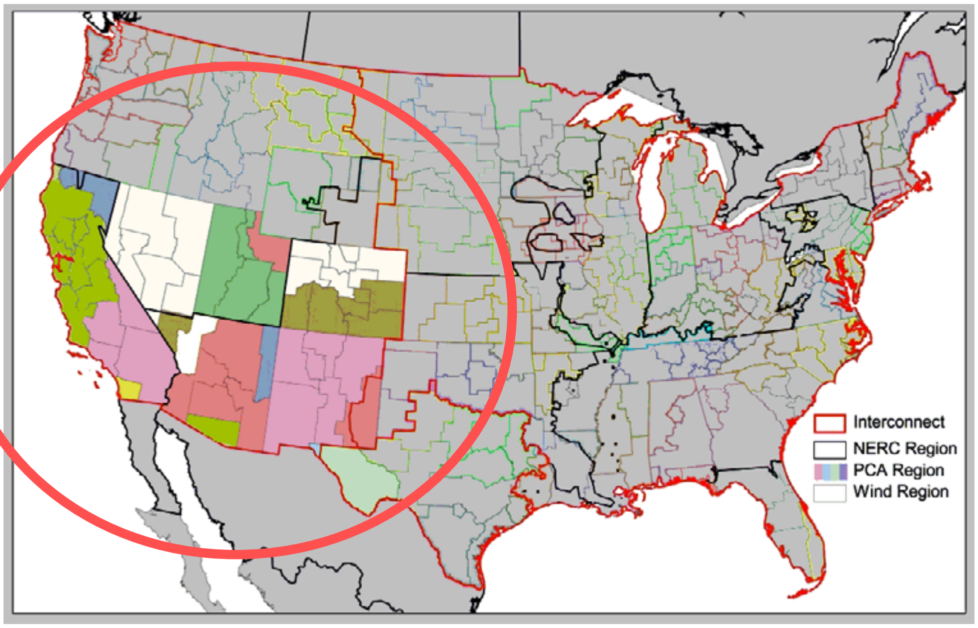

Figure 1. ReEDS regions in which CSP can be built are only in seven southwestern states

As shown below, the solar resource appropriate for concentrating solar power systems has been disaggregated into five classes that are defined by the annual average direct normal radiation.

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

Additionally, there are a variety of exclusions applied to the solar resource areas. The following areas are excluded:

1) Areas that have less than 6.75 kWh/m2/day annual average direct normal resource (May 2003 Perez data)
2) Areas with average terrain slope greater than 1%
3) Major urban areas and water features
4) Protected federal lands (wilderness, parks, monuments, etc.).
5) Areas with less than 5 contiguous sq. km.

Linear programs, such as ReEDS, work by minimizing an objective function. The ReEDS 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 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 and ancillary services.

By minimizing these costs while meeting the system constraints (discussed below), the linear program determines (A) at what level to operate the currently installed capacity and (B) which types and how much new capacity 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. Non-dispatchable technologies with negligible variable operating costs are assumed to operate at their maximum availability. Hydroelectricity dispatch is limited in ReEDS by the availability of water.

The cost minimization that occurs within ReEDS 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**
- **Access to existing transmission lines**
- **Load constraints**
- **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 (as discussed below). Conversely, for wind power, ReEDS estimates the marginal capacity value of the next wind farm built in each region using a detailed statistical approach in each period. The capacity value is set equal to the amount of load that could be added – along with the wind – without changing the risk of a shortage in generation capacity at peak load times.
- **Operating reserve constraint:** This constraint ensures that there are adequate operating reserves – spinning, quick-start, and interruptible loads – for reliable system operation. CSP with storage is assumed to be fully dispatchable and, therefore, requires no additional operating reserve. Wind power adds to the operating reserve requirement, and wind resource availability varies independently of load and other generators' availability. Thus, the additional operating reserve required by wind is calculated from the variance in the sum of the normal operating reserve and the wind generation.
- **Wind or Solar Surplus:** During extreme off-peak demand hours, high penetrations of non-dispatchable technologies such as wind could generate more power than is needed. In the current implementation of CSP, it is assumed that there is no surplus power generation. Again, due to the assumption of storage plus the favorable diurnal alignment of solar resource and peak load, this is an appropriate assumption. If a solar-only CSP plant were modeled with the associated resource variation, the possibility for surplus is present. However, this is not as significant as it is for wind, because the lowest loads are typically at night when the wind can blow but, obviously, the solar plant will not have output. For wind, ReEDS uses the variance of the sum of all wind generation together with a load duration curve and the forced outage rates of conventional technologies to stochastically compute the expected amount of wind that cannot be used. This can be done for solar but should not be a significant impact unless CSP were providing a very significant fraction of total U.S. generation.

2. Current CSP System Assumptions

Currently, the representation of CSP in the model is limited to a single technology (parabolic trough Rankine cycle similar to the SEGS plants 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 performance assumptions. The basic plant configuration and operating assumptions were based on Excelergy.

The CSP storage assumption greatly simplifies the treatment of resource variability. Because the plant is fully dispatchable during the peak period, the capacity value for the plant is essentially the nameplate capacity.

Excelergy was also used outside of ReEDS 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 seasonal/diurnal timeslices within ReEDS 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.,

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[2] Price, H. (2003). Parabolic Trough Solar Power Plant Simulation Model: Preprint. 12 pp.; NREL Report No. CP-550-33209.

solar plant performance) were unchanged in the future. In reality, it is expected that these would improve through R&D and shared operational improvements.

TimeSlice	Solar Class 1	Solar Class 2	Solar Class 3	Solar Class 4	Solar Class 5	Season	Time
H1	0.384	0.367	0.381	0.395	0.446	Summer	weekends plus 11PM-6AM weekdays
H2	0.642	0.769	0.821	0.872	0.855	Summer	weekdays 7AM-1PM
H3	0.989	0.974	1.020	1.065	1.066	Summer	weekdays 2PM-5PM
H4	0.831	0.732	0.794	0.856	0.920	Summer	weekdays 6PM-10PM
H5	0.274	0.199	0.229	0.259	0.276	Fall	weekends plus 11PM-6AM weekdays
H6	0.535	0.661	0.677	0.694	0.740	Fall	weekdays 7AM-1PM
H7	0.900	0.894	0.890	0.887	0.978	Fall	weekdays 2PM-5PM
H8	0.405	0.402	0.401	0.399	0.558	Fall	weekdays 6PM-10PM
H9	0.115	0.111	0.106	0.102	0.122	Winter	weekends plus 11PM-6AM weekdays
H10	0.259	0.326	0.326	0.326	0.327	Winter	weekdays 7AM-1PM
H11	0.502	0.581	0.560	0.540	0.542	Winter	weekdays 2PM-5PM
H12	0.035	0.047	0.040	0.034	0.031	Winter	weekdays 6PM-10PM
H13	0.330	0.313	0.328	0.343	0.327	Spring	weekends plus 11PM-6AM weekdays
H14	0.682	0.702	0.719	0.735	0.719	Spring	weekdays 7AM-1PM, 6PM-10PM
H15	0.947	0.935	0.973	1.010	0.950	Spring	weekdays 2PM-5PM
H16	0.989	0.974	1.020	1.065	1.066	Superpeak	weekdays 2PM-5PM

Table 1. Seasonal and diurnal resource impacts on CSP plant capacity factors

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 (EIA) Annual Energy Outlook (AEO) for 2007.[3] In particular, electricity demand and fossil fuel prices are taken from the AEO2007 Reference Case. Conventional technology (such as coal, gas, and nuclear) cost and performance values were from an upcoming report by Black and Veatch in conjunction with the U.S. Department of Energy (DOE) and the American Wind Energy Association on a vision for future wind power industry growth. The source for parabolic trough cost and performance data is from a recent report prepared by Black and Veatch for Arizona Public Service[4] combined with DOE Solar Program Cost Improvements to 2015. Table 3 shows the resulting R&D-driven cost and performance improvements used in ReEDS for the Base Case. Note that the capital cost does not vary by solar class, but the annual capacity factor does (resulting from six hours of thermal storage in this case). Note also that the “Simple LCOE” column doesn’t include any financing or incentives but only costs and performance data. In addition to the R&D-driven cost improvements, the model calculates “learning” improvements due to industry growth and the growing installed capacity base.

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[3] United States Department of Energy, Energy Information Administration, “Annual Energy Outlook 2005,” January 2005, DOE/EIA-0383(2005)

[4] Arizona Renewable Energy Assessment Final Report, Black & Veatch Corporation, http://www.bv.com/resources/energy_brochures/renewables/rsrc_AZ_RenewableEnergyAssessment.pdf

Solar Class	Year	Capacity Factor	Cap cost 1000$/MW	fixed O&M 1000$/MW-	Var O&M $/Mwh	simple LCOE $/MWH
1	2000	0.41	5850	55.7	0.1	15.7
1	2005	0.41	5850	55.7	0.1	15.7
1	2010	0.41	5572	51.1	0.1	14.4
1	2015	0.41	4179	44.6	0.1	12.5
1	2020	0.41	4179	44.6	0.1	12.5
1	2025	0.41	4179	44.6	0.1	12.5
2	2000	0.41	5850	55.7	0.1	15.5
2	2005	0.41	5850	55.7	0.1	15.5
2	2010	0.41	5572	51.1	0.1	14.2
2	2015	0.41	4179	44.6	0.1	12.4
2	2020	0.41	4179	44.6	0.1	12.4
2	2025	0.41	4179	44.6	0.1	12.4
3	2000	0.43	5850	55.7	0.1	15.0
3	2005	0.43	5850	55.7	0.1	15.0
3	2010	0.43	5572	51.1	0.1	13.7
3	2015	0.43	4179	44.6	0.1	12.0
3	2020	0.43	4179	44.6	0.1	12.0
3	2025	0.43	4179	44.6	0.1	12.0
4	2000	0.44	5850	55.7	0.1	14.5
4	2005	0.44	5850	55.7	0.1	14.5
4	2010	0.44	5572	51.1	0.1	13.3
4	2015	0.44	4179	44.6	0.1	11.6
4	2020	0.44	4179	44.6	0.1	11.6
4	2025	0.44	4179	44.6	0.1	11.6
5	2000	0.46	5850	55.7	0.1	14.0
5	2005	0.46	5850	55.7	0.1	14.0
5	2010	0.46	5572	51.1	0.1	12.9
5	2015	0.46	4179	44.6	0.1	11.2
5	2020	0.46	4179	44.6	0.1	11.2
5	2025	0.46	4179	44.6	0.1	11.2

Table 2. Base case R&D-driven CSP costs and performance ($2004)

Because of the large number of regions, the ReEDS model is capable of capturing (as in Figure 2) where the CSP capacity (in MW) is installed. The map in Figure 2 represents the case without any state or federal incentives for deployment in 2050. The CSP capacity is predominantly deployed at locations that are close to major load pockets (such as Phoenix and Los Angeles) and also have class 5 solar resource. The majority of the CSP capacity is deployed in the area to the east and south of Los Angeles in California.

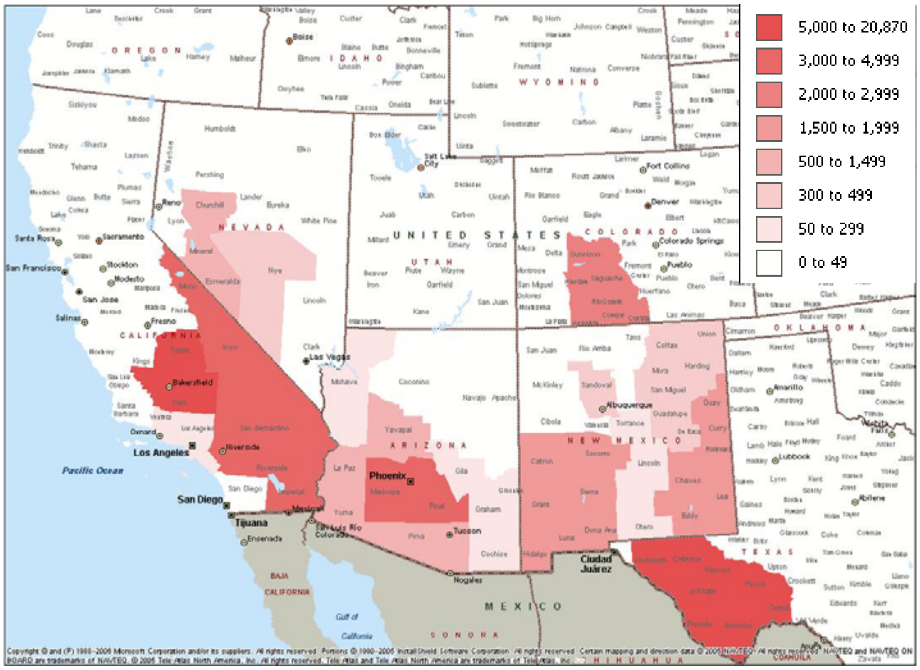

Figure 2. Map of CSP capacity (MW) in 2050 by ReEDS regions for State Incentive Case

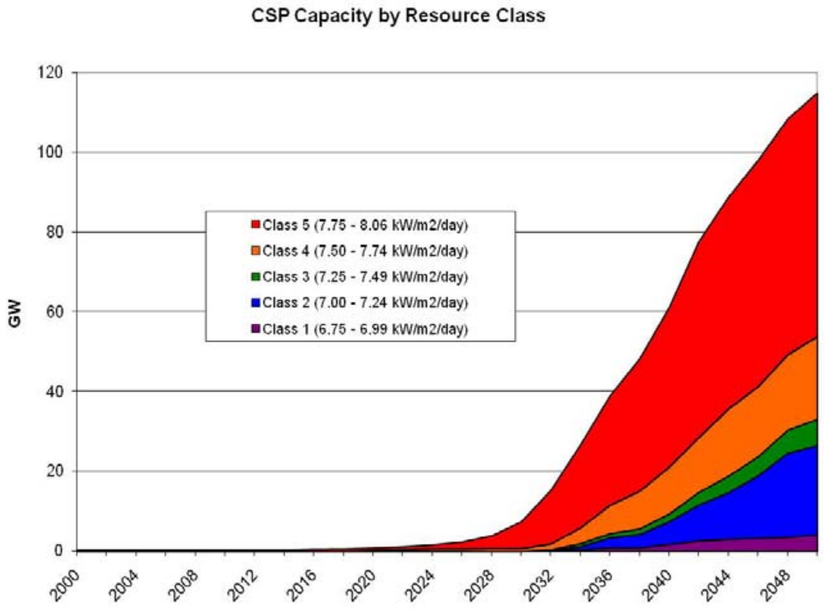

Figure 3. Chart of CSP cumulative capacity (GW) by year and solar class

The best solar resource (class 5) is deployed first in Figure 3. However, note that some lower-class solar resource (class 3 in Figure 3) is deployed just about a decade after the class 5 starts to be deployed. At this point in time, class 5, 4, and 3 are all built. This is partly due to the proximity of lower-class solar resources close to load centers and the fact that identical cost values (but different capacity factors) for all solar classes imply that the levelized cost of energy is not sufficient to build transmission from a higher-class resource further from the load.

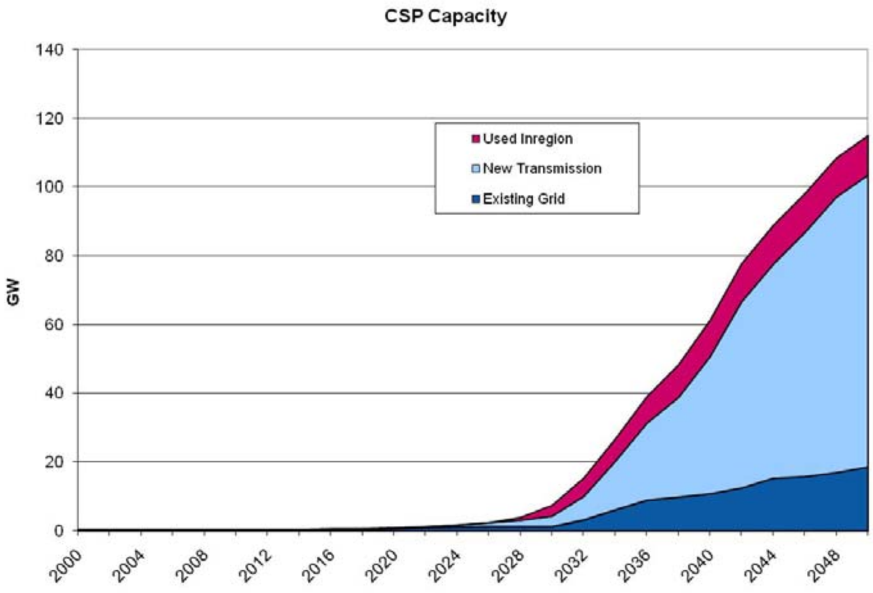

Figure 4. Chart of CSP by transmission type

In ReEDS, there are three ways for power to be transmitted from a CSP power plant (Figure 4). The first is via a short, new transmission line from a CSP plant to a nearby load – such as a city – without actually being involved with the larger grid. The second is via a short line, which gets to a nearby main transmission line and is transmitted over the existing grid to meet loads in another region. Finally, the CSP power can be desirable enough that the model builds a new transmission line to another region specifically for the power from this power plant. As shown in Figure 4, the model builds some of each, but the largest mode of transmission is via new lines.

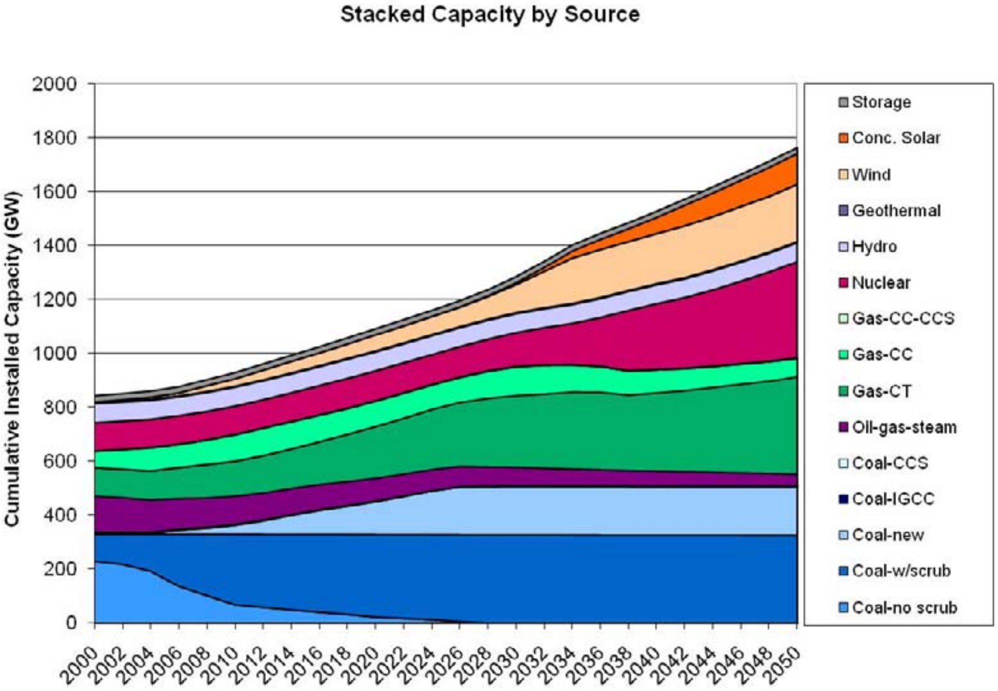

Figure 5. U.S. electrical capacity to 2050 with only current law renewable requirements

CSP capacity competes to be built with all other generating technologies including all other conventional (primarily various coal, gas, and nuclear) technologies and renewables currently represented in the model including wind, geothermal, and hydropower. Note that even with a growth in renewables (Figure 5), coal, gas, and nuclear power continue to dominate the electric power sector through 2050.

4. Sensitivity to Two Renewable Requirement Levels

There are 25 U.S. states with some form of renewable portfolio standard (RPS). Of the seven states in the West that we are currently modeling as capable of deploying concentrating solar power, six have an RPS (California, Nevada, Arizona, New Mexico, Colorado, and Texas). Only Utah does not have an RPS. Several of these have small solar set-asides but all allow for central-station solar thermal plants such as the parabolic trough technology modeled in ReEDS. In fact, several states in the Southwest already have utilities that have signed power purchase agreements (PPAs) with various companies planning to provide solar thermal capacity to meet the states' RPS.

ReEDS has been run with two additional cases, in addition to the No-Incentive Case (above), including one in which the full state RPS, as currently enacted, is assumed to be met. The second case assumes no state's RPS is enforced, but a national 20% RPS by 2030 is assumed to be met for the entire country. Both of these cases have an impact on the amount of CSP capacity that is deployed. Interestingly, even though the current RPSs in the western states are being stated as the cause of the recent resurgence in interest in the CSP technology, the current scenario of costs and performance has caused wind to be generally cheaper than CSP in western states. This means that the near-term RPS goals are met in the model with wind rather than with CSP. Because CSP capacity doesn't begin to be significantly deployed until after 2024, the current state RPSs do not have a significant impact on CSP penetration (Figure 6). However, the later enforcement date of 2030 for the federal 20% RPS has a more significant impact on CSP capacity deployment. The point at which significant CSP deployment begins to happen occurs almost a decade earlier than in the State RPS Case and reaches a higher level throughout the future period including 10 GW more in 2050 than in the State RPS Case.

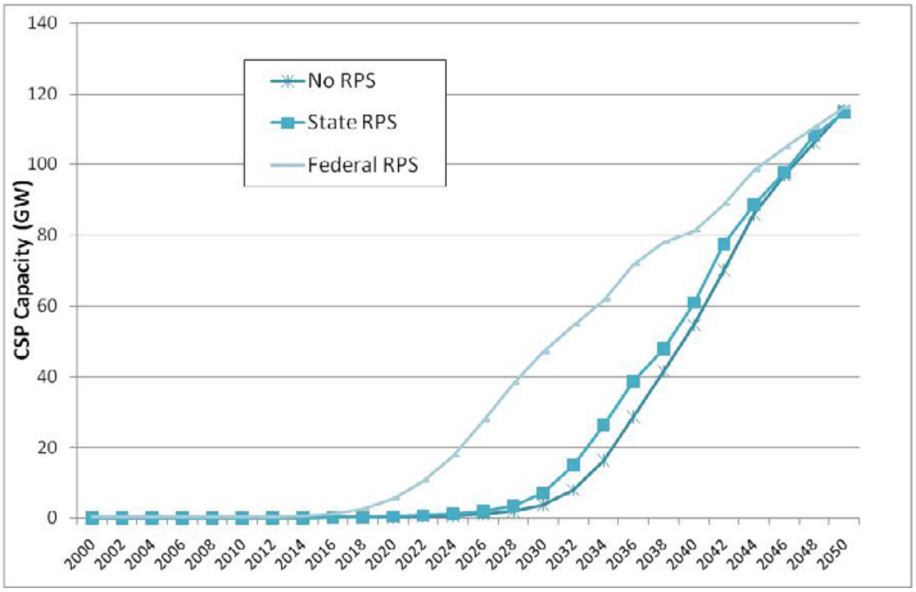

Figure 6. Impact of state and federal RPS requirements on the future penetration of CSP trough technology.

Therefore, even though there are existing RPS requirements in most states in which CSP could be a major contributor, CSP is not able to penetrate early in the State RPS Case because wind is generally more cost competitive in the near term. Once CSP becomes cost-effective – around 2024 – and the best wind sites have already been developed, CSP begins to take a fraction of the new required generation from wind in certain states. It is important to note that none of these scenarios include an extension to the investment tax credit that is currently scheduled to reduce from 30% to 10% at the end of 2008. Any extension of the 30% investment tax credit (ITC) will significantly impact these results.

5. Conclusions

- With the current cost and performance scenario, CSP is not a significant near-term contributor in any scenario without an extension of the 30% ITC, which is set to expire at the end of 2008.
- The rate and timing of CSP market penetration is not generally impacted by state RPS requirements because, by the time CSP really becomes cost-effective, wind and other renewables have met a large chunk of the RPS requirements.
- A federal RPS (of 20% by 2030 and maintained afterward) dramatically accelerates the market penetration and level of CSP penetration.