**California IRES WORKING PAPER SERIES**
California Integrated Renewable Energy Systems Program Working Paper 10-001
California Renewable Energy Collaborative
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# Renewable Energy Futures Comparison – California vs. Rest of US

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November, 2010

**Contents:** **Page**

## Abstract

**California will encounter deployment challenges and opportunities as renewable energy penetration into California's electricity systems increases. Will California's response require special efforts that complement generic research and technology advancement work of Federal programs?**

**According to the comparisons in the report, yes they will. Such efforts will point the way to a high penetration renewable energy portfolio for California that delivers maximum economic benefit and helps minimize California's carbon emissions. California's wind resources are unique, and the mix of onshore and offshore resources likely to develop over the long term poses special questions of integration and assessment. California's solar resources are exceptional, suggesting a scenario in which California will be the first to encounter the challenges and opportunities of optimizing high penetration deployment across multiple scales and venues of deployment. California's geothermal resources will be an exceptionally valuable asset, complementing the high penetration deployment of utility scale wind and solar resources, and each major increment of additional supply will require new information and solutions. California's most opportune biomass feedstock inventories are limited and geographically dispersed but nevertheless an exceptionally valuable asset complementing high penetration deployment of community and building scale solar and wind resources.**

**Referring to published information for the US overall and comparable information from earlier assessments for California, it is possible to identify areas where conclusions for the US as a whole would generally also apply to California, as well as areas where comparable analysis would be needed using California-specific assumptions. California has been dealt a good hand in terms of world class renewable energy resources. Playing it well will require careful attention to the renewable energy deployment factors where California differs from or is unique relative to the rest of the US.**

## Acknowledgements

**This working paper is a product of work specified by the California Energy Commission in Work Authorization Number BOA-99-215-R of Basic Ordering Agreement Contract Number 500-99-013 with the University of California. Specifically, this report is the primary deliverable under Task 2 of the work authorization. Colleagues at the California Renewable Energy Collaborative, William Glassley and Jan Kleissl, provided helpful comments on the geothermal and solar sections respectively.**

## EXECUTIVE SUMMARY

### Introduction:

The US Department of Energy and its national laboratories are working to advance renewable energy technology and to better understand renewable energy's role in the country's energy future. These efforts are important to California as California invests in renewable energy deployment. California may need similar efforts of its own if it is to tailor its policies to opportunities and constraints that differ from those of other states.

Accordingly, this working paper assesses the need for programs and organizational capacities addressing unique or especially important issues and elements of California's renewable energy future. It is organized around resource categories historically addressed by the PIER Renewables Program and/or California's renewable energy centers, i.e., wind energy, solar energy, geothermal energy and bio-power. Within each category, overview level information on the following topics is presented and discussed:

- Resource availability in California vs. resource availability across the rest of the US
- Technology cost and performance typical of California sites vs. sites prevalent in the rest of the US
- Preferred technology menu choices for California vs. preferred choices in the rest of the US
- California supply curve vs. supply curve for US overall
- Technology output characteristics typical of California sites vs. sites more typical in the rest of the US
- Large scale production and deployment issues common to California and the US and unique to California
- Grid integration and environmental issues common to California and the US and unique to California

### Getting Supply Curves Right:

Thanks to its implementation of the Public Utilities Regulatory Policy Act in the 1980s and prior investments in geothermal resource development, California is getting significant electricity supply contributions in all major categories. In general, the best resources in each category were the first to be developed. Related projects provide experience with 20$^{th}$ century technology solutions applied to the most economically attractive resources. There is now a need to understand how additional resources in each category can be developed using 21$^{st}$ century technology solutions.

For purposes of modeling and evaluating high penetration renewable energy deployment scenarios, supply curves can be used to show how costs change as less economically developable resources come into play. Supply curves recently developed for California renewable electricity resources are shown in Figure 1.

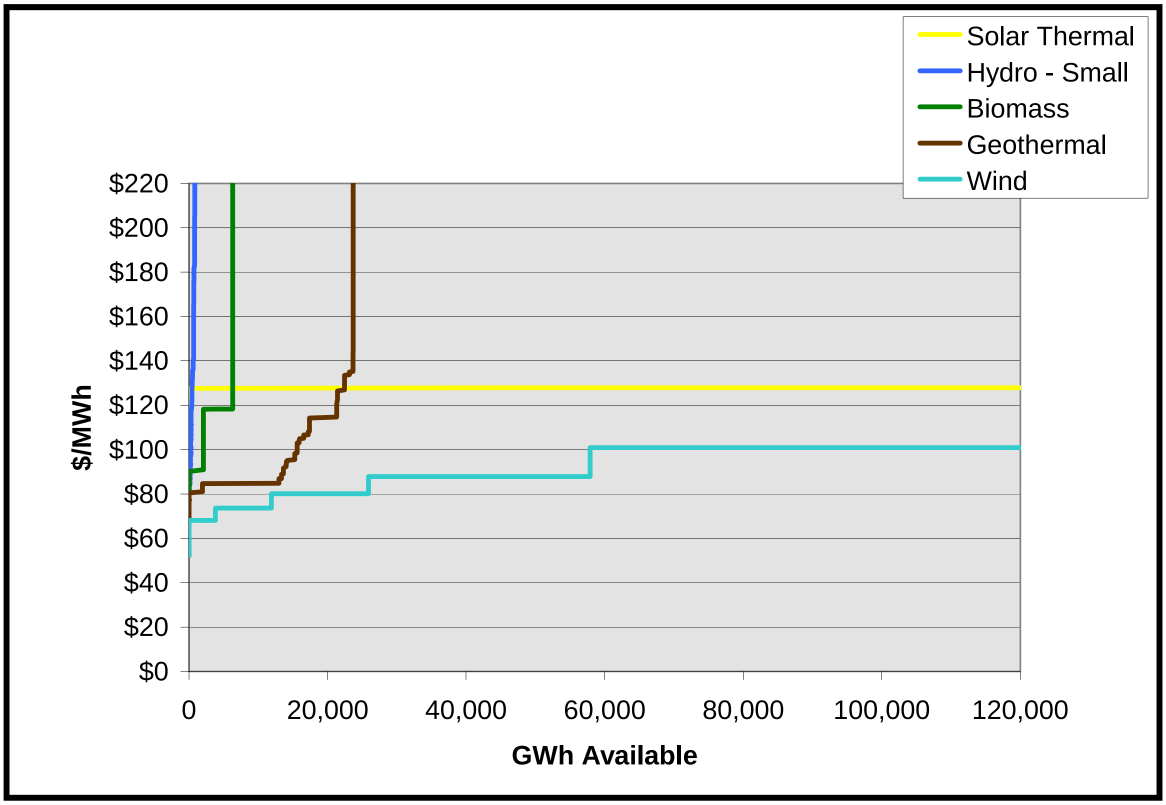


**Figure 1: California Renewable Energy Supply Curves by Major Resource Type (Bus-bar $/MWh)[1]**

No matter how carefully they are assembled, such supply curves hinge on a daunting array of assumptions and unknowable statistics. Their strategic planning value is that they provide quantitative guidance for long term planning that accounts for limits on the availability of specific project opportunities at specific costs. Their value is greatly enhanced if they are continually refined based on market experience, innovation and policy adjustments. They also can serve as an input to the apportionment of public resources allocated to supporting renewable energy deployment.

Deep technology and market insight is required to mine market experience and technology advancement efforts for information on which to base supply curve updates, improvements and refinements. Each curve is effectively a composite of analyses of market segments that require more specific assessments. To the extent that California's renewable energy supply curves differ significantly from those of the rest of the US - and they do in most cases - it will be important for California to maintain a living repository of relevant technology and market insight.

[1] Source: Energy and Environmental Economics, http://www.ethree.com/public_projects/cpuc2.html

**Focusing on California:**

Will California encounter high penetration renewable energy deployment challenges and opportunities requiring special efforts that complement generic research and technology advancement work of Federal programs?

According to the comparisons in this report, yes they will, if California's renewable energy portfolio is to be both balanced and economically maximized and optimized. California's wind resources are unique, and the mix of onshore and offshore resources likely to develop over the long term poses special questions of integration and assessment. California's solar resources are exceptional, suggesting a scenario in which California will be the first to encounter the challenges and opportunities of optimizing high penetration deployment across multiple scales and venues of deployment. California's geothermal resources will be an exceptionally valuable asset, complementing the high penetration deployment of utility scale wind and solar resources, and each major increment of additional supply will require new information and solutions. California's most opportune biomass feedstock inventories are limited and geographically dispersed but nevertheless an exceptionally valuable asset complementing high penetration deployment of community and building scale solar and wind resources.

Referring to published information for the US overall and comparable information from earlier assessments for California, it is possible to identify areas where conclusions for the US as a whole would generally also apply to California, as well as areas where comparable analysis would be needed using California-specific assumptions. Based on this working paper's comparative analysis, Table 1 identifies combinations of resource category and strategic topic where on-going California-specific assessment and analysis will be needed.

In most cases it will be important that assessment and analysis be closely linked to test, demonstration and commercial experience. The table shows that, while few of California's challenges and opportunities are unique, many are qualitatively and quantitatively different. So, California's renewable energy deployment efforts will be best served by reference to both national programs supporting national deployment and state programs tailored to issues and opportunities of special importance in California.

| California/US Comparison: Renewable Energy Deployment Factors | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Wind | | Solar | | | Geothermal | | Biomass | |
| | Onshore | Offshore | PV | Heat/Cool | CSP | Utility | Heat/Cool | Forestry | Agriculture |
| | | | | | | | | | |
| Supply Curve | Different | Different | Similar | Similar | Unique | Unique | Different | Similar | Unique |
| | | | | | | | | | |
| Resource Availability | Different | Unique | Similar | Similar | Different | Different | Different | Similar | Similar |
| | | | | | | | | | |
| Cost and Performance | Unique | Similar | Similar | Different | Similar | Similar | Different | Similar | Similar |
| | | | | | | | | | |
| Preferred Techology Mix | Similar | Different | Different | Similar | Similar | Similar | Similar | Different | Different |
| | | | | | | | | | |
| Output Characteristics | Different | Different | Different | Similar | Different | Similar | Similar | Similar | Similar |
| | | | | | | | | | |
| Large Scale Production | Different | Different | Similar | Similar | Unique | Similar | Similar | Different | Different |
| | | | | | | | | | |
| Grid Integration and Environment | Different | Different | Different | Different | Different | Different | Different | Different | Different |

**Table 1: California Compared to Rest of US: Renewable Energy Deployment Factors**

## INTRODUCTION

In the context of climate change legislation and related goals, both California and the US have an interest in understanding the long term electricity supply potential of renewable energy. California's interest is focused on the next decade, because, as shown in Figure 2, most of California's renewable energy and climate related targets occur in or prior to 2020.

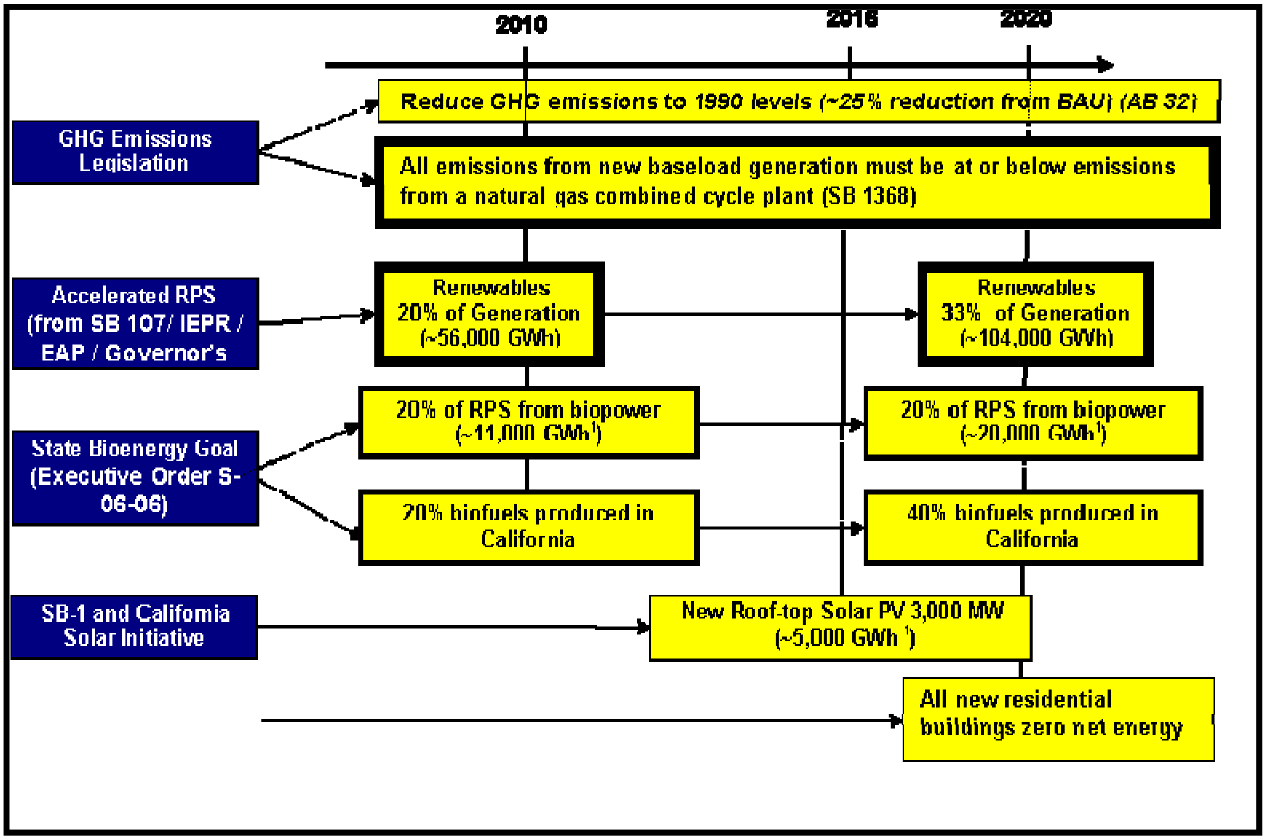


**Figure 2: California's Clean Energy Targets**[2]

Meanwhile, the US Department of Energy has undertaken multiple analyses that look beyond 2020, including an effort completed in 2009 addressing a goal of 20% penetration of wind in the US electricity market by 2020[3], and more recent effort addressing a comparable level of deployment for solar[4]. In late 2009, the USDOE commissioned a comprehensive analysis to determine the extent to which renewable energy could supply US needs by 2050. Results of this effort are under review, with economically feasible scenarios identified for up to 80% renewable energy penetration.

Much depends on California's current efforts, including utility deployment programs overseen and supported by the California Public Utilities Commission (CPUC), power plant licensing

[2] Source: Sandra Fromm, Supervisor, PIER Renewables
[3] See http://www1.eere.energy.gov/windandhydro/pdfs/41869.pdf
[4] See http://www1.eere.energy.gov/solar/vision_study.html

processes administered by the California Energy Commission (CEC), and the renewable energy RD&D programs underway that are funded through the California Solar Initiative and the CEC's PIER program.

California led the way in deploying renewable energy in the 20th century. California can also aspire to leadership in renewable energy deployment in the decades beyond 2020. Do current efforts suffice to support this aspiration? If not, what is the nature of the most important gaps? Are the challenges of high penetration renewable energy deployment for California being adequately addressed by programs and laboratories of the USDOE, or will California encounter high penetration renewable energy deployment challenges and opportunities that require special attention complementing generic research and technology advancement work of Federal programs?

This working paper addresses several questions of a comparative nature, the answers to which can provide guidance regarding the extent of California's need for programs and organizational capacities focused on California's renewable energy future. It is organized around categories historically addressed by the PIER Renewables Program and/or California's renewable energy centers, i.e. in reverse alphabetical order, wind energy, solar energy, geothermal energy and bio-power. Within each category, overview level information is provided and discussed on the following topics:

- Resource availability in California vs. resource availability across the rest of the US
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## WIND ENERGY

### Resource availability in California vs. resource availability across the rest of the US

Wind resources vary significantly across the US. Excellent wind maps are available for the US with new high resolution maps available for average speeds at 80m on shore. Offshore resource maps are also available, but their data is less reliable. As suggested by Figure 3, California and adjacent states are not as well endowed with high quality resource areas to the extent that the Plains states are. However, California has large and high quality resource areas off shore. For reference, 20% higher wind speed results in 70% greater power density, so resource quality is a major cost driver.

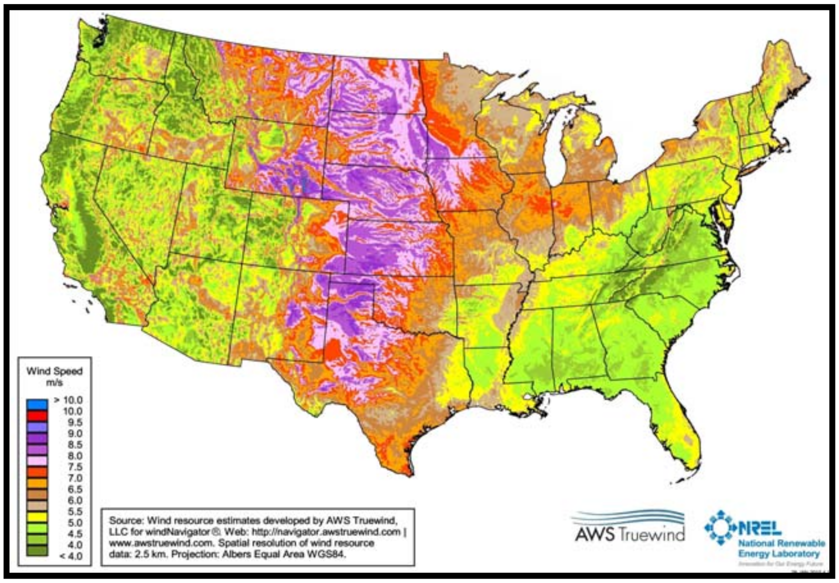


**Figure 3: United States - Average Wind Speed at 80 Meters**

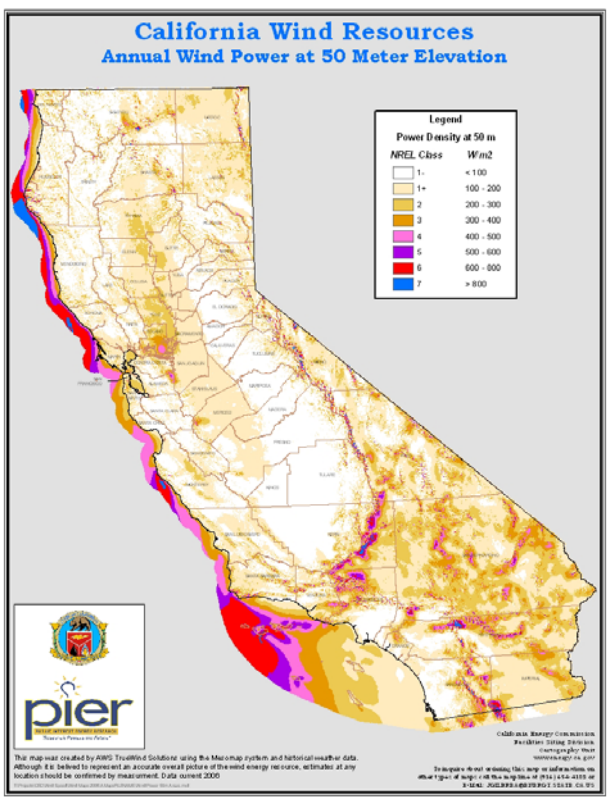


**Figure 4: California Wind Energy Map Showing Relative Power Density and Abundance of Onshore and Offshore Resources**

Thus, for onshore areas, California costs may be higher than the average across the US. However, this may not impede project development; because the potentially higher market referenced prices may neutralize the effect of higher costs.

**Technology cost and performance typical of California sites vs. sites prevalent in the rest of the US**

Onshore wind technology is relatively mature with unsubsidized "levelized" electricity costs in the $80/MWh range for good and excellent resource areas[3]. Technology for offshore wind energy capture, esp. for deep water areas along the California coast, is less mature, and costs are less well documented and understood. In both cases, i.e. onshore and offshore, there are continuing opportunities for cost reduction, and performance improvements will accrue as offshore turbine size increases to the 5-10MW range, because wind energy content typically increases with rotor hub height.

Differences in technology cost and performance between California and the rest of the US will probably be modest, with the lower end of the cost range in the $60/MWh range for high quality resource areas in the Plains states[3]. It is important to consider cost in the context of value. Specifically, the economic value of wind will decline as penetration increases and as integration costs and costs of transmission upgrades are factored in. Also, the relationships between price and cost will vary depending on incentive levels, the nature and extent of market competition, and variations in market structure, plant ownership, and weighted average cost of capital.

**Preferred technology menu choices for California vs. preferred choices in the rest of the US**

Intuitively, one would expect the California wind resource to differ from resources in other regions. It consists of a combination of onshore resources in areas ("windy passes") that funnel winds from coastal to inland areas, along with an offshore resource that relies on winds generally sweeping unimpeded toward California's coast from the Pacific. By contrast, for example, resources in other states are now being developed at a faster rate.[5]

The resource map in Figure 3 shows many states having onshore wind resources superior to California's both in terms of quality and quantity. Early wind development in California involved machines with hub heights below 50 meters. The effect of positive wind shear typical of flat terrains is that wind speed increases with height, with resulting increases in energy capture and capacity factor.[6] Thus, economies of scale and also the impetus to maximize energy capture have driven the wind industry toward larger, taller machines. This trend does not necessarily favor onshore wind deployment in California, where wind shear in California's windy passes can be zero or even negative; tall machines can actually be subject to winds that come from

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[5]In 1999 California had 1616MW of wind capacity out of a US total 2472. At the end of 2009, it had 2798, or less than 10%, of the US total of 34863MW. Source: USDOE and AWEA

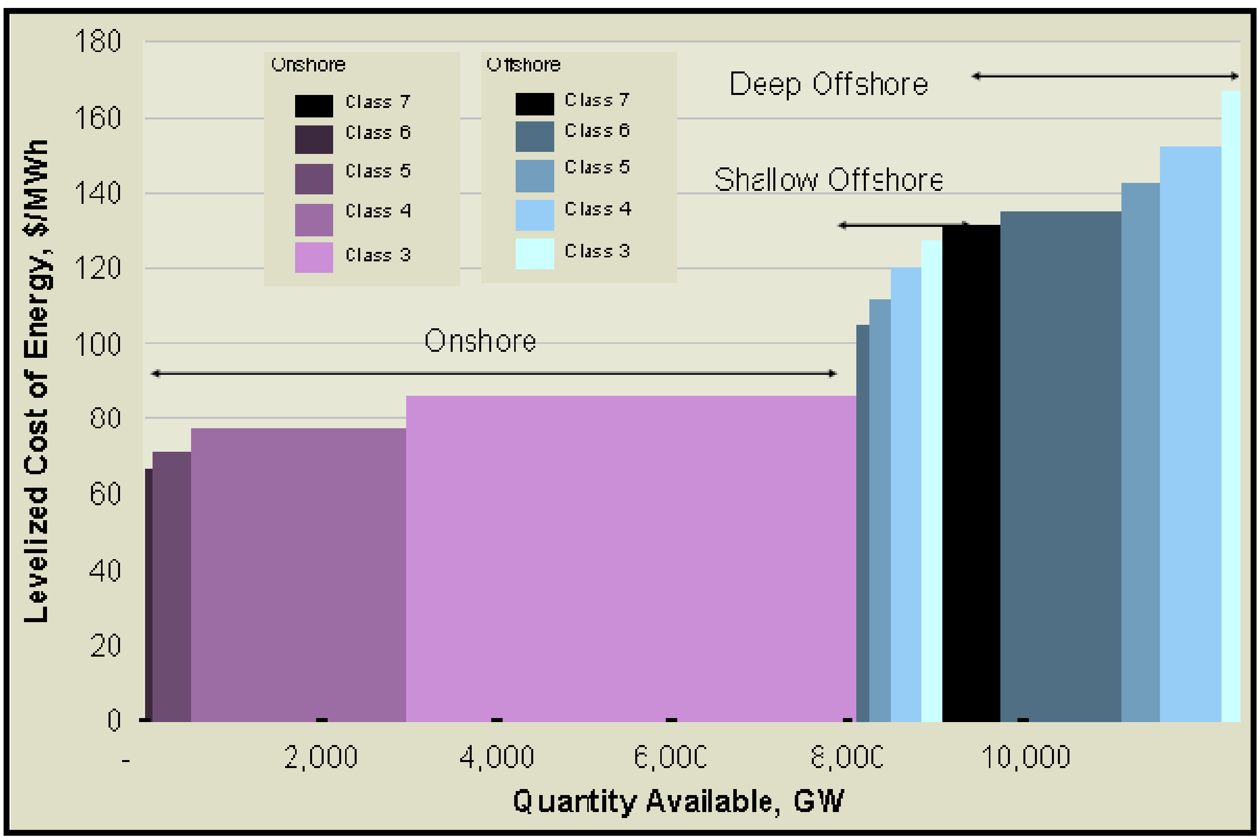
[6] According to Elliott (http://www.windpoweringamerica.gov/pdfs/workshops/2006_summit/elliott.pdf) tall-tower data from Midwest and Plains regions indicate many locations can have high annual average wind shear (0.2-0.25) at heights between 50-100 m. At these locations, Class 3 sites at 50 m can have Class 4-5 equivalent wind resource at 80-100 heights and gross capacity factors exceeding 40%.

opposing directions at different heights.[7] California's unique onshore wind resource appears to have important technical and economic implications and may therefore call for technology and economic assessments that account for its unique character.

Off shore wind resources available to California are unique relative to most other states in that they consist of limited shallow water resources and abundant deep water resources likely requiring floating turbines and arrays. Technological challenges of deep water sites have several dimensions including transmission to onshore grids, anchoring to the sea floor and overall deployment logistics.

**California supply curve vs. supply curve for US overall US supply curve:**

Rapid growth in the wind industry results in rapid change, in the design and size of machines, and in the understanding of factors affecting optimization of wind power plants, including factors related to wind regimes and topography, e.g. wake effects, turbulence, wind shear, etc. Efforts to create supply curves for large economies provide a very generalized and temporary snapshot of the relationship between cost and market penetration. Such snapshots for the US and California are presented in Figures 5 and 6.

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7 http://www.wind-works.org/articles/MWPerfProj.html

**Figure 5: US Wind Supply Curve, Assuming 2010 Busbar Cost (w/o PTC)[8]**

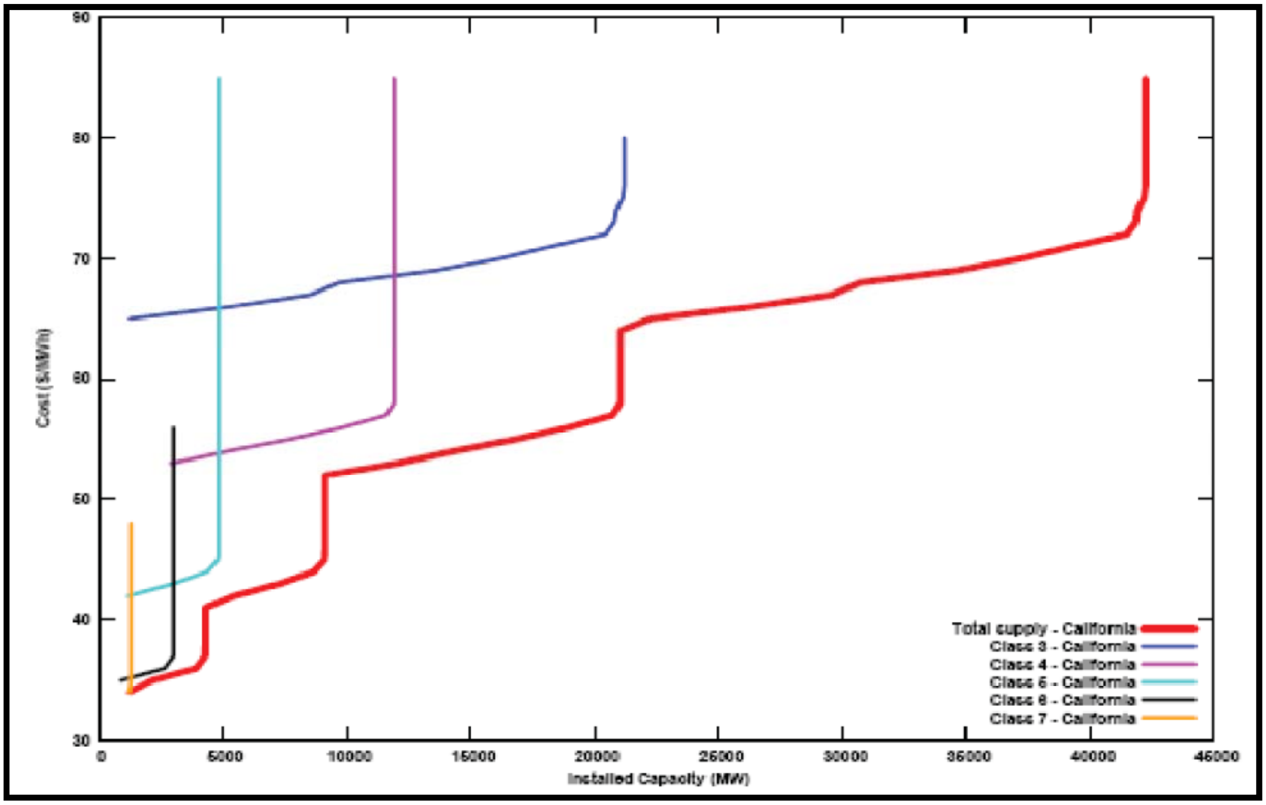


**Figure 6: California wind supply curves assuming 20% of existing transmission is available for wind[9]**

Figure 5 shows a rather steep supply curve for California over a range of installed capacity up to 45,000 MW, while Figure 6 shows a much flatter curve for the US overall over a range of installed capacity up to 2,000,000 MW Prices at the beginning of the California supply curve range from $65/MWh for Class 3 onshore resources to $35/MWh for Class 6 onshore resources, in contrast to prices at the beginning of the US supply curve ranging from $65/MWh to $85/MWh for the same classes of onshore resources. This is a serious discrepancy. From a policy development and planning perspective It would be desirable to have reference to a supply curve for California that would be properly comparable to supply curves for US overall and to those of adjacent states.

According to Figures 5 and 6, economically accessible onshore wind energy resources across the US appear to dwarf comparable California onshore resources. The same may not be true in

[8] Source: 20% Wind Energy Penetration in the United States, Black and Veatch, 2007 http://dnr.wi.gov/environmentprotect/gtfgw/documents/Black_Veatch_20_Percent_Report.pdf

[9] Wind Supply Curves and Location Scenarios in the West, NREL Conference Paper, 2006 http://www.nrel.gov/wind/pdfs/40050.pdf. The supply curve in assumes that once 20% of existing transmission capacity is allocated to wind, new transmission must be built to carry additional supply to the nearest load center.

the case of offshore wind resources. This suggests a particular need in California for economically optimum development of its (relatively) limited onshore resource. Likewise, California may have a unique opportunity over the long term to develop an optimized mix of both onshore and offshore resource

**Technology output characteristics typical of California sites vs. sites more typical in the rest of the US**

As noted earlier, nearly 60% of California's installed wind capacity was installed prior to 1999, and much was installed in the 1980s. Earlier generations of wind turbines are smaller and do not incorporate variable speed drives and other features favorable to grid integration. Early generations of technology are in still in operation because their marginal production costs are less than prices paid for their output, and because their residual asset value, plus the cost of repowering, does not yet justify replacing them with larger, more efficient machines having greater grid compatibility.

There is a need to understand the repowering issue in the context of optimizing the economic use of California's limited onshore wind energy resources. Other states, where wind deployment started up more recently, do not face this issue. In California, there is a need to understand the costs and economic benefits of policies that would encourage replacement of aging wind power plants in the Altamont and San Gorgonio passes with equipment and plant layouts that would more efficiently capture wind energy potential. Expanding production in these areas would ultimately off-set investments and environmental impacts involved in developing plants elsewhere. California may have a special need to conduct scoping analyses and as a first step in considering policies that would encourage exploration of the repowering option.

**Large scale production and deployment issues common to California and the US and unique to California**

Other states are able to optimize economic use of wind energy based on a more complete and mature menu of technology options than originally available in California. In a market dominated by machines in the multi-MW range, California is also disadvantaged by the fact that some of California's most favorable wind resources exist in a thin layer close to ground level, the top of which sometimes exceeds the top of a large wind machine's swept area. In more favorable regimes the largest machines are preferred because of their high utilization factors and overall economics.

California's best onshore resources are in specific passes that funnel prevailing winds and are more concentrated and less pervasive than in the Great Plains. However, unlike the Plains states, California has the possibility of exploiting offshore resources of exceptional quality that are relatively close to its major population centers.[10] While the US supply curve presented in

[10] Dvorak, Archer, and Jacobson, 2009, modeled 80 m average power density and wind speed for shallow California offshore resource areas , highlighting urban load centers and transmission corridors where offshore wind farms could connect to existing grid infrastructure. See: http://www.stanford.edu/group/efmh/jacobson/PDF%20files/dvorak-archer-jacobson-2009.pdf

Figure 5 suggests that in most of the US there is an inventory of economical onshore resources that will be more economical to exploit than offshore resources, the cost basis for this conclusion must be viewed as speculative in the absence of comparable experience with onshore and offshore wind development. For reasons of limited onshore resources and exceptional offshore resources, California has good reason to better understand the related trade-offs as soon as possible.

**Grid integration and environmental issues common to California and the US and unique to California**

There are other reasons to better understand California offshore/onshore wind trade-offs as soon as possible.[11] According to the California Energy Commission[12], "based on a preliminary review of the relative quality of California's onshore and offshore wind resources, offshore wind may offer higher capacity factors, lower variability, better predictability, better match to state load profiles, and delivery profiles that are equal or better than utility scale solar electricity at high renewable penetration levels….The fact that California's highest quality solar, geothermal and onshore wind resources are located in areas having low population density and thus limited transmission capacity has become a major concern for state policy makers and transmission system operators."

"Much of California's current thermal power generation capacity is located along the coast, and many of these plants will be retired in coming decades and may not be replaced with thermal power plants for which existing coastal transmission infrastructure was built. This not only raises concerns about operation of the grid without the benefit of these stabilizing generation resources but also suggests an opportunity for a plan for wind deployment in California in which a mix of onshore and offshore wind power plants is used to minimize the need for expensive and problematic new transmission infrastructure….There may be opportunities to increase transmission capacities and electricity transfer capabilities in relatively unpopulated areas of California with minimal electric grid infrastructure, including areas that may offer favorable wind resources, such as counties north of San Francisco along the coast."

In recent years, California wind deployment and the transmission investments to enable it have been outpaced in other states. This raises questions which are beyond the scope of this report. A better understanding of causal factors and whether they are temporary, permanent, or related to relative resource quality, economic or regulatory factors, would seem to be in order. Likewise, the ability of the California transmission grid to accommodate significant additional wind energy penetration has been confirmed[13], and similarly, the same question has been addressed for the western grid that inter-connects with California[14]. However, questions remain

[11] For a complete discussion of the technical and economic drivers of offshore wind power, see Robinson's and Musial's Offshore Wind Technology Overview, 2006, at http://www.nrel.gov/docs/gen/fy07/40462.pdf

[12] Letter to the US Department of Energy responding to a request for input on offshore wind demonstration projects, 2010, http://cal-ires.ucdavis.edu/files/research/DOE%20Offshore%20Wind.pdf

[13] See http://www.uwig.org/CEC-500-2007-081.pdf

[14] See http://wind.nrel.gov/public/WWIS/Miller.pdf

regarding the extent of wind penetration that would be feasible if in-state and out-of-state deployment could be coordinated to minimize reliability challenges and maximize economic benefits.

## SOLAR ENERGY

As indicated in Figure 7, California is, on the average, a relatively sunny state. In general terms, the best California locations for solar radiation equal the best in the world, and the difference between the best and average California locations is relatively small. Practically the whole state can be said to have good average radiation conditions for non-concentrating systems converting radiation to heat and electricity, though the difference between summer and winter averages can be quite pronounced. Radiation inputs are important, but so are other conditions related to locating solar energy systems. These include topography, heating and cooling energy demand, access to transmission resources and many other factors.

Concentrating systems offer more flexibility in leveling output from season to season, but seasonal differences cannot be eliminated without sacrificing overall economics. Figure 8 evaluates the southwest US in relation to one aspect of topography, i.e. the slope of local terrain, and one aspect of grid integration, i.e. the location of major transmission corridors. This is a good start, and efforts to better characterize California solar resources will be needed to support planning and operation of the state's energy systems at significantly increased levels of solar penetration.

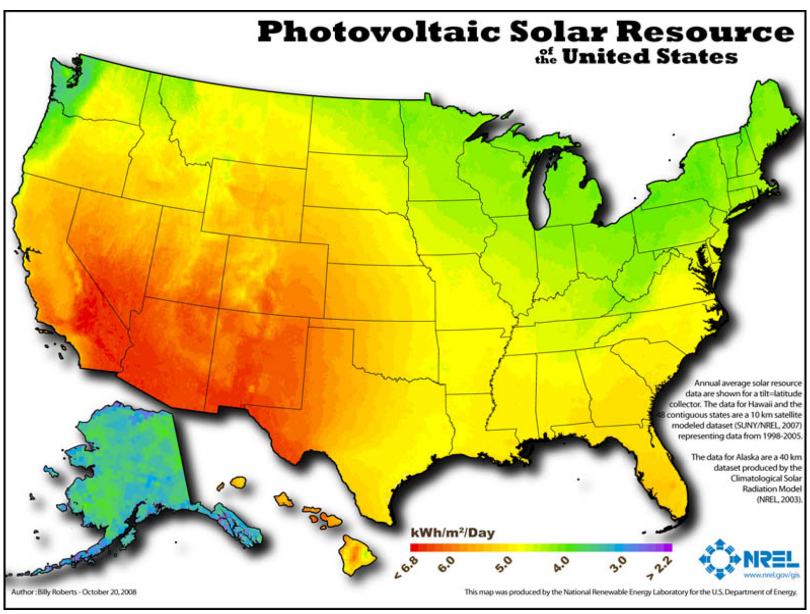


**Figure 7: Total Solar Radiation on Flat Surfaces Tilted According to Latitude[15]**

[15] Source: NREL

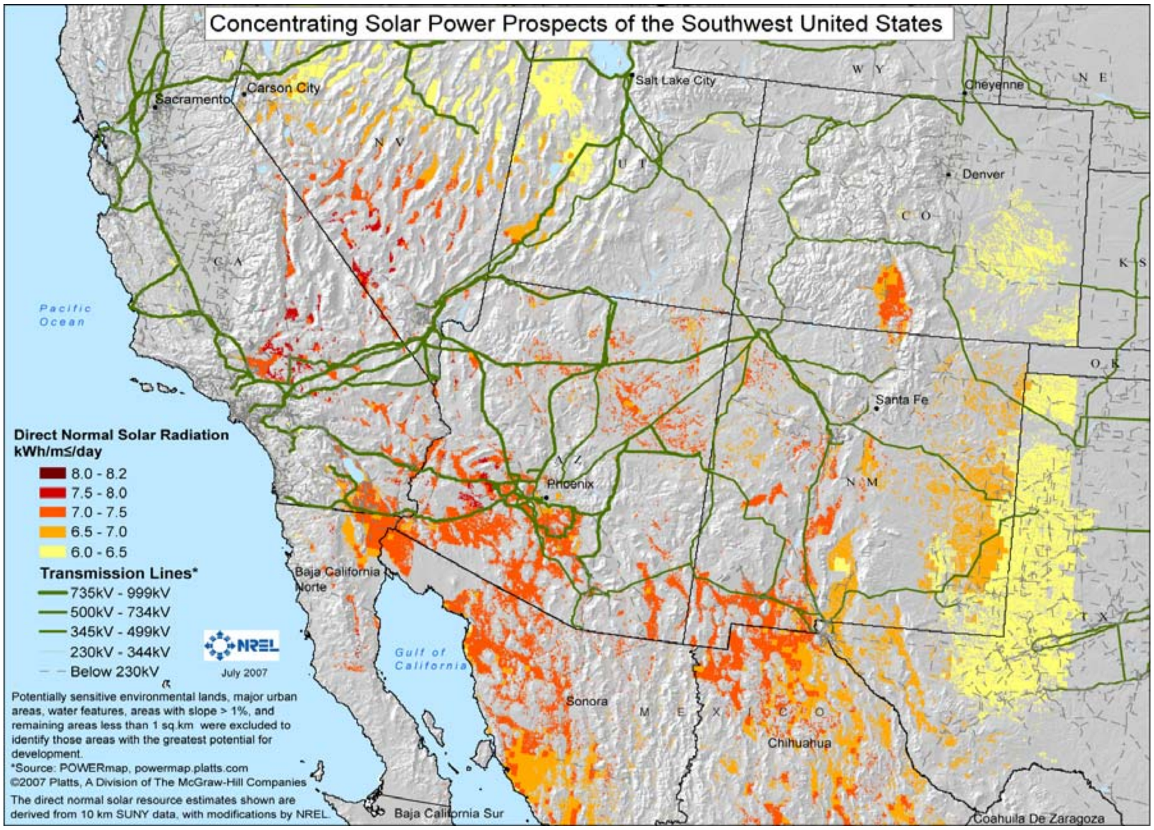


**Figure 8: High Potential Concentrating Solar Power Resource Areas in the Southwest US[16]**

Specifically, California's solar resources vary across a large span of time scales, from instantaneous changes related to passing clouds to seasonal changes related to sun angle, to yearly changes related to weather cycles. They also vary according to the spectral distribution of sunlight which depends on atmospheric conditions, e.g. humidity, and to the relative proportions of radiation that can be reflected for purposes of concentration to that which cannot. Micro-climate effects are not insignificant and may affect the performance and location of community scale systems.

### Technology cost and performance typical of California sites vs. sites prevalent in the rest of the US

Solar resources vary significantly across the US and even in California, but Figure 7 makes it clear that much of the geographic area of the US receives at least 70% as much annual sunlight on properly aligned flat surfaces as does California in its sunniest locations.[17] Figure 8 demonstrates that California's beam or direct radiation (the part that can be concentrated to generate high temperatures) sets it apart from all but a few other states having extremely arid desert areas. Concentrating systems capture greater portions of the incoming radiation at the

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[16] Source: NREL

[17] Almost all of the US receives more than 60% of California's best.

collector aperture.  In much of the US the spectral portion of total radiation that can be concentrated is relatively small compared arid regions in the west.  So, concentrating systems in the best locations in California can collect twice the amount of sunlight as systems in most of the US west, and more than three times the amount of sunlight as concentrating systems in most of the US east.  Concentrating solar power systems located in arid areas of California and the US southwest perform have much better economic performance than those located elsewhere.

California is also advantaged in the possible use of solar energy for heating and cooling.  Solar water heating (SHW) is an opportune option for California, especially in the context of its goals to reduce greenhouse gas emissions.  SHW systems reduce, but typically do not eliminate, the need for electric or gas as back-up heat sources. The performance of a specific SWH system may be defined by its *solar fraction* or the fraction of a building's water heating energy demand met by the SWH system. A system with a 60% solar fraction reduces the water heating demand (and also the water heating energy costs) by 60%. Typical solar fractions in the United States are in the range of 40-80%.  Figure 9 shows that in the heavily populated areas of California solar fractions are in the range of 70-90%.

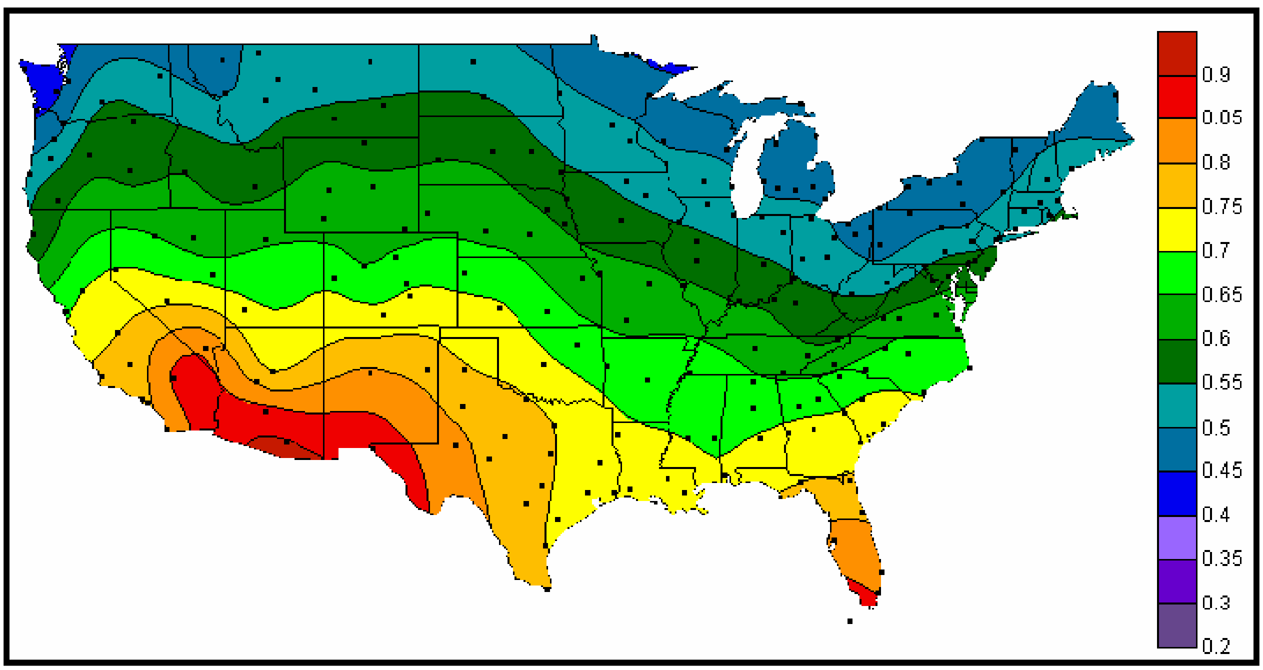


**Figure 9:  Simulated Solar Fraction Using a (Current Technology) Residential Solar Water Heating System**[18]

In deploying solar electricity systems, there are some specific needs in California related to climate and weather which impact solar resource assessment and forecasting. The coastal urban area has the best coastal resource in the nation and will see some of the highest PV

[18] Source:  NREL Report entitled "The Technical Potential of Solar Water Heating to Reduce Fossil Fuel Use and Greenhouse Gas Emissions in the United States", 2007, http://www.nrel.gov/docs/fy07osti/41157.pdf

penetration levels. However, these areas are subject to summer overcast clouds. The prediction of the 'burning off' of the cloud layer is important to PV integration on urban distribution feeders. The synchronous occurrence of the PV ramping caused by the burning off (unlike the more typical random cloud patterns), creates unique challenges for the cycling of automated line equipment and maintenance of voltage levels on these feeders. Power flow modeling of some representative feeders will allow the assessment of limits to high PV penetration.

Other specific California needs related to climate and weather include the fact that desert areas with the best resources are impacted by dust storms, thin cirrus clouds, air pollution, and forest fire smoke. The impacts of these California-specific phenomena on reduction in beam irradiance have not been quantified. Current satellite and numerical weather models are not capable of measuring or simulating these processes. Specially designed measurement campaigns and modeling research is necessary to quantify the reduction in the direct normal solar resource and assess ways to forecast these processes. Accurate forecasting would benefit both transmission system operators and CSP plant operators. [19]

**Preferred technology menu choices for California vs. preferred choices in the rest of the US**

Technical solutions and applications of solar technology are diverse, and the level of diversity is increasing as the global industry and the venture capital community invests in new technology. California has major population centers in relatively close proximity to areas of exceptional direct radiation. This may result in more reliance on concentrating technologies than nearly anywhere else.

Regarding non-concentrating solar technologies, there is no obvious resource or economic factor that would result in technology preferences for California substantially different from overall global market preferences as they evolve. However, as elsewhere, California energy policy is strongly influenced by incumbent industries, and policies affecting solar deployment are not an exception. Northern California has had an active retail solar electricity industry since the 1970s, and retail solar electricity deployment has therefore had effective advocates and has progressed more steadily and rapidly than solar heating and cooling deployment. As incentive levels decline, the deployment balance is likely to be driven by the relative economic competitiveness of offerings on the global market. Other factors that may affect technology preference differently in California include population distribution and density and site availability. California's population remains concentrated in coastal areas which have good but not exceptional average solar radiation. This will result in a preference for solar electricity technologies that can be economically deployed in inland zones where solar resources are exceptional. However, this preference will be mitigated by the need for transmission infrastructure investment to access the high quality resource zones.

Likewise, existing building stock in high population density areas is not likely to accommodate the level of building or community based deployment that will be possible in new communities or

[19] Discussion of specific climate and weather factors in this and the preceding paragraph was provided by Jan Kleissl, Co-Director, California Solar Energy Collaborative

on new buildings.  Taken together these factors suggest a possible preference for technologies that are either especially amenable to building retrofit applications or technologies that can be deployed close to but not necessarily within load and demand centers.  Technologies that feature higher energy collection and conversion efficiency will likely be favored over those that are restricted to locations where array footprint vs. output is not a concern.

Another factor, more difficult to evaluate, is the fact that California's natural gas and electricity markets are structured for competition at the wholesale market level but not at the retail level. Market structure differences and difficult-to predict-market structure changes could well be decisive in shaping California's solar energy market and determining how solar energy deployment in California will differ from other states, e.g. in terms of the mix of various photovoltaic system deployment options and the policy support or lack of policy support for solar heating and cooling.

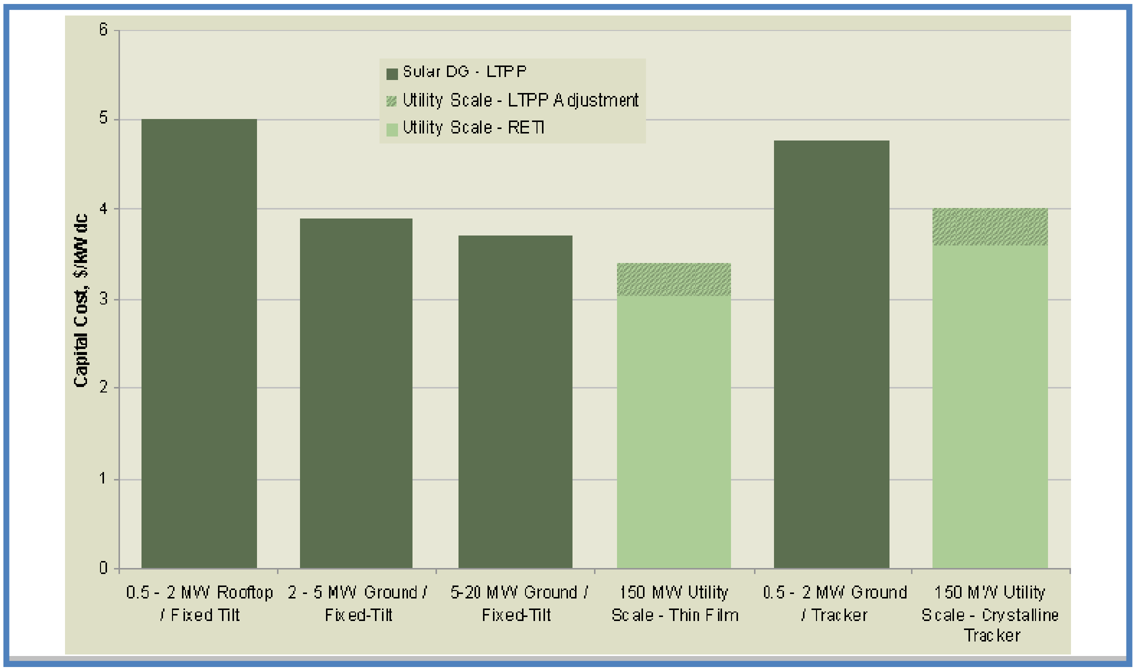


**Figure 10:  Comparison of PV Costs, Plus Large Central Station Costs[20]**

Figure 10 shows that several combinations of solar photovoltaic technology and scale have comparable costs, to the extent current power sales prices accurately reflect fully built up costs and their future trajectory.  Given the closely comparable costs[21], and the variations in location

[20] From a recent presentation by Energy and Environmental Economics entitled "LTPP Solar PV Performance and Cost Estimates", 2010, http://www.ethree.com/documents/LTPP/LTPP%20Presentation.pdf

[21] In practice costs for specific market applications vary widely, so there is substantial overlap in cost ranges for the market applications being compared in the figure.  Comparisons that do not account for variations can be misleading.

related benefits, it is clear California solar deployment policy will benefit from models calibrated using information generated by actual installations. A great deal of market insight will be needed to assess future costs. The global solar market, though already very large, is still subject to considerable price volatility and cross-subsidization as manufacturers compete for projects and market share and react to industry-wide supply/demand imbalances, as well as volatility in the project finance environment.

**California supply curve vs. supply curve for US overall**

Supply curves have been developed for specific solar technologies and for applications using different methodologies, making it problematic to create aggregated supply curves for the many combinations of solar technology, application and scale. Development of supply curves for concentrating solar power in the southwestern US has been enabled by extensive analysis conducted by NREL and others. Figure 11 shows the result, i.e. a flat supply curve for California up to 10 GW. Other states show more variation based on the constraints assumed relating to demand and transmission capacity. The constraints are plausible but may not consistently apply in the future. Specifically, they reflect an assumption that CSP power would be delivered to loads in the same state in which it is generated subject to availability of transmission capacity. Also, production costs were assumed to be constrained by market price referents, e.g. California's.

There is a need for analysis of cases where electricity, specifically CSP electricity, is exchanged between states or delivered to multiple states from sources in one state. Multiple southwestern US states, including California, have greater direct normal radiation resources than needed to meet in-state electricity demand. States that have smaller populations and electricity demand aspire to be net exporters. Depending on future California RPS targets and the rate of progress toward meeting them, California would not likely be the first southwestern state to become a net exporter. Transmission capacities connecting resource areas and population centers will be a critical consideration. California's RETI process addresses this consideration, but so far no such comprehensive look at resource areas and transmission corridors outside California has been launched. More detailed and integrated supply/transmission analysis will be required to inform California policy.

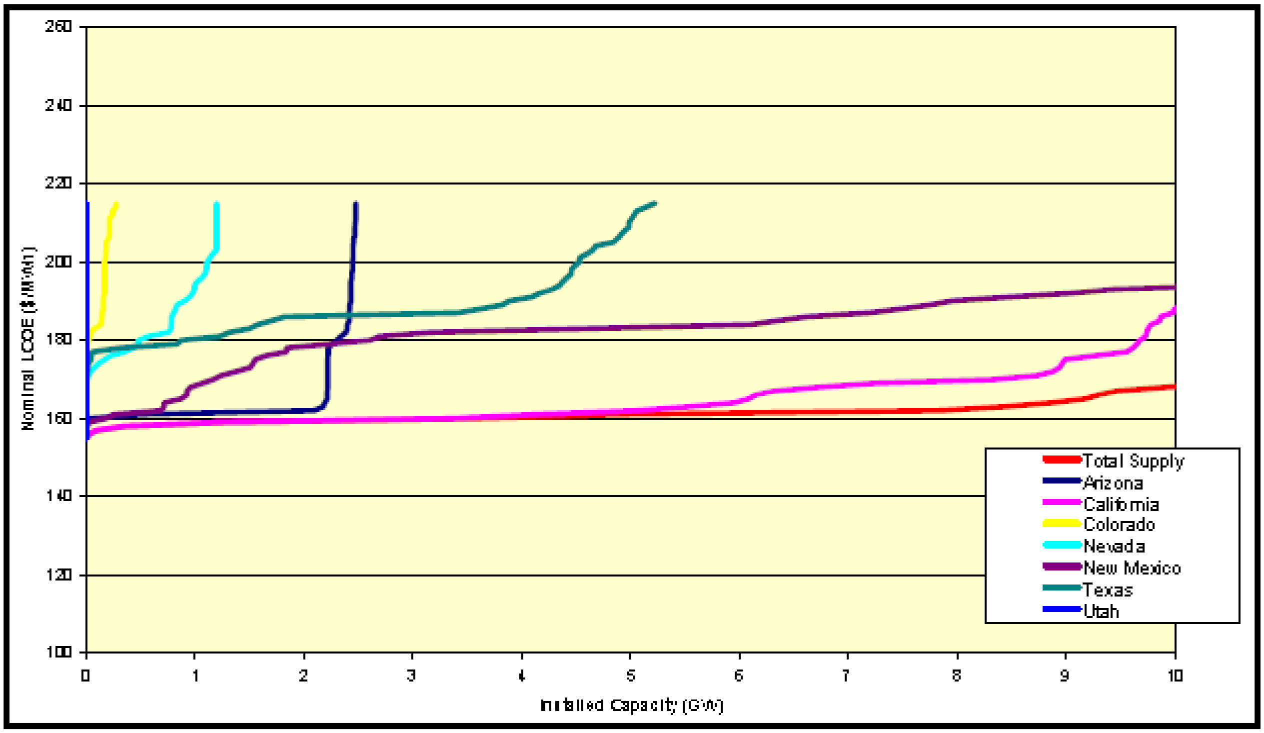


**Figure 11: CSP Energy Supply Curve, Assuming 20% Availability of City Peak Demand and 0% Availability of Transmission Capacity**[22]

Other analysis by NREL resulted in supply curves for US rooftop PV, assuming both residential and commercial building rooftops. Results are summarized in Figure 12 and suggest a flatter and higher penetration supply curve for the west than for the east or Texas, based primarily on the relative levelized cost of rooftop PV in different regions. The implication for California is that, assuming PV penetration is economically driven, California will benefit if it can accommodate penetration levels well above the 15% limit currently applicable to individual distribution feeders. Again, this circumstance suggests the need for earlier and more in depth analysis of higher penetration cases in California than would be relevant in most other US states or regions.

[22] Source: Western Governors Association Solar Task Force Report, 2006, http://www.westgov.org/wga/initiatives/cdeac/Solar-full.pdf

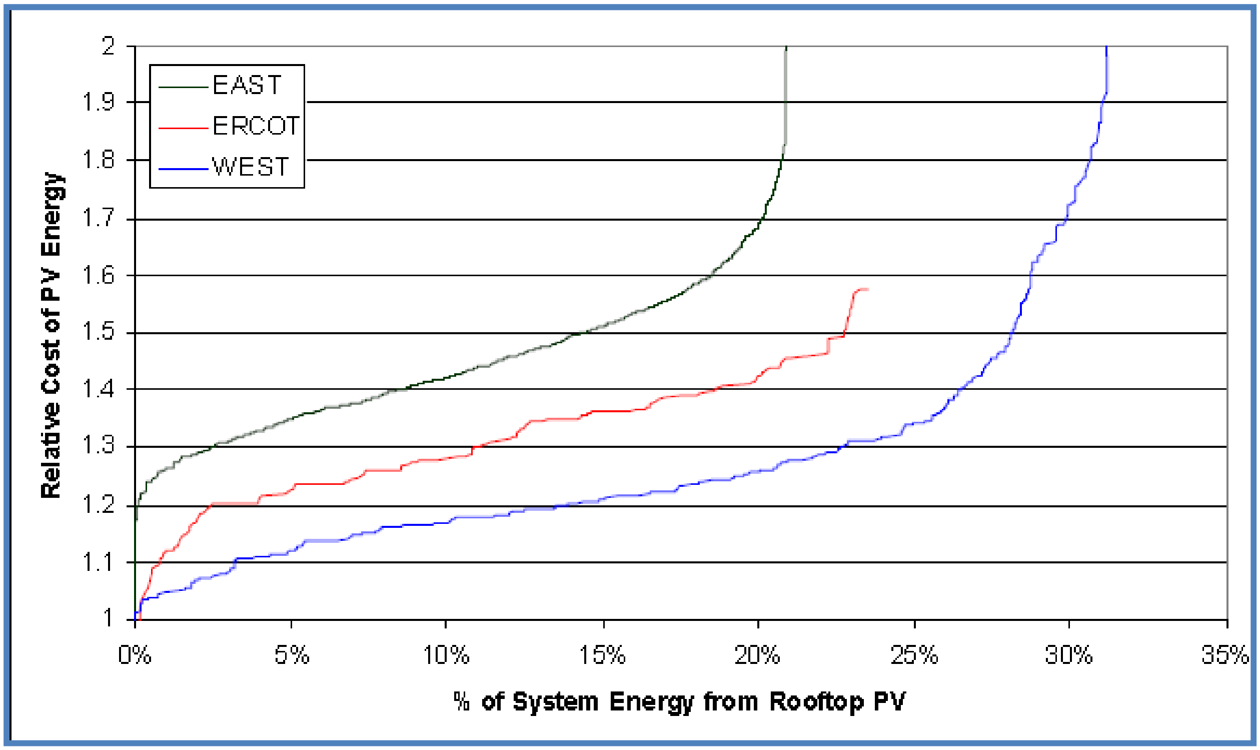


**Figure 12: Technology output characteristics typical of California sites vs. sites more typical in the rest of the US[23]**

### Large scale production and deployment issues common to California and the US and unique to California

Anticipating that its excellent solar resources will create market opportunities for solar companies across the entire supply chain and across multiple industries, California might consider how to leverage this scenario to the benefit of its overall economy. Which commodities and jobs are best generated in California? What deployment scenarios have the double benefit of enhancing California's balance of payments and also minimizing the cost of its energy?

Also, high penetration scenarios for variable resources raise the question of how energy storage investments can enhance overall economic benefits. For example, utility scale storage options such as compressed air storage, pumped hydro, and high temperature thermal storage have already been demonstrated and are in commercial use in daily cycling applications, and their economic benefits tend to increase as the penetration of variable renewable sources increase in a particular balancing area.[24] Further, almost all recent scenario work and long term supply planning assumes energy storage will be deployed according to the requirements of a market

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[23] NREL report entitled "Supply Curves for Rooftop Solar PV-Generated Electricity for the United States", Denholm and Margolis, 2008, http://www.nrel.gov/docs/fy09osti/44073.pdf

[24] Utility scale options typically provide services that either store off peak energy for delivery during higher demand periods. Thermal storage coupled to solar thermal power plants can also be used to boost overall plant output during peak periods or increase a plant's overall capacity factor,

that has no current structures or mechanisms to monetize value. Nevertheless, it is already clear that energy storage will find its way into California energy infrastructure one way or another.

Direct current electricity from solar photovoltaic systems can charge electric and hybrid vehicle batteries or at least supplement charging from the grid. High temperature storage that couples to concentrating solar arrays is in its commercial infancy. Even so, there is reason for confidence that it will not only serve to reduce bus-bar costs but also contribute value to the grid by transforming variable resources into "dispatchable" resources.[25]

Envisioning and evaluating scenarios that assume the coupling of CSP arrays with high temperature thermal storage is especially appropriate for California, because high penetration deployment of CSP will likely occur sooner in California's and adjacent desert southwest states than elsewhere in the US.

### Grid integration and environmental issues common to California and the US and unique to California

For the most part California does not differ significantly from other states in terms of grid integration and environmental issue facing solar deployment. California will likely reach high levels of market penetration sooner than most other states. The issues at these levels are generally not unique to California. Environmentally appropriate site selection and development of large CSP plants is an important but manageable issue.

There are, however, regulatory and market structure differences. One important difference, though difficult to evaluate, is the fact that California's natural gas and electricity markets are structured for competition at the wholesale market level but not at the retail level. Market structure differences and (difficult-to-predict) market structure changes could well be decisive in shaping California's solar energy market. These differences and changes will determine how solar energy deployment in California differs from deployment in other states. For example, the mix of electricity supply from building, community and utility scale solar photovoltaic systems may differ from that in other states. Differences in applications mix will indirectly influence the mix of technical solutions employed. For example, concentrating PV may have a particularly strong role in community scale systems in urban areas because of its smaller footprint than arrays using flat panels.

## GEOTHERMAL ENERGY

### Resource availability in California vs. resource availability across the rest of the US

Resource availability varies according to heat recovery technology. Figure 13 identifies the major categories as: 1) hydrothermal, 2) enhanced geothermal systems (EGS). Within these major categories there are significant variations related to resource temperature, geothermal

[25] The USDOE Concentrating Solar Power project portfolio is heavily weighted toward R&D on high temperature storage concepts, materials, components and systems. Results presented at a 2010 program review support the conclusion that thermal storage will be adopted as a standard feature of future generations of large CSP plants.

fluid characteristics, reservoir permeability, etc.  California has significant installed hydrothermal capacity, i.e. as shown in Figure 13, more than 80% of installed the roughly 3GW of current US installed capacity.  California also has 35-40% of the remaining capacity assumed by NREL for scenario development purposes.[26]

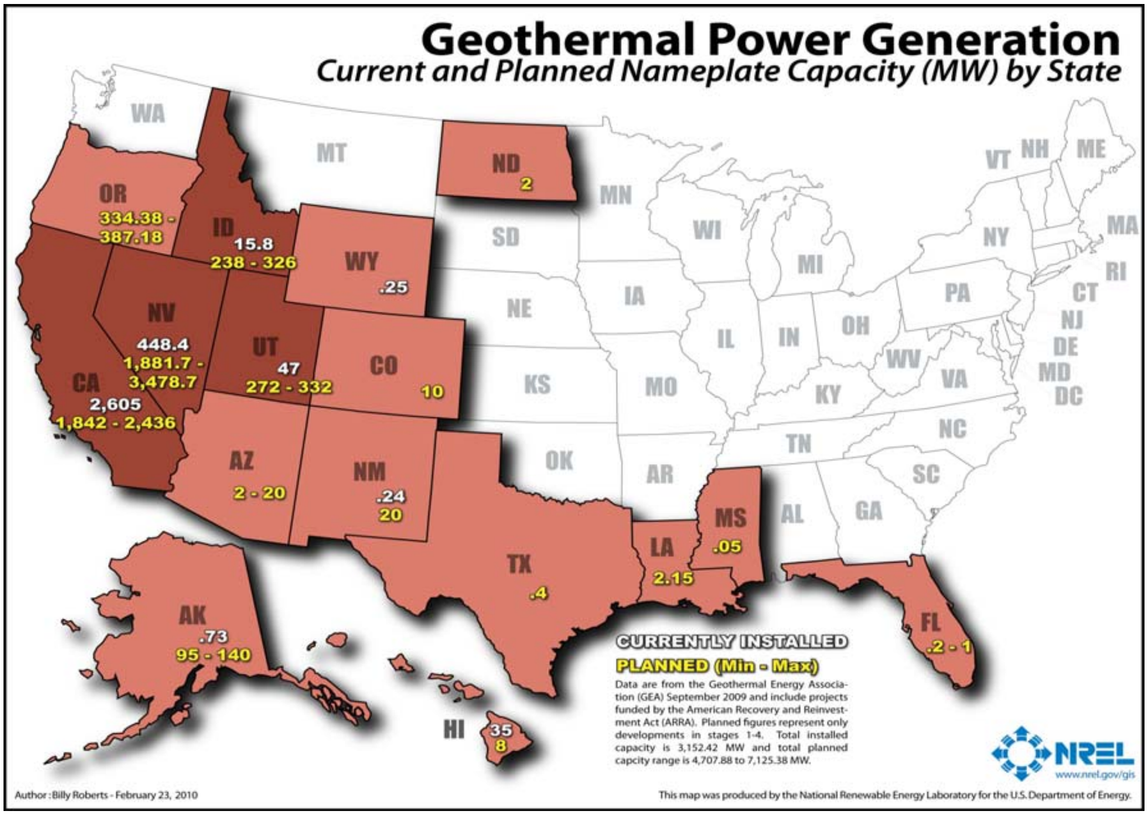



**Figure 13:  Current and Planned US Geothermal Power Generation**

Based on GIS mapping tools and statistical models of the spatial correlation of geological factors, estimates of undiscovered hydrothermal capacity in the range of 30GW have been also been published by NREL.[27]  They are summarized along with comparable estimates for other categories in Figure 14.  Favorable California geothermal areas are in the Sierras and Imperial Valley, the Coast Ranges and northeastern counties.  In addition, in the EGS category, NREL assumes 7GW of "near-hydrothermal fields in surrounding currently identified geothermal sites, and 16GW of deep EGS resources in rock at 3-10km depth and >150 degrees C.

[26] Inferred by the author from unpublished working papers of the on-going USDOE Renewable Energy Futures study

[27] Augustine, Young, and Anderson, Updated U.S. Geothermal Supply Curve, NREL Report, February, 2010, http://www.nrel.gov/docs/fy10osti/47458.pdf

| Resource | | Resource Potential Capacity | |
|---|---|---|---|
| | | Capacity ($GW_e$) | Source(s) and Description |
| Hydrothermal | Identified Hydrothermal Sites | 6.39 | USGS 2008 Geothermal Resource Assessment[1]<br>- Identified hydrothermal sites<br>- Sites ≥110 °C included<br>- Currently installed capacity excluded |
| | Undiscovered Hydrothermal | 30.03 | USGS 2008 Geothermal Resource Assessment[1] |
| Enhanced Geothermal Systems (EGS) | Near-Hydrothermal Field EGS | 7.03 | Assumptions based on USGS 2008 assessment[1]<br>- Regions near identified hydrothermal sites<br>- Sites ≥110 °C included<br>- Difference between mean and 95th%ile hydrothermal resource estimate |
| | Deep EGS | 15,908 | NREL 2006 Assessment[2], MIT Report[3], SMU Data[4]<br>- Based on volume method of thermal energy in rock 3-10 km depth and ≥150 °C<br>- Does not consider economic or technical feasibility |

[1] (Williams, Reed et al., 2008a)
[2] (Petty and Porro, 2007)
[3] (Tester et al., 2006)
[4] (Richards, 2009)

Figure 14: Summary of Geothermal Resource Characterization Used in NREL Supply curve Analysis[28]

California has significant opportunities to exploit low temperature resources useful for space heating and cooling, as well as direct use applications and cascaded systems.[29] Areas of California having long heating seasons are also areas with limited population densities, so geothermal heat pump markets may develop faster elsewhere.[30] Finally, California's solar power plants may be located close enough to hydrothermal resources or near-hydrothermal resources in some cases to justify consideration of hybrid power plant configurations.

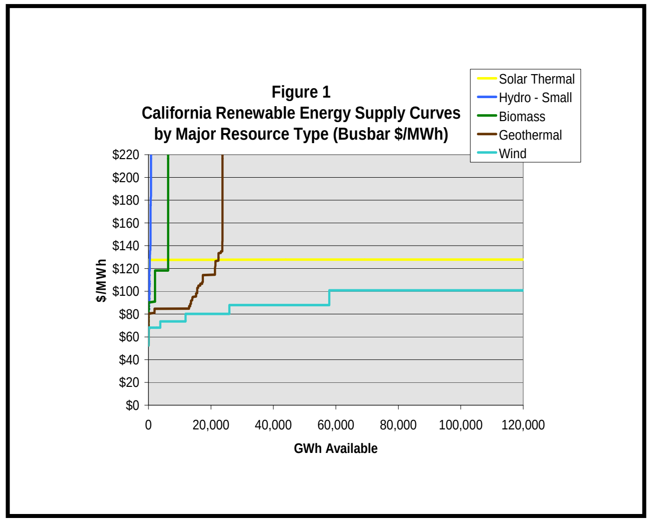
**Technology cost and performance typical of California sites vs. sites prevalent in the rest of the US**

[28] Augustine, Young, and Anderson, Updated U.S. Geothermal Supply Curve, NREL Report, February, 2010, http://www.nrel.gov/docs/fy10osti/47458.pdf

[29] Hybrid systems coupling geothermal sources with co-located or nearby wind and solar resources are also a possibility that is more likely to occur in California than elsewhere.

[30] Even so, these systems are consistently several times more efficient than the most efficient electric heating and cooling systems, providing a low carbon solution that can be obtained anywhere.

Geothermal power plant performance is dictated primarily by the resource and plant design, so there are no apparent reasons why California plants would perform differently than others. It is important to mention, though, that the performance of geothermal heating and cooling systems depends on other factors, including system size, design and local conditions affecting heat transferSuch systems may be advantaged in California based on higher avoided costs of electricity supply and delivery than in other parts of the country. This is not a permanent consideration but will likely apply in the near term. The combination of higher avoided costs, established industry capacity, and abundant potential market applications should enable California to continue to lead in geothermal energy deployment.**Preferred technology menu choices for California vs. preferred choices in the rest of the US**




Near-hydrothermal field EGS may be more opportune in California simply because for now, California has more existing hydrothermal capacity. The likely higher cost of near-hydrothermal plant development may also be better accommodated in California.

**California supply curve vs. supply curve for US overall**

The supply curve in Figure 14 shows the likely order in which resources would be developed based on levelized costs of energy calculated using NREL models. The base and target cases reflect the difference between funded (target case) and unfunded (base case) national R&D programs.

The supply curve for the US suggests a possible tenfold (from 3GW to 30GW) expansion of US geothermal capacity at comparable and probably affordable costs. The California supply curve from Figure 1 (see inset) suggests not only significantly higher current costs but also only a threefold (from roughly 5000 GWh to roughly 15,000 GWh) increase in expansion of supply at current costs. Some of the difference can probably be explained in terms of the deployment time horizons, i.e. 10 years for California and 40 years for the US. In any case, it would be in the interest of better understanding and more reliable scenario development assumptions to reconcile the differences.

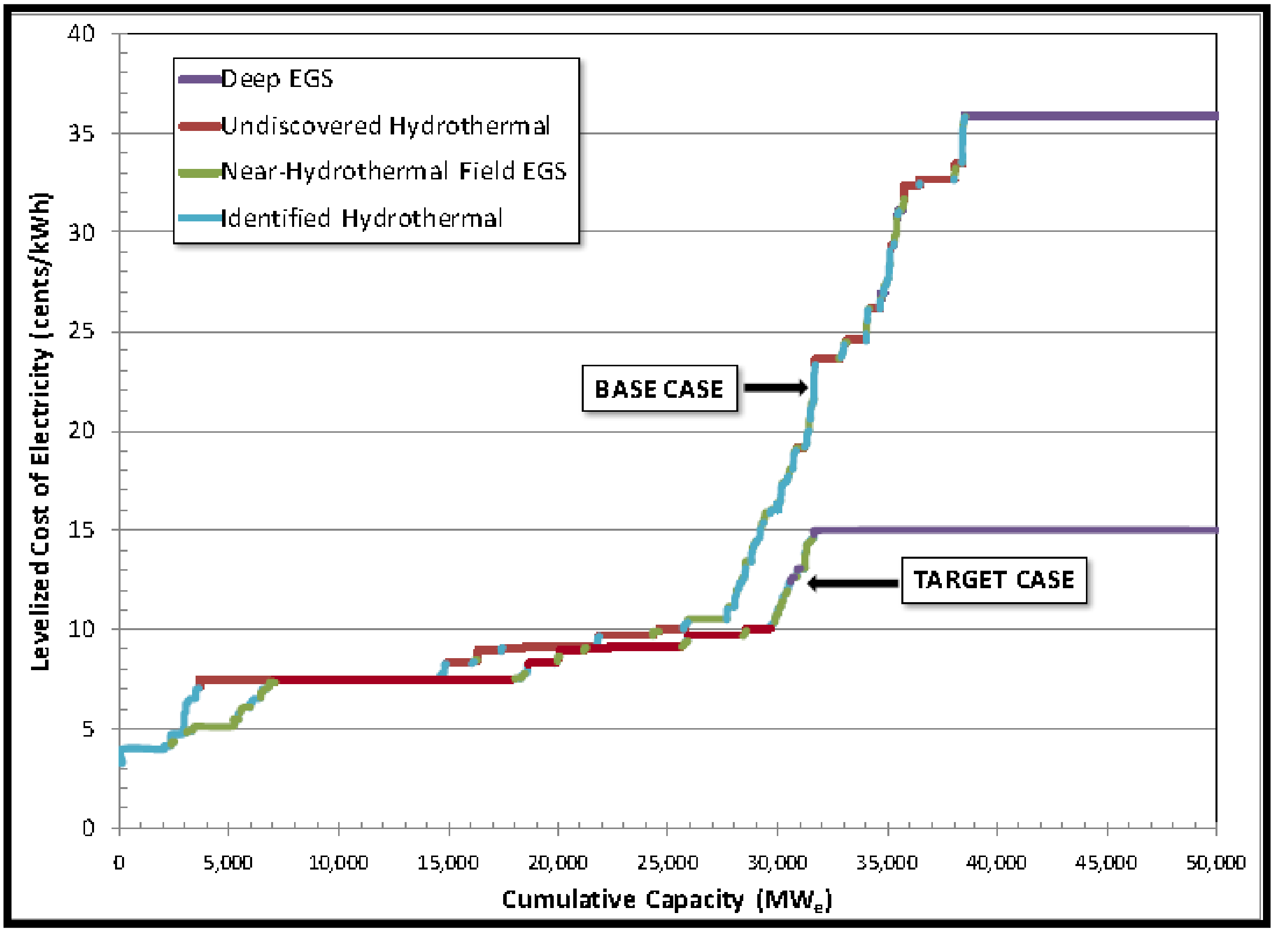



**Figure 14: Aggregated supply curves of the four geothermal technologies analyzed for base and target cases.** [31]

**Technology output characteristics typical of California sites vs. sites more typical in the rest of the US**

Geothermal resources are typically "base-loaded" and have high utilization factors up to 85 or 90%. Their short term variability relates to seasonal ambient temperature and humidity changes that affect thermodynamic conversion efficiencies. Their long term variability relates to reservoir pressure, fluid and temperature declines that can affect plant output prior to the end of plant life, as has been experienced at The Geysers. These variations can be mitigated by geothermal fluid reinjection or water surface water injection and by other techniques of reservoir stimulation. Having more existing capacity, California will face a greater need to address long term variability

Typically, geothermal power plants are not operated for load following purposes, because variable production costs are low and justify continuous full capacity dispatch. However, some California plants do have the technical capability for efficient part-load operation. In the long

[31] Augustine, Young and Anderson, Updated US Geothermal Supply Curves, NREL Report, February, 2010, http://www.nrel.gov/docs/fy10osti/47458.pdf

term variable output geothermal plants will enable higher overall renewable electricity penetration than would otherwise be possible, and so it is not too soon to begin to understand the technical and economic trade-offs involved in such scenarios.[32]

### Large scale production and deployment issues common to California and the US and unique to California

Hydrothermal power plant development is limited to naturally occurring sites. These sites vary in terms of convenience to existing transmission corridors. California's known hydrothermal areas are relatively convenient to population centers in most cases. Other states may face greater or lesser challenges in accessing their best geothermal resource opportunities. Deep EGS, when mature, will likely have greater site selection flexibility, resulting in opportunities to better use existing transmission resources.

### Grid integration and environmental issues common to California and the US and unique to California

Economic attributes favoring base-load design and operation may be favored in California to a greater extent than in states having generation mixes weighed toward coal and nuclear. The evolution of California's generation mix would appear to be in the direction of variable resources like wind and solar with base-loaded natural gas resources gradually phasing out. In a generation system optimization context, geothermal is an excellent complement to inherently variable resources. Looking to the longer term, some degree of ramping and load following capability may have economic value even if planned for limited use under relatively unusual modes of grid operation.

Land use, water use and emissions characteristics of geothermal power plants vary significantly according to geothermal fluid conditions and heat recovery methods. California is advantaged in having assessed and developed mitigation strategies that allow environmentally acceptable project development. Emerging issues, such as induced seismicity apply more to EGS than hydrothermal and are common to California and the US. Land subsidence occurs as a result of long term operation where fluid production exceeds recharge rates. Other underground resource (e.g. fresh water, oil, and natural gas) production methods can also cause subsidence, which is of greatest concern in population centers subject to flooding.

## BIO-POWER

### Resource availability in California vs. resource availability across the rest of the US

Biomass resources are generally classified into five major categories: urban wood wastes, mill residues, forest residues, agricultural residues, and dedicated energy crops. These resources

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[32]It is a good starting assumption that a mix of energy storage and flexible geothermal or bio-power will be the preferred solution to achieve acceptable reliability in net zero carbon community scale systems and eventually in state and national power grids as well.

are widely distributed throughout much of the United States, as shown in Figure 15. The availability, characteristics, and acquisition costs of each of these resources vary significantly.

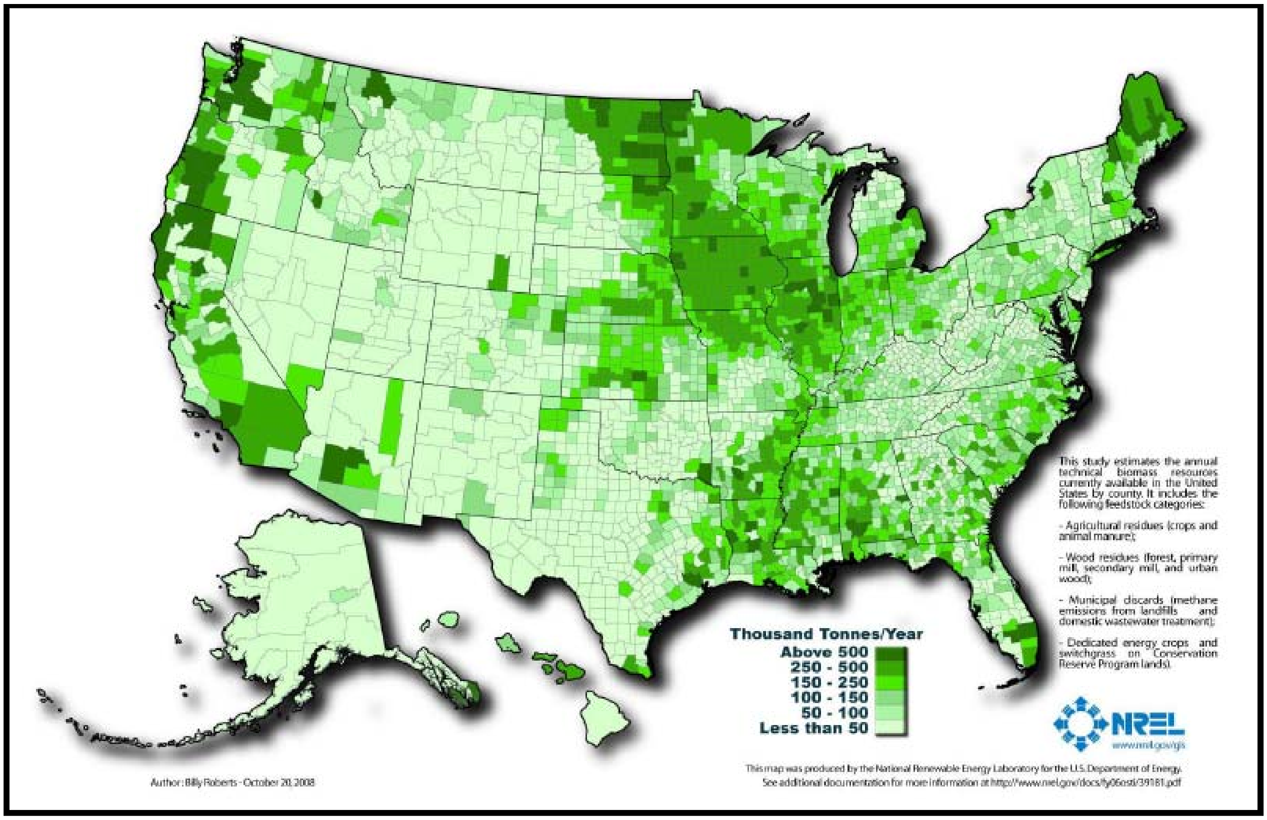


**Figure 15: US Biomass Resource**

Urban waste consists of woody materials, such as yard and tree trimmings; site-clearing wastes; pallets; packaging materials; construction and demolition debris. These wastes are concentrated at single source; diverted from landfills and, in some cases from composting facilities.

Primary mill residues consist of bark stripped from logs; coarse residues (chunks and slabs) and fine residues (shavings and sawdust) from processing of lumber, pulp, veneers, and composite wood fiber materials. These residues have the benefit of being concentrated at single source and are clean but with significant moisture content, i.e. ~20% moisture; most material is used as fuel or inputs in manufacture of products

Forest residues consist of Logging residues (small branches, limbs, tops, and leaves); rough, rotten, and salvable dead wood (RRSD). Most of the RRSD material is inaccessible due to the absence of roads or access, is not economically retrievable with current technology, or is located in environmentally sensitive areas. Forest residues include tops, limbs, and other woody material not removed in forest harvesting operations in commercial hardwood and softwood stands, as well as woody material resulting from forest management operations such as pre-commercial "thinnings" and removal of dead and dying trees.

Agricultural residues are primarily corn stover and wheat straw; other grain crops are limited in acreage or the amount of residue is small. Dedicated energy crops are typically short rotation woody crops (SRWC) such as hybrid poplar and hybrid willow; herbaceous crops such as switch grass. Geographically, the land that could be used for dedicated crops overlaps forest and croplands.[33]

Figure 16 shows the available energy content for each US biomass resource based on the 2005 inventory, the estimated 2020 potential, and the long term 2050 potential. Across the US, mill, forest and agricultural residues currently predominate. California has its share.[34]

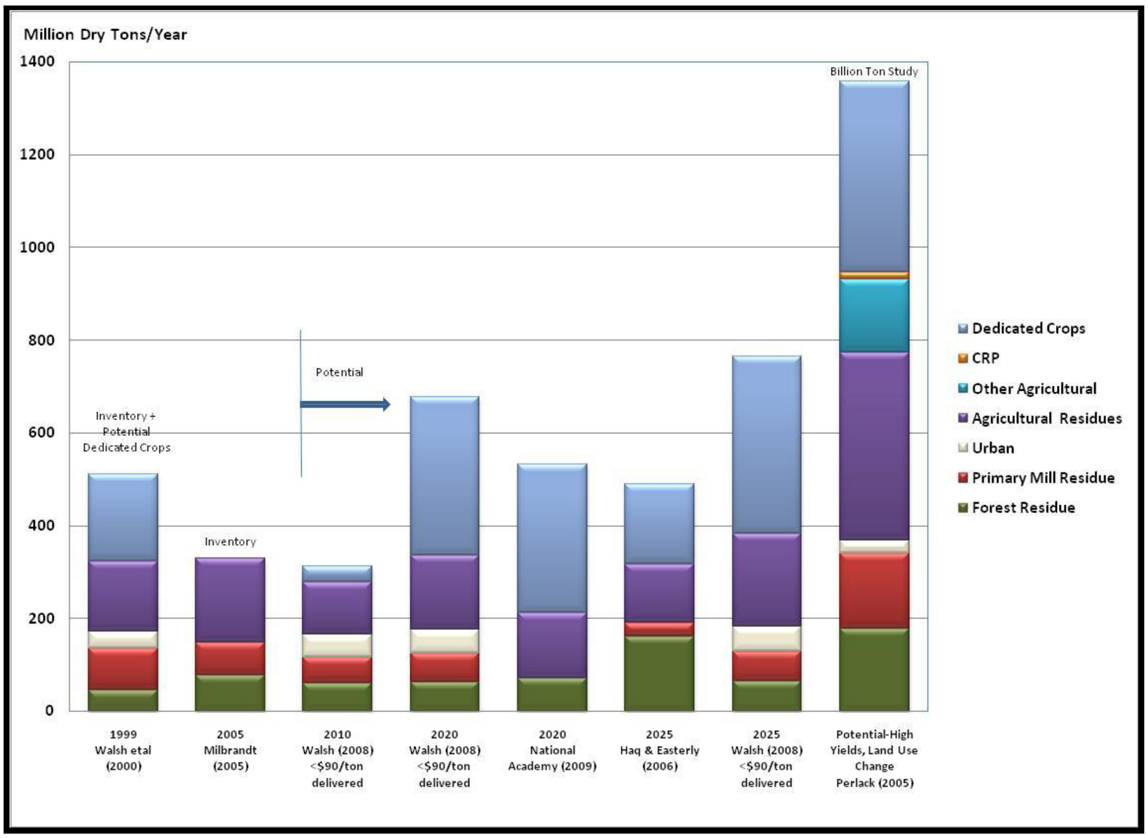


**Figure 16: Biomass Supply Scenarios[35]**

[33] http://www.narucmeetings.org/Presentations/Bain,%20Biopower,%20NARUC,%20Jul%202010.pdf

[34] An exhaustive inventory of California biomass resources is presented in a report prepared by Robert Williams of the California Biomass Collaborative in 2007.

[35] http://www.narucmeetings.org/Presentations/Bain,%20Biopower,%20NARUC,%20Jul%202010.pdf

Figure 17 shows a distribution of existing California bio-power resources in line with national fuel inventory distributions, but more heavily weighted to forestry resources vs. agricultural resources.  Reference to estimates of gross potential, California appears to be exploiting about 10% of its gross potential (968MWe out of 9500MWe) and 25% of its technical potential (968MWe out of 3820MWe).  This suggests a need to investigate the question of economic potential.

Forest residues may be the major area of current economic use where the California outlook may differ from the rest of the US.  In the future California may generate more than its share of forest residues if forest thinning for purposes of wildfire suppression becomes more prevalent. On the other hand it may lag other states having significant agricultural residues given its relatively limited production of grain crops.  The outlook for dedicated crops in California is clouded by uncertainties in pricing and allocation of water for irrigation, a subject of current and increasing concern.

| | Fraction | Allocated Mwe |
|---|---|---|
| Urban Wood | 0.31 | 176 |
| Forest | 0.46 | 262 |
| Agricultural | 0.16 | 91 |
| Food Processing | 0.07 | 40 |
| Total | 1.00 | 569 |

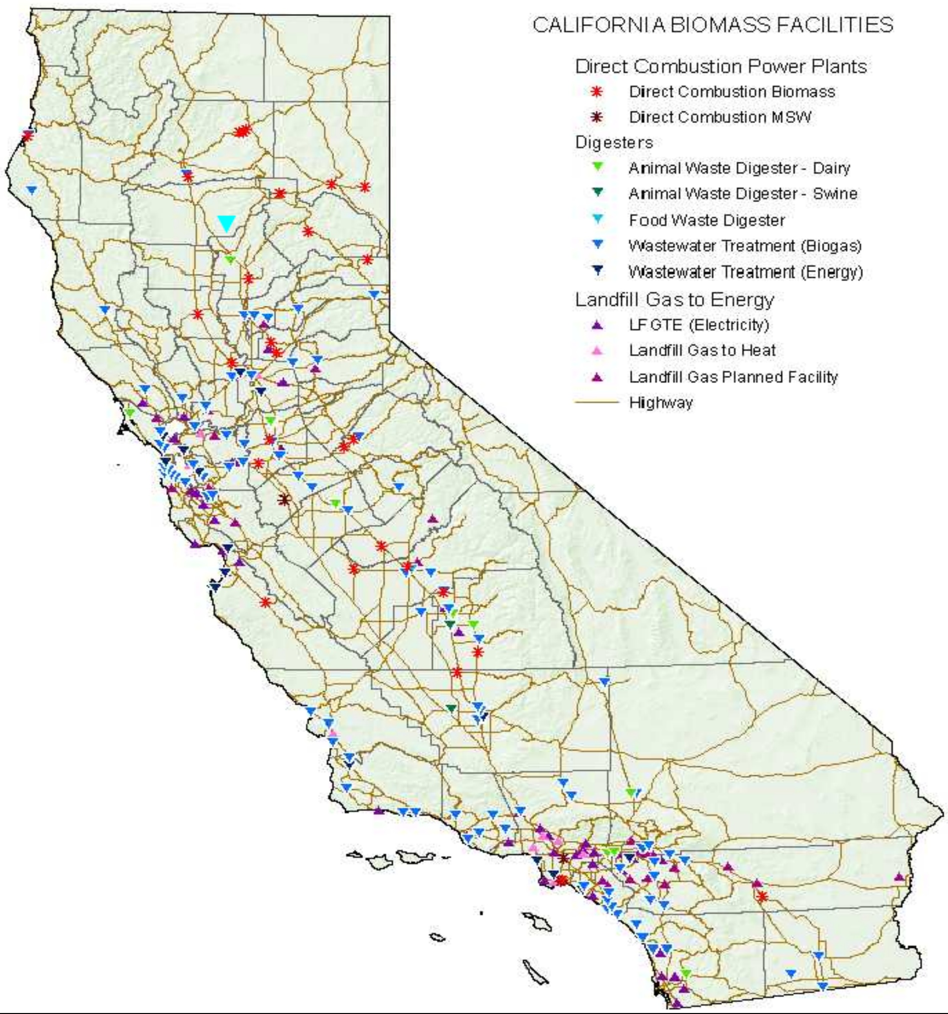


**Figure 17: California Biomass Facilities**[36]

### Technology cost and performance typical of California sites vs. sites prevalent in the rest of the US

Bio-power cost and performance is heavily influenced by feedstock sourcing and processing, and also by the cost of meeting air quality standards. Generally, urban wood wastes are the least expensive biomass resource, followed by mill residues, forest residues, agricultural residues, and energy crops. This reflects the costs of acquisition (offsetting landfill tipping fees), collection (or production and harvesting), and processing. Urban wood wastes, mill residues,

[36] http://biomass.ucdavis.edu/materials/reports%20and%20publications/2008/CBC_Biomass_Resources_2007.pdf

agricultural residues, and forest residues are often available in small and dispersed amounts, creating high transactions costs. Prices do not include any processing of wastes at conversion facilities.

Because of the non-attainment of healthy air quality in certain areas, including part of the Central Valley where agricultural residues are available, California's air quality standards are relatively stringent and particularly costly to meet using conventional distributed generation technologies.

**Preferred technology menu choices for California vs. preferred choices in the rest of the US**

For power generation from biomass fuels, direct combustion has long been the preferred technology in the US. Almost all biomass- and waste-fired power plants in the United States rely on direct combustion technology. Because biomass has lower sulfur content, coal-fired power plants that co-fire biomass can significantly reduce sulfur dioxide emissions. Biomass gasification is an emerging technology that can be used in advanced power cycles such as integrated gasification combined cycle (IGCC).

Commercial technology choices in California have mirrored US choices and its bio-power fuel mix is not unlike the average US bio-power fuel mix. However, in its research and demonstration programs, California has emphasized bio-digesters rather than thermo-chemical gasification, and its emphasis has been on coupling bio-gas sources to distributed generation technologies such as micro-turbines, fuel cells, and diesel generators adapted to convert methane based gas streams. Other California efforts have involved injection of bio-gas into natural gas grids for purposes of virtual bio-power generation at power plants whose fuel source is natural gas.

Looking ahead, California will see less biomass co-firing of coal-fired plants than the rest of the US, for the simple reason that there are relatively few coal-fired plants in California and little likelihood of adding any in the foreseeable future. Heat rates of existing dedicated biomass fuels thermal power plants in California are higher than the US average, perhaps because the plants are aging, having been commissioned in the 1980s. This leads to interest in IGCC retrofits at existing plants, a topic the California Biomass Collaborative is investigating under PIER sponsorship. Experience, especially cost experience, with digester based bio-power systems in California has been mixed, and there is growing interest in virtual bio-power enabled by pipeline injection. One of PIER's RESCO projects is addressing the need for better understanding of the engineering and economic experience with bio-digesters.

Estimated supply curves for the US are shown in Figure 18. Comparable estimates for California per se do not appear to be available in published form, but a supply curve developed by NREL based on California data is presented in Figure 19. Its price ranges and volume dependencies are consistent with the US supply curve in Figure 18. As noted earlier, there is a need to develop supply curves that account for potential incremental biomass resources available in California. This will require attention to the matter of conversion efficiency. California's existing plants were deployed twenty or more years ago and consist of relatively small, aging Rankine cycle plants that have heat rates in the range of 18,000BTU/kWh, somewhat above the national average for bio-power and about twice the heat rates of modern coal and natural gas fired power plants. Thus, inefficient fuel utilization in existing plants may suggest investigations into repowering of existing plants or development of new plants that make better use of current fuel resources and permit economic utilization of additional resources in the technical potential category.

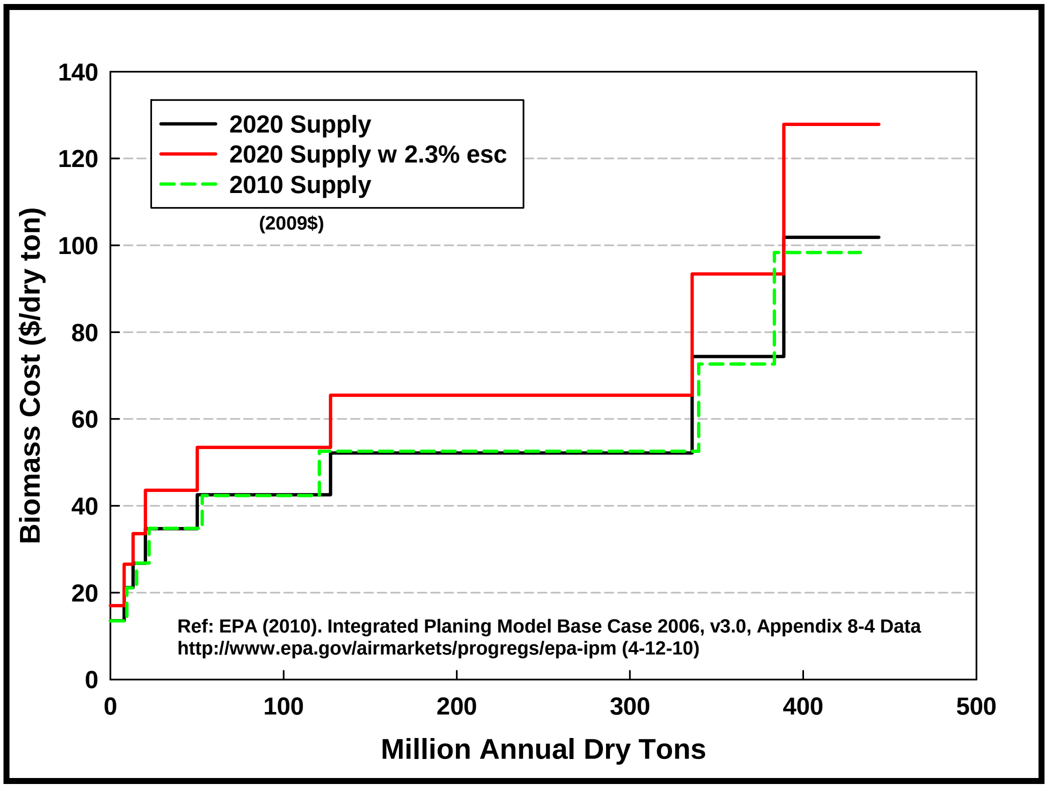


**Figure 18: US Biomass Power Plant Fuel Supply Curve[37]**

[37] Data from which the curves are developed may be found at http://www.epa.gov/airmarkets/progsregs/epa-ipm/docs/v410/Chapter11.pdf

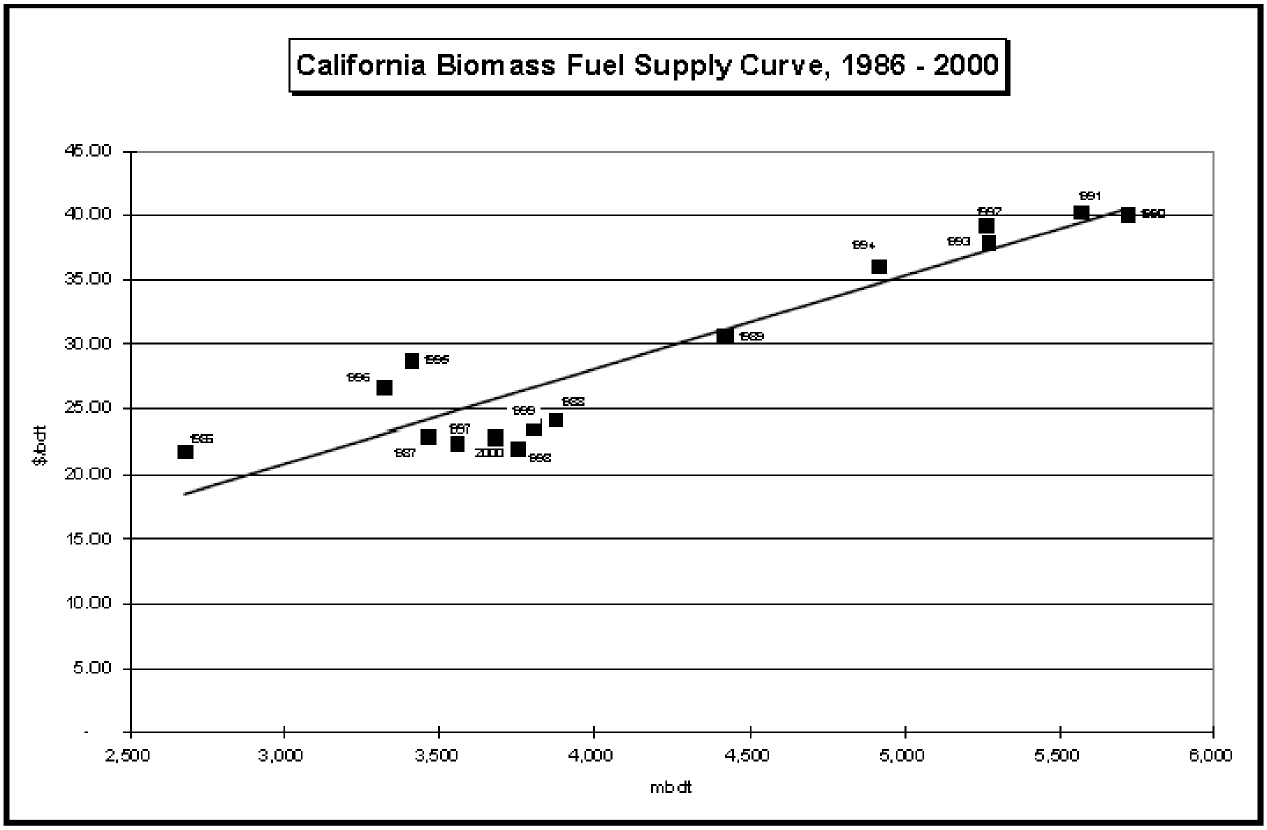


**Figure 19: California Biomass Power Plant Fuel Supply Curve**[38]

**Technology output characteristics typical of California sites vs. sites more typical in the rest of the US**

As discussed above, biomass power plants typically operate at high utilization factors, and thermal plants converting solid fuel typically have limited load-following or ramping capability. However, this is necessarily the case for small plants using gasified biomass or large plants designed for natural gas conversion and able to accommodate natural gas supplies that are supplemented by bio-methane. A major emphasis of PIER's biomass program has been on bio-digester and thermo-chemical gasification based distributed generation, and California almost certainly has more demonstration experience with such solutions than most other states. This supports a possible strategy of deploying distributed bio-power as an element of renewable energy secure communities, micro-grids and virtual power plants that may become commercially feasible depending on policy changes that provide encourage related planning and investment. Distributed bio-power would be a natural complement to a generation mix featuring variable distributed generation resources, e.g. solar and wind.

[38] Source: NREL Report, Bain and Amos, 2003. See http://www.fs.fed.us/ccrc/topics/urban-forests/docs/Biopower_Assessment.pdf

### Large scale production and deployment issues common to California and the US and unique to California

There are no technology related issues associated with large-scale deployment of co-firing and dedicated bio-power technologies since they are commercial technologies. There is currently comparable dedicated and co-fired bio-power capacity in the US, and economic considerations strongly favor expansion of co-fired capacity. California has limited options for co-firing, so its mix of bio-power capacity between co-fired and dedicated plants will increasingly diverge from the rest of the US. This has cost and deployment strategy implications for California that deserve attention.

In the context of limited co-firing options, the largest issue for larger scale deployment of bio-power in California may become feedstock competition with ligno-cellulosic bio-fuels. Since biomass is a limited resource, the amount of electricity and bio-fuels that can be produced is also limited, and it will be important to policy makers to understand whether to encourage attention to electricity production or bio-fuel generation and whether California's bio-power strategy should emphasize electricity generation close to the feedstock source or gasification of feed-stocks for purposes of pipeline injection and "virtual bio-power" generation in California's natural gas fired power plants.

### Grid integration and environmental issues common to California and the US and unique to California

Bio-power faces more significant grid integration issues as a distributed generation resource than as a traditional central station resource. The direction of California's bio-power research has emphasized deployment at the distribution level of the state grid. Bio-power shares with other distributed generation options a general lack of appropriate market structures and properly quantified avoided cost benchmarks.

Across the US, bio-power faces barriers at the local, state, and federal levels, including high capital and operating costs for demonstration and scale up systems, feedstock cost and supply uncertainty, limited and short-term incentives, inconsistent regulations, high investment risks, and conflicting expert views regarding primary and secondary impacts of deployment, e.g. short and long term greenhouse gas generation and carbon sequestration. In California, there has been strong policy support for bio-power by the California Energy Commission, and many research, development and demonstration projects have been conducted in support of California policies. This legacy may result in greater future success in addressing barriers.

## SUMMARY AND CONCLUSIONS

Will California encounter high penetration renewable energy deployment challenges and opportunities requiring special efforts that complement generic research and technology advancement work of Federal programs?

According to the comparisons in this report, yes they will, if California's renewable energy portfolio is to be both balanced and economically maximized and optimized. California's wind resources are unique, and the mix of onshore and offshore resources likely to develop over the long term poses special questions of integration and assessment. California's solar resources are exceptional, suggesting a scenario in which California will be the first to encounter the challenges and opportunities of optimizing high penetration deployment across multiple scales and venues of deployment. California's geothermal resources will be an exceptionally valuable asset complementing the high penetration deployment of utility scale wind and solar resources, and each major increment of additional supply will require new information and solutions. California's most opportune biomass feedstock inventories are limited and geographically dispersed but nevertheless an exceptionally valuable asset complementing high penetration deployment of community and building scale solar and wind resources.

Referring to published information for the US overall and comparable information from earlier assessments for California, it is possible to identify areas where conclusions for the US as a whole would generally also apply to California, as well as areas where comparable analysis would be needed using California-specific assumptions. Based on this working paper's comparative analysis, Table 1 identifies combinations of resource category and strategic topic where on-going California-specific assessment and analysis will be needed.

In most cases it will be important that assessment and analysis be closely linked to test, demonstration and commercial experience. The table shows that, while few of California's challenges and opportunities are unique, many are qualitatively and quantitatively different. So, California's renewable energy deployment efforts will be best served by reference to both national programs supporting national deployment and state programs tailored to issues and opportunities of special importance in California.

| California/US Comparison: Renewable Energy Deployment Factors | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Wind | | Solar | | | Geothermal | | Biomass | |
| | Onshore | Offshore | PV | Heat/Cool | CSP | Utility | Heat/Cool | Forestry | Agriculture |
| Supply Curve | Different | Different | Similar | Similar | Unique | Unique | Different | Similar | Unique |
| Resource Availability | Different | Unique | Similar | Similar | Different | Different | Different | Similar | Similar |
| Cost and Performance | Unique | Similar | Similar | Different | Similar | Similar | Different | Similar | Similar |
| Preferred Techology Mix | Similar | Different | Different | Similar | Similar | Similar | Similar | Different | Different |
| Output Characteristics | Different | Different | Different | Similar | Different | Similar | Similar | Similar | Similar |
| Large Scale Production | Different | Different | Similar | Similar | Unique | Similar | Similar | Different | Different |
| Grid Integration and Environment | Different | Different | Different | Different | Different | Different | Different | Different | Different |

**Table 1: California Compared to Rest of US: Renewable Energy Deployment Factors**