CALIFORNIA WIND RESOURCES

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Abstract

California has one of the most diverse electricity supply systems in the nation with a large potential to generate electricity from renewable sources, such as wind, biomass, geothermal, hydroelectric and solar. With the recently adopted Renewable Portfolio Standard (RPS), the challenge facing the state will be how best to integrate and manage renewable energy resources with traditional generation while ensuring a reliable electrical system.

Renewable technologies are continuously improving. Although many of the power qualities with existing wind technology have been address, issues related to increasing intermittent wind resources are introducing new challenges. Though new technologies are on the horizon, several barriers combine to limit the number of areas to generate power form renewable resources such as wind. These barriers include transmission capacity constraints, intermittency management issues, and occasionally perceptions, which combine to limit available areas of renewable resources like wind.

California continues to be a leader in installed wind capacity with just over 2000 megawatts (MW), and the potential exists to double this amount in the next 5 years. In the future, renewable resources will play an even larger role in providing bulk electricity for the state.

Introduction

California has a tremendous supply of renewable resources that can be harnessed to provide clean and naturally replenishing electricity supplies for the state. Currently, renewable resources provide approximately eleven percent of the state's electricity mix. [i]

California's Renewable Portfolio Standard (RPS) established in 2002 by Senate Bill 1078 (SB1078, Sher, Chapter 516, Statutes of 2002) requires electricity providers to procure at least one percent of their electricity supplies from renewable resources so as to achieve a twenty percent renewable mix by no later than 2017. More recently, the California Energy Commission, the California Public Utilities Commission and the California Power Authority approved the Energy Action Plan (EAP), accelerating the twenty- percent target date to 2010.[i]

The purpose of this white paper is to provide estimates of the wind resources located within California and potentially available for use in meeting the RPS and EAP goals. Estimates are provided on the "gross" potential (i.e., the potential unconstrained by technical, economic or environmental requirements) and the "technical" potential (i.e., unconstrained by economic or environmental requirements). This information updates and expands upon resource information provided in the Renewable Resources Development Report of 2003.[i]

Wind Energy in California

Existing utility-scale wind power generation facilities can be found in five major resource areas in California (Figure 1):

- Solano
- Altamont
- San Gorgonio
- Tehachapi, and
- Pacheco.

Three of these primary regions (Altamont, Tehachapi and San Gorgonio) account for nearly 95 percent of all commercial wind power generation in California, and approximately 11 percent of the world's wind-generated electricity (Source: Energy Commission WPRS 2001-2002). With an average California household using 6,500 kWh of electricity per year, 3.5 billion kilowatt-hours (kWh) of annual electricity generation from wind resource in the state provides electricity sufficient to power over 530,000 homes.

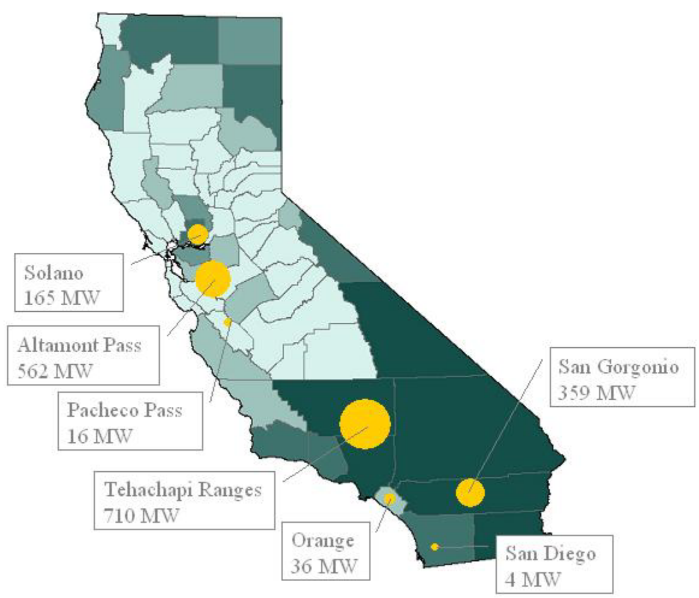


Figure 1. Existing Wind Resource Areas in California
(Source: Energy Commission WPRS 2003)

Quarterly wind output trends for 2001 are shown in Figure 2.

- 1st Quarter (January-March),
- 2nd Quarter (April-June),
- 3rd Quarter (July-September),
- 4th Quarter (October-December)

These trends are consistent with the typical California wind resource profiles: low winds at the beginning and end of the year and high winds during spring and summer when the warmer seasons create a natural draw of cool coastal air into hot inland valleys and deserts. The data indicate that almost 70 percent of all annual output was produced in the second and third quarters of 2001 and corresponds with California's peak demand for electricity during summer months. Since most of these facilities were installed in the early 1980s, the majority of the California wind turbine fleet turbines are under 1-MW, with annual capacity factors (CF) averaging in the mid-20 percent. In 2001, nearly 84 percent of operating wind turbines were smaller than 200-kW. These older and smaller turbines are considerably less efficient than the current turbines, which have higher CFs and are more economical. Figure 3 summarizes turbines types by resource areas in 2001. Since 2001 new installations and repowering of existing sites with larger, greater than 700-kW, higher efficiency turbines is underway at various sites.

With improved power electronics, lower tip speeds and reduced cost of electricity (COE), the larger size turbines are helping to revitalize California's wind energy industry.

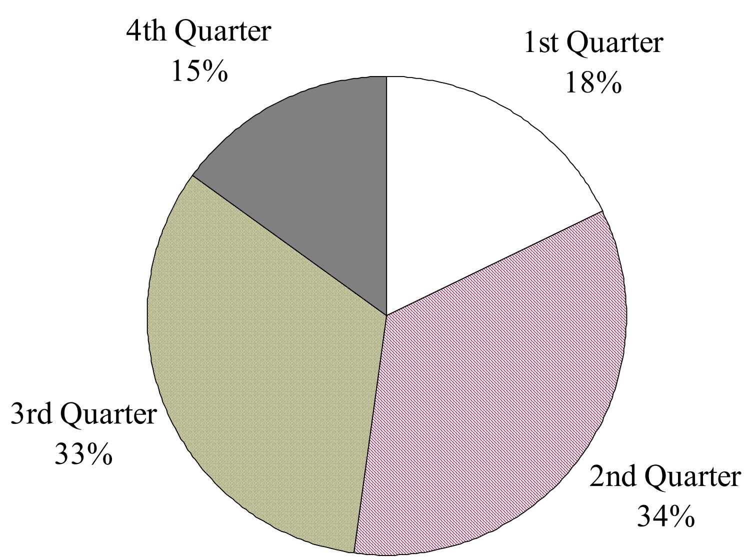
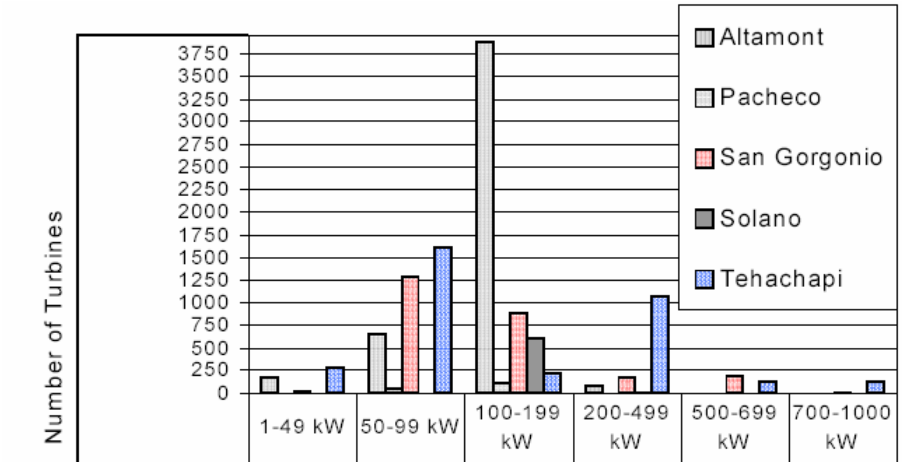


Figure 2. Statewide Wind Energy Production (Percentage per quarter in 2001)

(Source: WPRS 2001)



	1-49 kW	50-99 kW	100-199 kW	200-499 kW	500-699 kW	700-1000 kW
Altamont	171	655	3879	83	0	0
Pacheco	0	47	115	4	1	0
San Gorgonio	21	1283	879	172	191	10
Solano	0	0	600	17	0	0
Tehachapi	281	1610	223	1068	130	132

Turbine size

Figure 3. Type and Number of Turbines by Resource Areas
(Source: WPRS 2001)

Operator data trends from 1997 to 2001 show a general increase in operational capacity (Figure 4). This trend was due in part to new project development and performance improvements on new turbines. Moderate growth in wind generation throughout 2000 was partly due to re-powering efforts that got underway before the energy crisis as well as to various state incentive programs supporting renewable energy development. In general, it is difficult to discriminate between re-powering and new capacity unless the facility is a newly added facility (i.e., other than the standard offer, Standard Offer 4 contracts). For this paper, re-powering refers to the physical replacement of older turbines with new, more efficient turbines. This definition differs from the traditional definition which refers to refurbishing existing turbines with new blades, generators, or other components to increase the capacity and output. The current trend is that turbines are generally replaced not refurbished.

Specifically, Assembly Bill 1890 (AB1890, Brulte, Chapter 854, 1996) and Senate Bill 90 (SB90, Calderon, Chapter 227, 1996) continue to provide funding to support existing and new renewable energy projects.

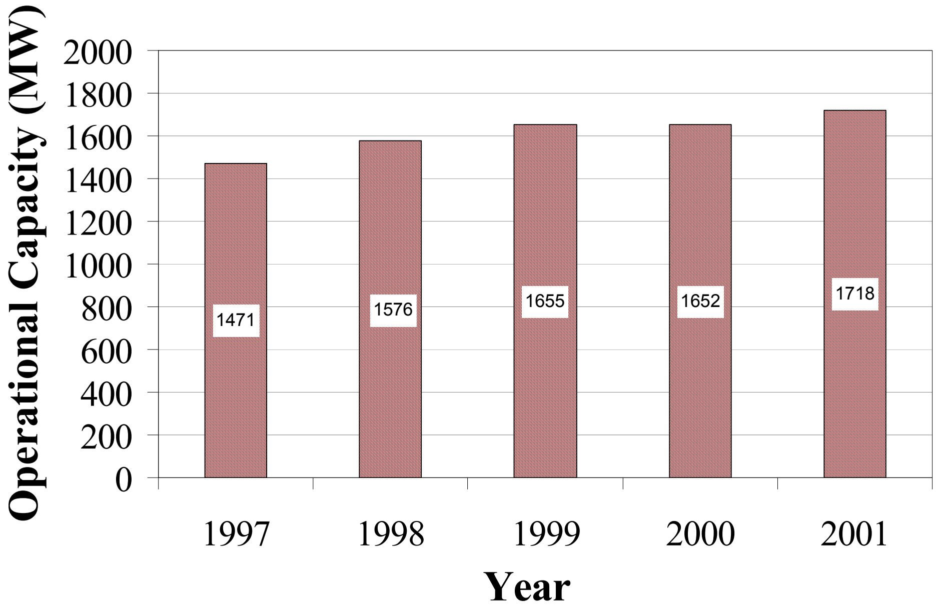


Figure 4. Total Installed Capacity in the State from 1997-2001
(Source: WPRS 2001)

Table 1 shows how the wind energy capacity in California changed from 1997 to 2001. Since 1997, installed capacity has generally been increasing. Re-powering activities accounted for much of the capacity changes in the late 1990s, but despite the instability in the California electricity market and changes to the federal production tax credit (PTC), new developments are still underway.

Table 1: Wind Energy Capacity Change from 1997-2001

Year	Capacity Change (MW)
1997	-164
1998	201
1999	65
2000	1
2001	68

(Source: WPRS 2001)

In 2001, over 65 MW of new capacity was installed at SeaWest's Mountain View facilities. In 2002, over 150 MW of new capacity went online at Florida Power and Light's (FPL) HighWinds facility in Solano County. (Source: WPRS 2003)

Wind Turbine Technology Characteristics

In the last few years, wind turbines have become sufficiently powerful, reliable, efficient and cost-effective to they rank them among the most appealing options for new power generation facilities. Wind power has been the fastest-growing energy source for over ten years, and their growth in the industry is accelerating with continuing advancements. During 2001 alone, the total wind power capacity installed worldwide grew by about 30 percent to approximately 24,000 MW by year's end.

Although many different configurations of wind turbines, most are classified as either horizontal-axis wind turbines (HAWTs) like the old-fashioned windmills, or vertical-axis wind turbines (VAWTs) such as the eggbeater-style wind turbines (Figure 5). VAWTs come in two major varieties; aerodynamic lift drives the Darrieus-style wind turbine, named for its French inventor, while the drag-based Savonius-style turbine captures and dumps wind with its cup-like fins to generate power. Many VAWT designs remain technically promising and may resurface in the future, but current economics and market perceptions have virtually eliminated them as contenders in the today's wind energy industry.

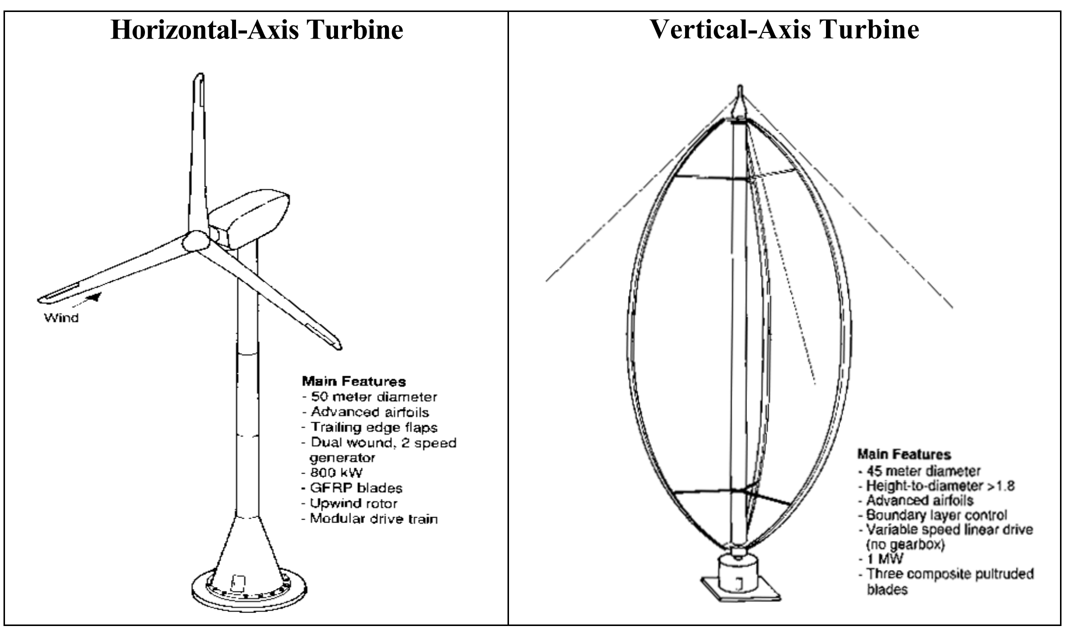


Figure 5. Two Common Types of Wind Turbines

(Source: Wind Turbine Technology[2])

In the past, the Energy Commission's Wind Performance Report Summary (WPRS) results tracked horizontal and vertical axis, utility-scale turbines performance numbers. After 1998, vertical-axis machines were not reported in the operating inventory. Nearly 100 percent of new and re-powered capacity comes from three-bladed, upwind, horizontal axis turbines manufactured outside of the U.S. With consolidations and restructuring of the California wind industry throughout the 1990s, operators have steadily cannibalized older turbines for parts and re-powered with new turbines whenever possible resulting in a general decline in the total number of turbines. In 1996, 13,404 turbines were reported in operation and at the end of 2001 there were approximately 11,572 turbines (Figure 6). This reduction in the number of turbines does not however indicate a souring market. In fact, the replacement of older turbines with newer and fewer turbines is helping to revitalize California's aging turbine fleet. Capacity factors are on the rise and generation numbers are remaining steady.

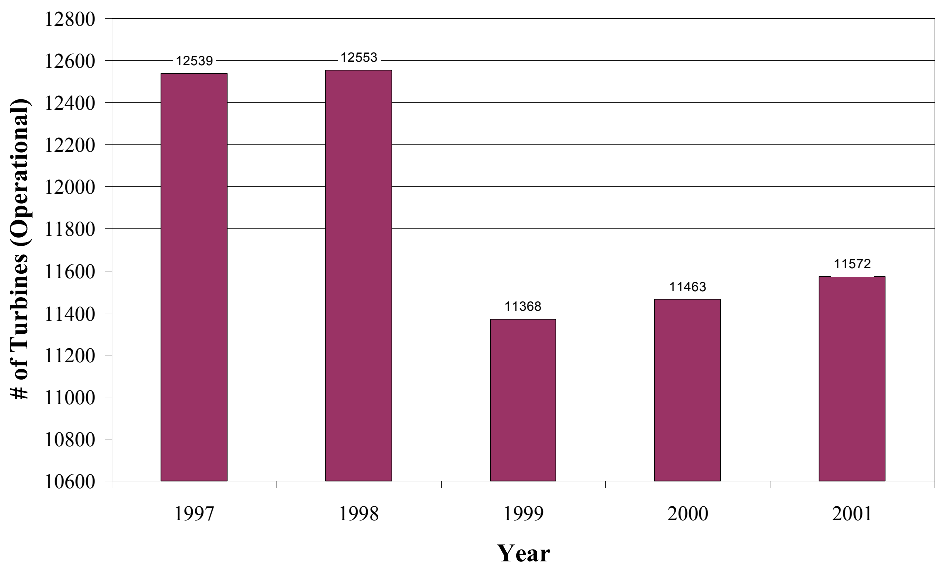


Figure 6. Total Number of Turbines in California from 1997 to 2001
(Source: WPRS 2001)

Almost all utility-scale wind turbines are currently two- or three-bladed HAWTs. HAWTs rely on aerodynamic lift to spin the rotor. As HAWT technology advanced during the last twenty years, power capacity from a single turbine grew from 24 kW in 1981 to 3,600 kW in 2001, while rotor diameters increased from 10 meters to over 100 meters (330 ft) today.[3] Large offshore turbines rated at 5 MW power output are currently under development.

The delivered electricity from wind is typically expressed in terms of capacity factor. The capacity factor is a performance parameter that assesses the net energy production from individual wind turbines in relation to their theoretical maximum output. This parameter can be helpful in monitoring performance within a wind power station over time. By definition the capacity factor is the ratio of actual net energy production to the product of the power rating times the calendar time interval of interest (see Equation 1).

$$CapacityFactor = \frac{NetEnergy\ Generated}{Power\ Rating \times Time} \quad (1)$$

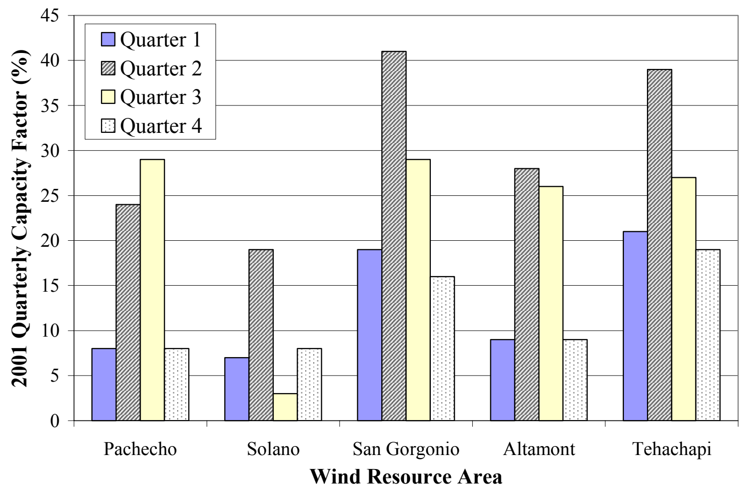
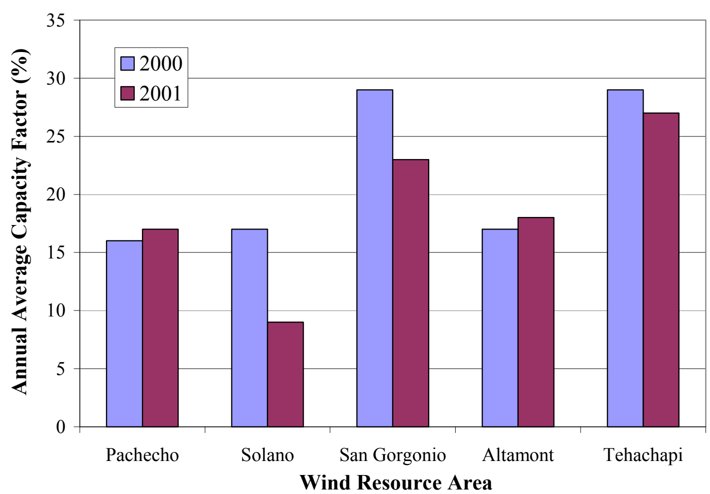


Figure 7. Average Capacity Factors for California Wind Facilities by Resource Areas - Quarterly Variations
(Source: WPRS 2000-2001).



(b)

Figure 8. Average Capacity Factors for California Wind Facilities by Resource Areas - Annual Average Variations
(Source: WPRS 2000-2001)

California's wind facilities have capacity factors that range from 10-41 percent depending on the year, season and weather conditions. Figure 7 and 8 illustrate the variability of capacity factors based on 2000 and 2001 data.

Over the past decade, various modifications and upgrades have increased the capacity factor by as much as 8 percent. Specifically, the turbines now include more aerodynamic blades, dual speed generators, power electronics and other component upgrades to improve and increase performance. To meet future challenges, turbine designs will need to look beyond incremental improvements in components. The next generation of turbines will need to operate over broader speed regimes, Class 2 to Class 6, to sustain generation in more turbulent and harsh environments and to be tailored for specific wind resource areas to maximize performance during peak demand.

Recent Development Trends in Wind Energy

Utility Scale Wind

With rising fossil fuel and natural gas prices, energy shortage concerns and environmental impact concerns, electricity from, non-polluting wind energy has steadily regained worldwide momentum. Trends throughout the 1990s have shown wind energy to be the fastest growing, most readily financed and implemented renewable energy technology, with worldwide operating installed capacity nearing 8,000 Megawatts (MW) in 1998 and exceeding 12,000 MW at the end of 1999. With some 3,900 MW of new wind capacity installed worldwide in 1999 alone[4], wind is proving to be valuable resource for affordable and reliable electricity generation.

In the United States (U.S.), federal and statewide support has helped to increase the market for wind generated electricity. From 1996 to 2000, wind generation capacity in the U.S. rose substantially, increasing by over 60 percent compared to about 25 percent increase in Europe. Table 2 summarizes the operational wind capacity worldwide in 2002.

Table 2. Worldwide Operational Wind Capacity.

	Installed Capacity (MW)				
REGION	**1996**	**1997**	**1998**	**1999**	**2000**
Europe	2,518	3,216	4,766	6,469	9,307
North America	1,676	1,681	1,611	2,010	2,619
Asia & Pacific	626	897	1,149	1,257	1,403
Others (South & Central America, Middle East & Africa)	24	45	62	78	126
Total	4,844	5,839	7,588	9,814	13,455

(Source: WindPower Monthly, 2003)

With nearly all U.S. manufacturers of utility-scale wind turbine out of business since the early 1990s, three-bladed, upwind turbines of foreign design dominate and remain the turbines of choice for new development and repowering efforts. Figure 9 compares U.S. and foreign turbine market between 1985 and in 2001. Domestic turbines accounted for 67 percent of the total installed capacity in 1985 as compared to only 37 percent in 2001. Approximately 35 percent of U.S.-manufactured turbines manufactured in the mid-1980s and early 1990s remain in operation in California. Currently the only U.S. supplier of utility-scale wind turbines is GE Wind Energy Systems, formerly Enron Wind Corporation.

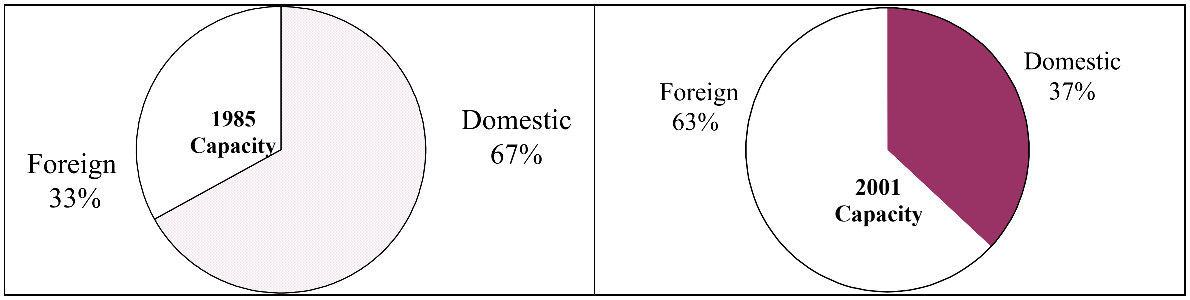


Figure 9. Comparison of Capacity by Turbine Origin from 1985 to 2001

(Source: WPRS 2001)

Current industry trend is toward larger and taller turbines (Figure 10). Driven in part by the economies of scale and by the offshore turbine market, the cost of energy (COE) for these mammoth systems is nearing an impressive $0.04/kW with capacity factors in the range of 38 percent-40 percent.
The new multi-megawatt turbines include mechanical improvements to blade design and aerodynamics, gearboxes, generators and other components which all potentially increase the capacity factor by as much as 4 percent.

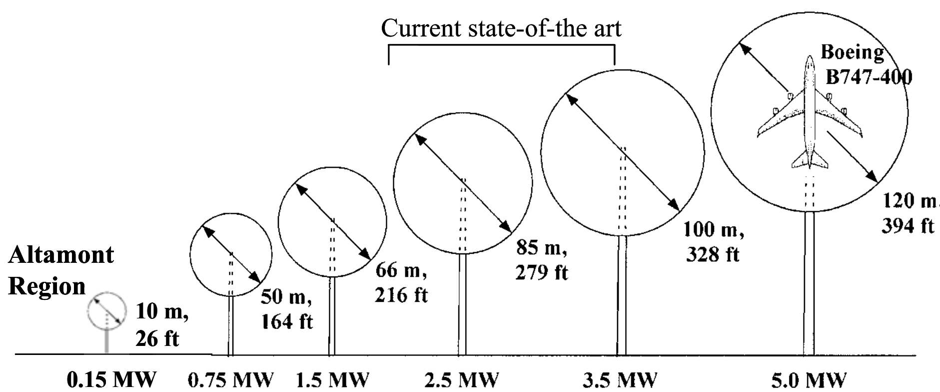


Figure 10. Wind Turbine Size Growth Trend

Additionally, implementing new designs for turbines could improve the capacity factor for a wind farm. For example, variable speed turbines have the potential to increase capacity factors by as much as 10 percent over fixed speed turbines because they provide peak efficiency a larger percentage of time, thereby increasing the net energy production of the turbine. For the large turbines, designing turbines with lower tip speeds, thus lower rotational speeds (RPM), is a way of increasing the capacity factor and increasing the longevity of individual turbines. Also lower tip speeds reduce the acoustic emissions from these systems, which helps to increase public acceptance.

Wind system trends in the 1980s focused on machines in the 25–250 kW range. In the mid-1990s, wind systems increased to the mid-range (500-kW but less than 1-MW). Currently, the state-of-the-art wind systems are multi-megawatt systems, standing 60 to 80 meters tall, these towering systems are exceeding the wind spans of large, commercial transport jets.

Recent turbine improvements allow them to operate better under turbulent wind loads, unsteady aerodynamic stall effects, and complex fatigue loads, making use of technology developments such as advanced airfoils tailored for wind turbine applications. Power electronics have been developed to allow variable rotor speed operation, which improves over-all turbine efficiency.[5]

Table 3 charts the increasing turbine sizes and energy and annual power output, from 1981 to 2000 and projected to 2020 for on-shore turbine applications. Notice that both the maximum diameter and tower hub height have increased over this period, enabling the typical annual energy output of a single turbine to increase by a factor of almost 80, with an order of magnitude decrease in energy cost. The world-wide trend is toward multi-MW turbines due to economies of scale and technological and material improvements allowing for taller turbines and larger rotors. However, besides wind resource location constraints, these turbines are approaching structural and material design limits.

For on-shore applications, multi-MW turbines will have realistic size constraints, potentially less than 2.5 to 3 MW. Assuming adequate wind resources at a site, the logistics of transporting 50 meters long turbine blades and other components well over the size and height of semi-trucks will prove to be a challenge.

Many of the multi-MW turbines (greater than 3 MW) are primarily targeted for offshore installations where winds are more consistent and less turbulent. As of 2003, the largest turbines have a rotor diameter of 104 meters, and a rated power output of 3.6 MW (GE Wind 3.6s). Numerous wind turbine manufacturers have their sights set on 5 MW turbines for offshore applications.

Table 3: Increases in On-Shore Wind Turbine Size and Output from 1981 to 2001 and Forecasted from 2005 to 2020.

Year	Rotor Diameter (m)	Hub Height (m)	Capacity Rating (kW)	Generation (MWh/yr)	Average Capacity Factor (%)
1981	10	25	25	45	21
1985	17	36	100	220	25
1990	27	40	225	550	28
1996	40	45	550	1480	31
1999	50	65	750	2200	33
2001	62	70	1200	3680	35
Projected					
2005	70	80	1500	4860	37
2010	80	80	2000	7000	40
2015	86	95	2500	9200	42
2020	92	105	3000	11000	43

(Source: EPRI 2002 Renewable Energy Technical Assessment Guide and Energy Commission)

Small-Scale Wind Energy

Since the mid 1990s, small-scale turbines have been increasing in size from under 1-kW to current systems approaching 100-kW. They are primarily used either on or off grid by residential homeowners, small farms, and rural areas. Unlike utility-scale wind turbines, several U.S. manufactures produce small-scale turbines. Bergey Wind Power has a successful line of 10-kW systems now available with a 50-kW turbine in development. Other U.S. manufacturers of turbines rated at 10 kW or less include Southwest WindPower and World Power Technologies (Figure 11).

(a) (b)

Figure 11. a) Bergey 10kW Wind Turbine, b) Southwest Windpower 3.5kW Turbine

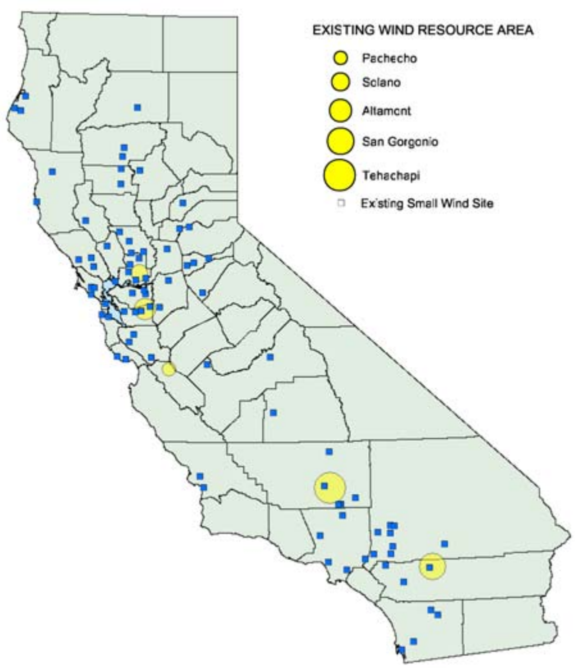


Figure 12. Grid-connect Small Wind Turbines in California

In 2001, small-scale turbines (less than 100-kW) account for just under 1 MW of grid-connected installed residential capacity and are spread across 36 counties throughout California. The number of small residential wind turbine systems is anticipated to rise with the passing of AB1207 requiring local counties to permit small wind systems. Figure 12 shows the locations of small wind turbine installations in relation to the large utility-scale wind generation facilities. Compared to utility-scale wind turbines, small systems have different aerodynamic control mechanisms and less efficient blade profiles. Small turbines are also reaching the limit of their directional or furling control capabilities. Many of the technology improvements made on large-scale systems are beginning to trickle down to the smaller systems.

As large turbines continue to grow in size, small turbine manufacturers will find a niche market offering small and mid-range turbines for low wind speed applications.

Understanding Our Wind Resources

In the late 1970s and early 1980s, the California Energy Commission conducted some of the first wind resource assessments in the world, leading to the development of the first large wind projects in the nation. The wind resource potential and power densities are shown in Figure 13 in relation to the utility-scale wind projects throughout the state.

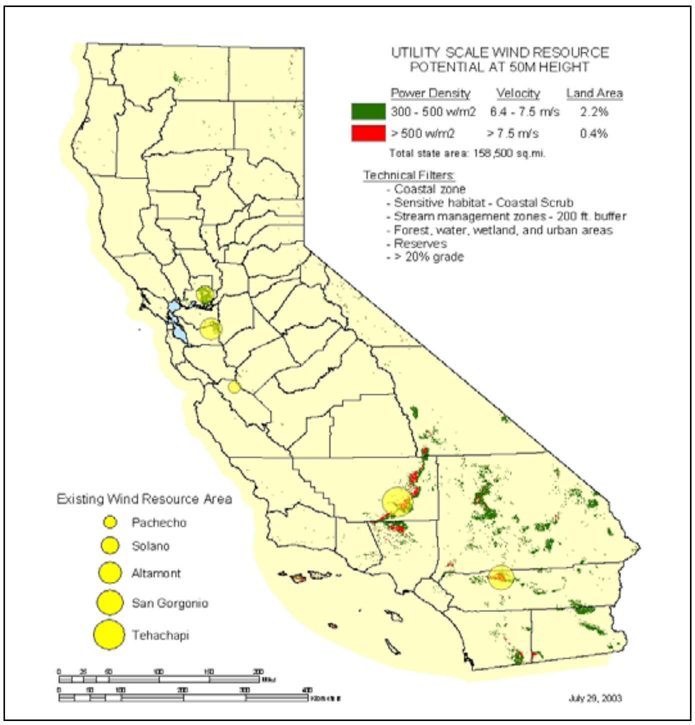


Figure 13. Existing Wind Resource Areas and Utility-scale Wind Resources in California at 50 m Hub Height

Table 5.1 summarizes the installed capacity, wind generation, and number of turbines from these five existing resource areas, based on 2003 data. The 1,880

MW of installed capacity translates to over 3.5 billion kilowatt-hours (kWh) per year of clean, renewable electricity for Californians.

Table 4. Wind Energy Resources Statistics

Resource Site	Capacity (MW)	Generation (GWh)	Number of Turbines	Location
Altamont	576	1,071	4,788	Northern CA
Solano	165	102	700	Northern CA
Pacheco Pass	16	25	167	Central CA
Tehachapi Ranges	710	1,482	3,444	Southern CA
San Gorgonio Pass	413	893	2,556	Southern CA
State Total	1,880	3,573	11,655	

(Source: WRPS 2003 data)

In addition to utility-scale resources, California has significant development in small wind for residential and rural applications. Figure 14 highlights the five major California wind resource areas and existing small-scale wind development with an overlay of wind resources less than 300 Watts per square meter (W/m^2) at 30m elevation. Even though any of the small turbines are located outside the high wind speed zones, they are still economically viable because of their proximity to the coastal and central valley areas, along high population and demand corridors.

Recognizing that the wind resource maps for California from the mid-80s were inadequate for current wind technologies, in 2002, the California Energy Commission released new, high-resolution wind speed and power density maps and Geographic Information System (GIS) compatible datasets for California's wind resources (Figure 15 and 16). TrueWind Solutions conducted the project using their proprietary MesoMap system (Contract No. 500-01-009). Maps of seasonal and annual wind speed and power for a range of heights above ground (30m, 50m, 70m and 100m) were produced to provide data more representative for siting modern tall tower wind turbines. These new wind maps and datasets provide the most complete and detailed picture of California's wind resources produced to date.

Numerous organizations throughout the U.S. have requested these data sets and they have been used by Energy Commission staff for planning and analysis. Aside from confirming and refining existing, well-known wind resource areas, the maps point to a number of other promising sites for new development. Some of these sites are known to wind energy experts, and others are previously unsuspected due to the lack of any monitored wind data in the area. The data sets provide insight for planning agencies, companies, and individuals seeking to develop policies and identify prospective sites for developing small and large wind energy systems. These indications may lead to new wind resource projects, which will help meet California's future electricity needs.

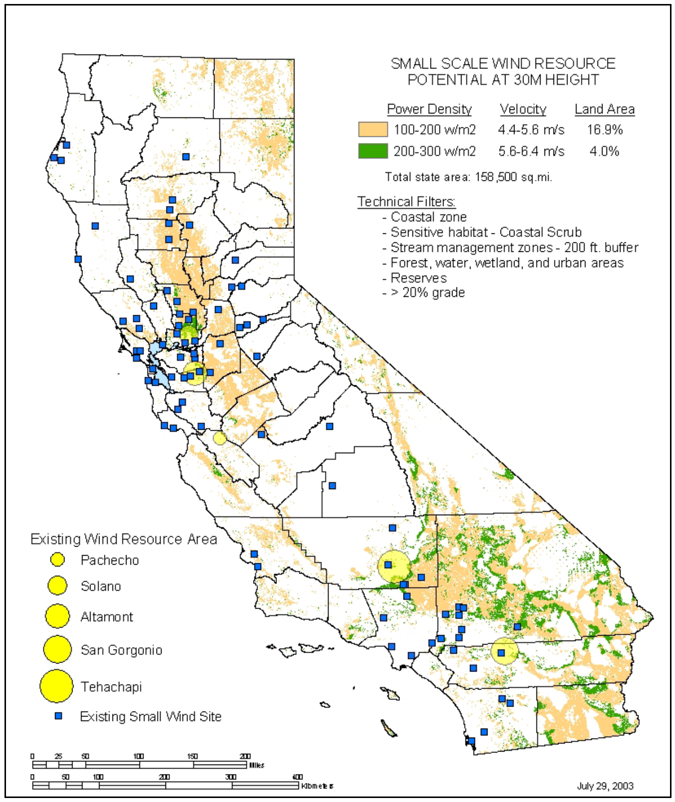


Figure 14. Overlay of 30 m Wind Resources with Utility-scale and Small-scale Wind Development in California

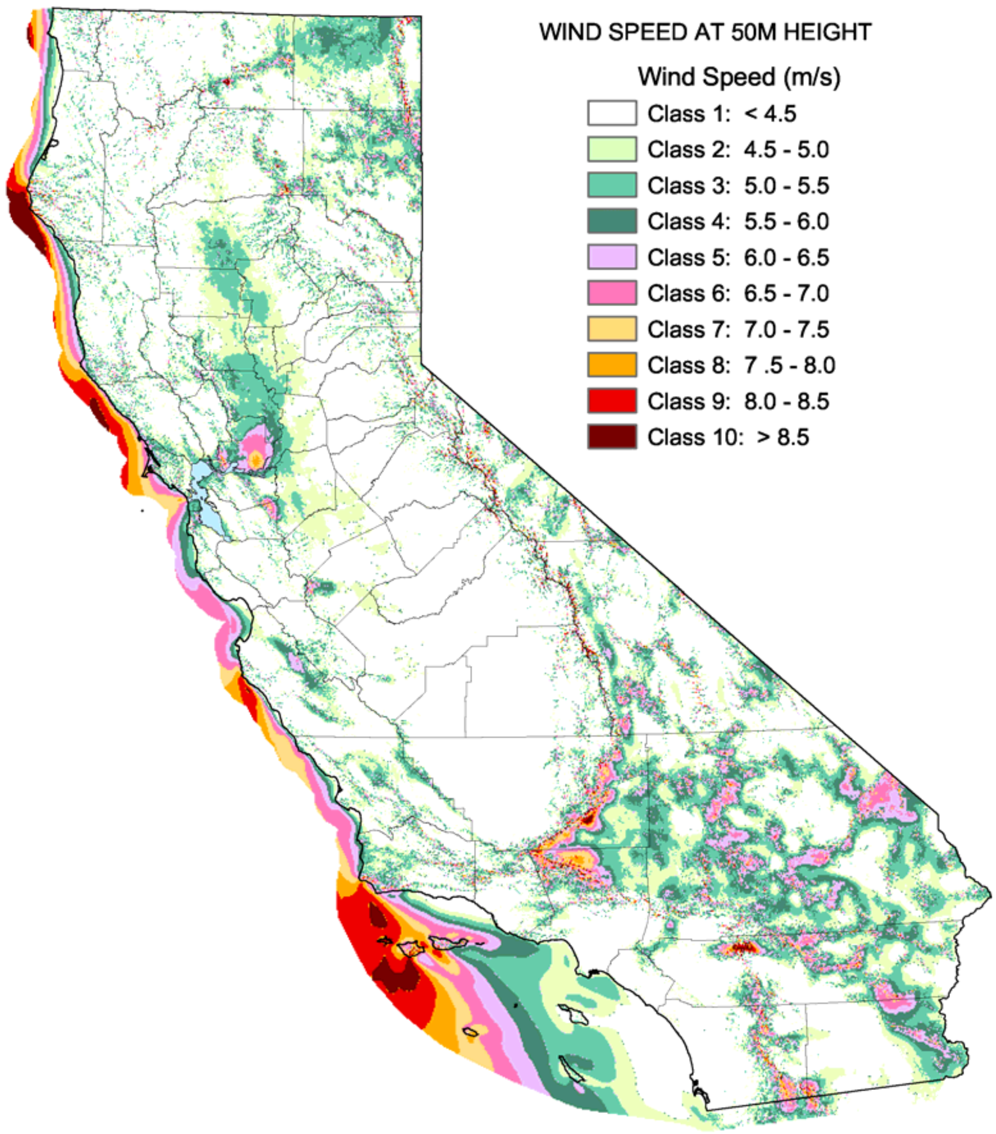


Figure 15. High Resolution Maps of California wind resources at 50m – Wind speed (m/s) (200m × 200m grid cell)

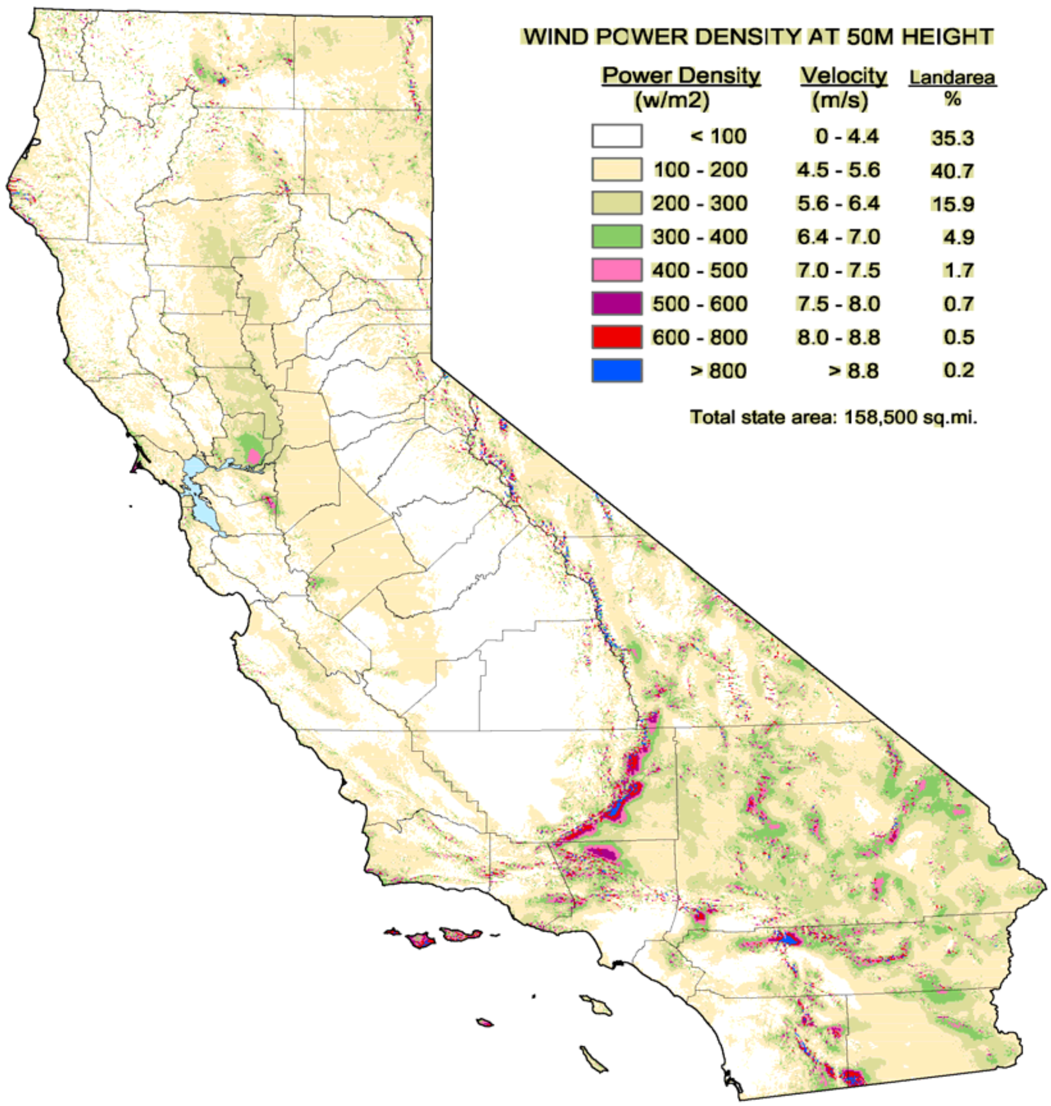


Figure 16. High Resolution Maps of California wind resources at 50m – Wind Power Density (W/m^2) (200m × 200m grid cell)

Gross Wind Resource Potential

New estimates were made on the statewide gross wind potential using the wind resource datasets and GIS analysis. Results are shown in Table 5. Total available land area at different wind speed and power potential is computed at four typical turbine hub heights. The total land area of the state is approximately 158,500 square miles at the map grid scale. With just over 1800 MW currently captured and over 50,000 MW of "harnessible" energy at 70 m, significant renewable wind energy remains untapped. With improved system designs, more detailed and accurate wind resource maps and reduced cost of turbines, California is poised to achieve a significant portion of the state's RPS goal of 20 percent renewable generation by 2017 just with wind power.

As an example, assume an average of 25 MW of wind capacity could be installed on each square mile of "suitable" windy land (approximately 40 acres per 1 MW). The actual density depends on many factors, including the type of terrain, directionality of the wind, as well as size and efficiency of the turbine. Then by counting grid areas with a certain predicted mean wind speeds (high wind speed = at least 7.5 meters per second, m/s) as "suitably" windy, about 23,000 MW could theoretically be installed at a hub height of 30 m and about 52,600 MW at a hub height of 70 m, assuming all areas was available to be developed.

Estimates were also made for moderate wind areas termed "low wind speed," which average 300 W/m^2 to 500W/m^2. Accounting for low wind speed resources, generation potential increases by an order of magnitude. The theoretical, unfiltered potential for wind power is estimated to be over 38,000 MW at 50m. Specifically for California, the raw potential is nearly 207 GW. These numbers provide a rough indication of the unfiltered potential of wind energy in the state. More realizable numbers have been obtained using land use information, transmission availability and economic filters as part of the Energy Commission's PIER Strategic Value Analysis project (SVA).

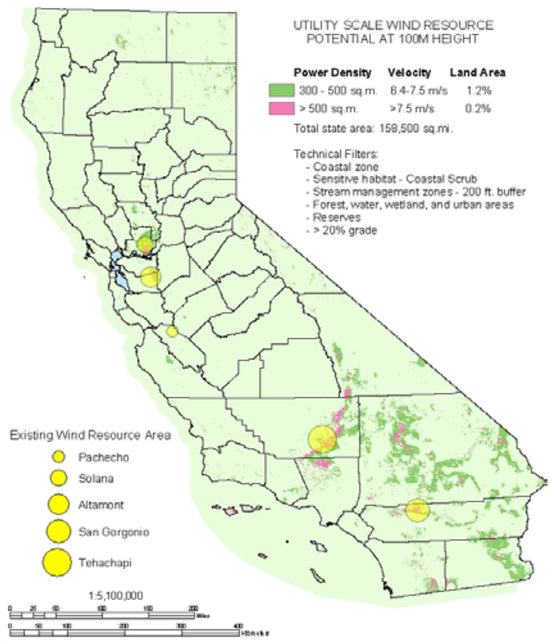
Table 5. California Total Gross Wind Power & Annual Energy Production Potential

	High Wind Speed >500W/m^2			Low Wind Speed 300W/m^2 - 500W/m^2			Total	
Height m	Land Area Percent	Capacity MW	AEP GWh	Land Area Percent	Capacity MW	AEP GWh	Capacity MW	AEP GWh
30	0.9	23020	74612	3.9	99889	323761	122909	398373
50	1.5	38035	123279	6.6	169744	550174	207779	673452
70	2.0	52605	170504	9.5	242582	786257	295187	956761
100	2.9	73219	237316	13.3	342453	1109960	415672	1347276

(Source: Energy Commission)

Wind Resource Technical Potential

To ascertain developable values, filters were applied, using GIS tools, to refine the raw potential. Initial filtering categories focused on technical and economic potential. Environmental impacts, (i.e. migratory pathways and acoustic buffers) as well as institutional (i.e. permit and zoning) filters may also be applied.



Technical Filters:
Grade > 20 percent
Bodies of Water
Forested Areas
Urban Areas
National Parks and Monuments
State Parks
Other Natural Reserves (refuges etc.)

Figure 17. Wind Resources with Technical Filters
(Source: Energy Commission)

Technical filters assume current state-of-the-art in wind turbine energy conversion technology. Other technical filters include suitability of land for development as shown in Figure 17 along with the maximum conversion efficiency, which is the amount of energy that can be converted from the kinetic energy in the wind to mechanical energy then to electrical generation. Application of these technical filters has reduced the raw potential by an average of 75 percent. The technical, filtered potential for wind is estimate to be over 9,500 MW at 50m. Table 6 summarizes the resulting generation potential at various heights for high speed wind and low speed wind resource areas.

Table 6. California Technical Wind Power & Annual Energy Production Potential

	High Wind Speed >500W/m^2			Low Wind Speed 300W/m^2 - 500W/m^2			Total	
Height m	Land Area Percent	Capacity MW	AEP GWh	Land Area Percent	Capacity MW	AEP GWh	Capacity MW	AEP GWh
30	0.2	4775	15478	1.2	30897	100144	35673	115623
50	0.4	9586	31070	2.2	56196	182144	65782	213214
70	0.6	14346	46500	3.3	85598	277441	99945	323940
100	0.8	21339	69164	4.9	126558	410199	147897	479362

(Source: Energy Commission)

From an energy producing perspective, sites suitable for large utility scale wind turbine installations have annual average wind speeds of at least 7 m/s (13 mph) with power potential greater than 500 W/m^2. However, new turbine technologies being developed are expected to be capable of producing power at lower wind speeds in the range of 300 W/m^2. A new class of low wind speed turbines is being developed to target sites with annual average wind speeds averaging less than 5 m/s (11 mph). Accounting for the low wind speed generation, California has a potential for harnessing 30.8 GW of installed capacity at 30 m and 86 GW at 70m.

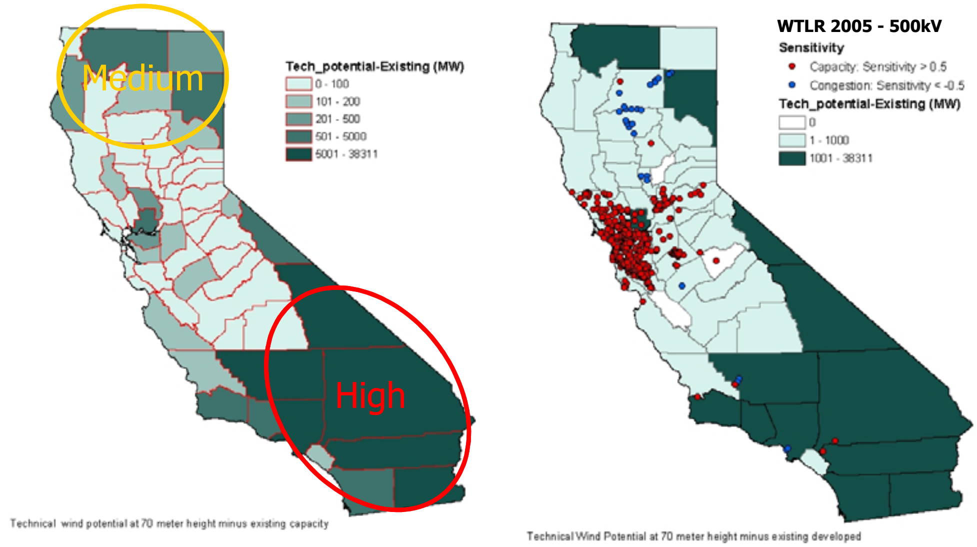
In addition, wind energy's dispatchability will be improved by locating wind generators closer to strategic locations in the electricity grid. Sites located close to transmission and distribution upgrades are necessary will be more reliable and dispatchable. Significant improvements have been made in turbine power electronics, gearbox components, lubrication, cooling and blade aerodynamics. These technological improvements have helped to increase the performance and efficiency of turbine systems (measured as capacity factor) significantly. These technological improvements also translate to added economic value. For these reasons, California wind resources need to be routinely assessed.

Plans for Increasing California Wind Energy Penetration

Wind industry investments have already provided both economic and employment benefits to California. With the Renewable Portfolio Standards (RPS) requiring 20 percent renewable generation by 2017, these benefits will continue to grow for the state. In 2003, the Energy Commission released a report of renewable resource development summarizing technical potential and projected development in the state from 2003 out to 2017 (500-03-080D). The goal was to provide some preliminary statewide estimates for increasing renewable generation based on new resource assessments. The renewable resource report also summarizes accelerated renewable energy needs to meet the statewide Energy Action Plan RPS goal of 20 percent by 2010 though it does not account for infrastructure improvements or operational enhancements needed for increasing penetration by renewable resources.

While preliminary estimates for the amount of renewable resources needed to meet the RPS have been developed, a complementary strategy to develop the technology and transmission requirements also needs to be developed. The Energy Commission is currently undertaking a Strategic Value Initiative (SVA) that will prioritize, identify and optimize transmission infrastructure and new technology R&D planning for renewable resources. Without considering the infrastructure needed by 2020 and the fostering targeted technology improvements, any estimate would be incomplete.

Renewable resource availability, transmission infrastructure and technology form the basis of the SVA, with the focus on identifying and developing the "lowest hanging fruit," which is defined as the most economic and beneficial renewable resource first. Figure 18a and 18b depict counties in California shaded by new wind development potential in MW, darker colors indicate more abundant wind resources.



(a)

(b)

Figure 16. Wind Resource Ranked by Counties: a) Priority Development Areas and b) Transmission Demand and Congestion Needs
(Source: Energy Commission)

Significant new development potential exist in the southern California area (San Bernardino, Imperial, and Kern counties) and northern California (Shasta and Modoc). Also, significant low wind speed resource potential (300 W/m^2 or greater) exists throughout the central valley region. Though existing wind turbine technologies are not cost effective in those regions, new technologies for low speed wind applications coupled with other hybrid technologies are envisioned.

Repowering and High Wind Speed Sites

Based on the estimated technical potential for wind in the state, new wind facility development, with current utility-scale technology (750kW-1MW scale, 37 percent capacity factor) should begin in southern California, northern California near the Oregon border, and along the foothills surrounding the central valley. Though planning for new installations remains the focus in many areas throughout the country, California also has significant re-powering potential in the existing five wind resource sites. Since many of California's wind resource areas were developed in the 1980s, they were sited and developed based on turbines of that era. The average size of wind turbines at these sites is 150kW, more than an order of magnitude smaller than current megawatt systems with capacity factors in the low 20 percent. The California Wind Energy Association (CalWEA) estimates many of these sites could be repowered with newer, higher capacity turbines in less than three years if the market incentives (federal PTC) and environmental permitting issues get resolved. By replacing the older, less efficient, lower capacity turbines with current technology, the generation at these windy sites could substantially be increased.

In addition, these sites offer the maximum system benefit when transmission infrastructure and utility service area are considered. All these sites have existing transmission capable of accommodating nameplate rating. With no net increase in nameplate capacity, the repowering effort alone is estimated to provide an additional 470 GWh/year of wind energy using current technology turbines. In addition, power purchase contracts are expiring for many of these sites. New agreements based on generation would allow additional capacity to be installed at these sites if long-term contract agreements could be negotiated to increase plant size with additional capacity.

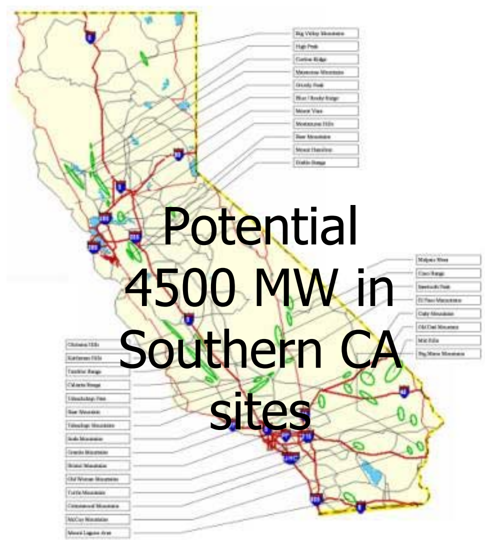


Figure 19. Estimated Potential from Southern California

Low-wind Speed Sites With New Technology

The mapping effort identified significant low-wind speed potential (Class 3 to 4) throughout California. Though small turbine systems can currently be found in the Class 3 areas, it is not economically viable developing the areas with existing utility-scale wind systems. Department of Energy/National Renewable Energy Laboratory along with the Energy Commission are continuing to sponsor R&D initiatives to develop low wind resource wind technologies. Examples include the following:

- decreasing overall turbine capital costs
- decreasing system weight
- applying advanced load alleviation capability
- design tailored for specific regime of operation (height, blade length)

Table 7 summarizes anticipated increases in wind development through 2020.

Table 7. SVA Wind Development Priorities and Timeframe

Development – Technology	Potential (MW)	Timeframe
Repowering existing wind facilities	900	2003-2006
High wind speed, southern CA	>4,500	2003 and beyond
High wind speed, northern CA	>2,000	2005 and beyond
Low wind speed & DG applications	>14,000	2012 and beyond
Building integrated technologies	--	2010 and beyond

(Source: Energy Commission)

Out-of-State Prospects

The Western Electricity Coordinating Council (WECC) estimates the total technical potential for renewable energy resources in its territory to be more than 3.7 million GWh/year. With on-line facilities currently accounting for over 8,000 GWh/year of generation, significant untapped potential remains. Table 8 presents the estimated technical wind potential in states sharing borders with California assuming an average 37 percent capacity factor.

Table 8. Technical Potential in Neighboring States

State	MW	GWh/year
Arizona	1,540	5,000
Nevada	17,000	55,000
Oregon	21,600	70,000

(Source: Western Electricity Coordinating Council)

In addition, the Energy Commission is currently investigating possible strategic sites for wind development that will maximize benefits to high demand areas and minimize the need for transmission upgrades.

Appendix A

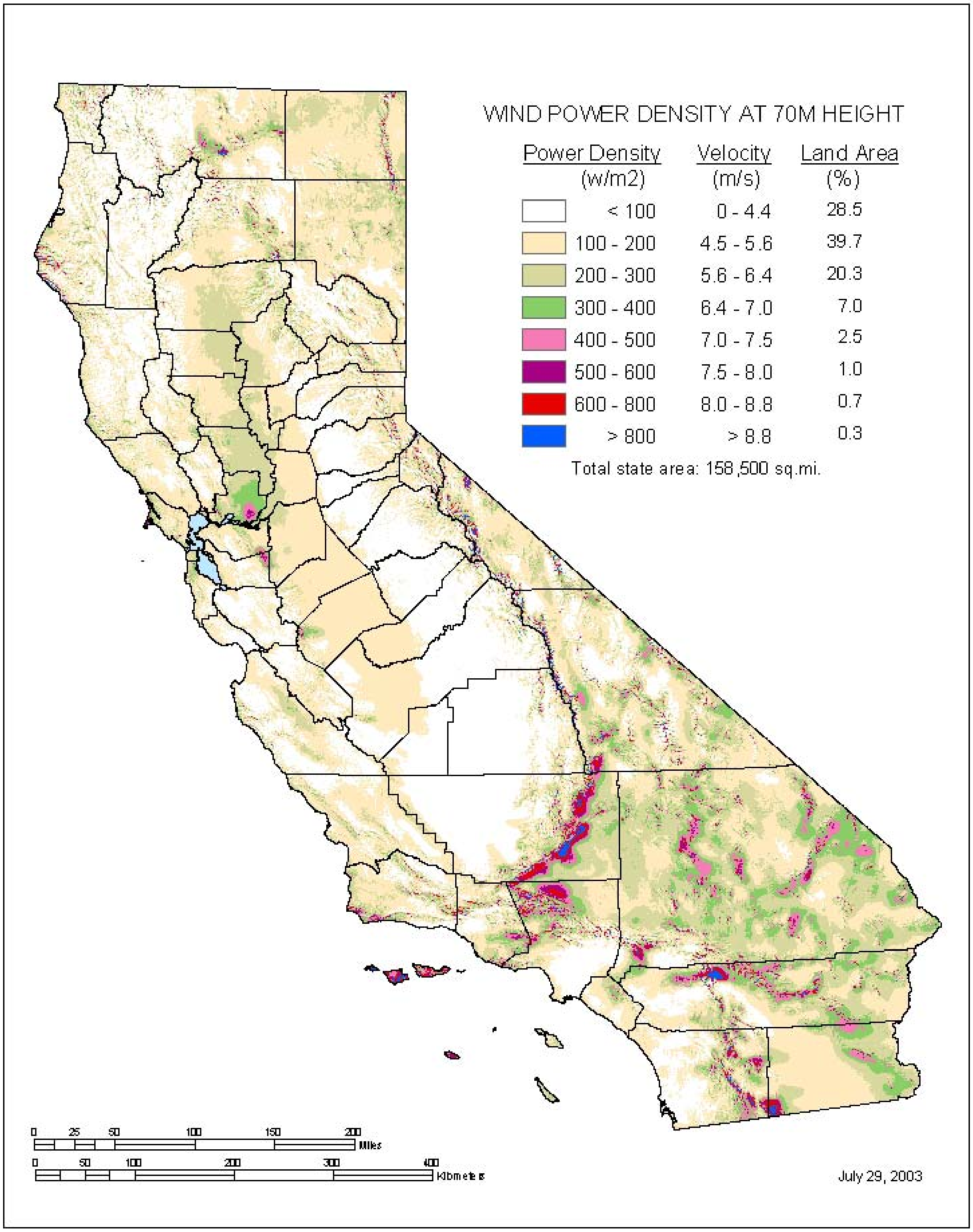
Gross Wind Resource by County at 70m
California Wind Resource Map at 70m
California Wind Resource Map at 30m
Data Layers used in Technical Filtering of Wind Resource Maps

Gross Wind Resource by County
Hub Height: 70 m
Wind Power Method

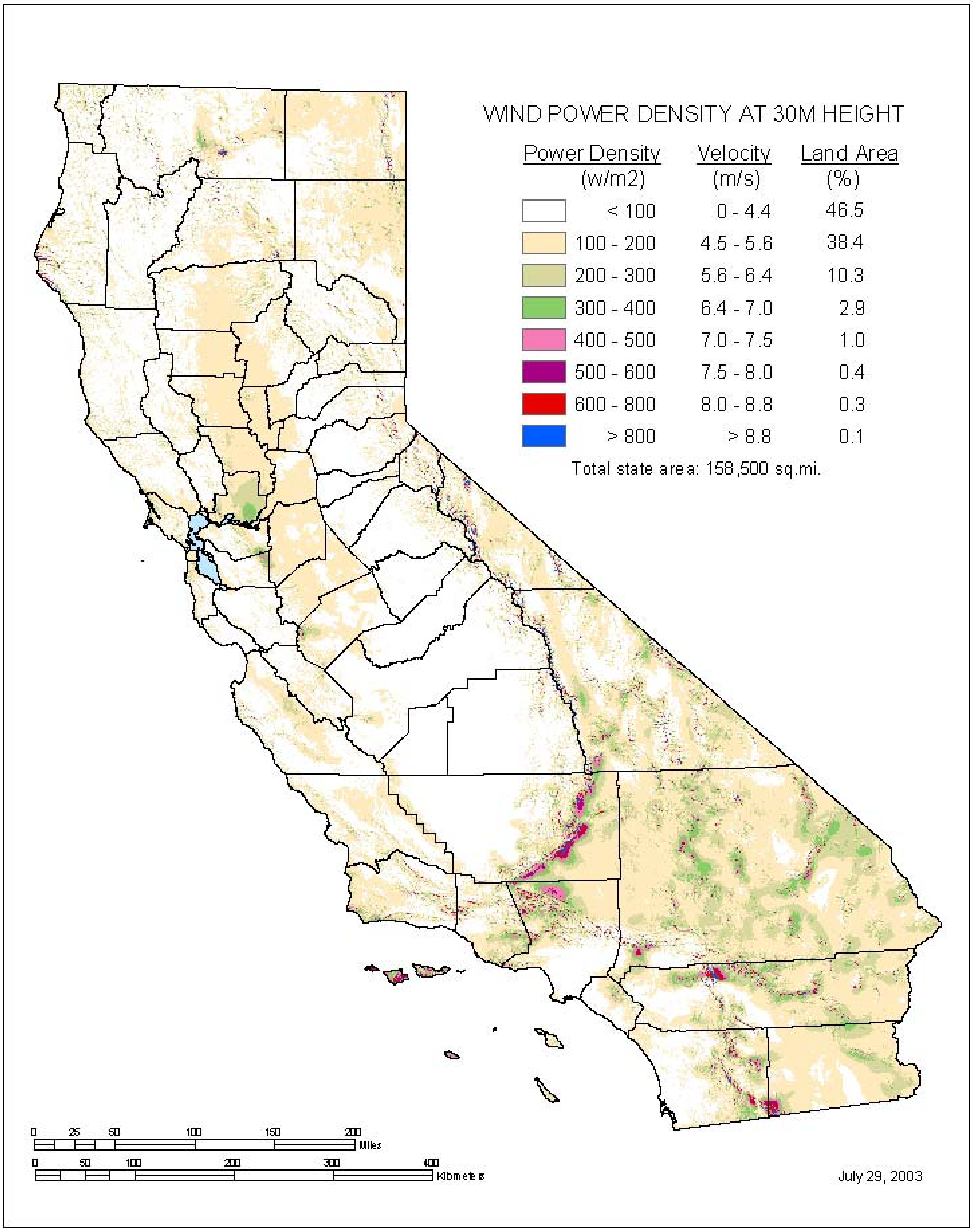
County	Land Area km^2	HWS Land Area km^2	HWS Capacity MW	HWS AEP GWh	LWS Land Area km^2	LWS Capacity MW	LWS AEP GWh
Alameda	2124	28	173	562	120	750	2431
Alpine	1918	117	733	2374	238	1487	4821
Amador	1568	2	11	36	8	51	165
Butte	4342	2	11	34	84	527	1710
Calaveras	2683	0	0	0	6	40	131
Colusa	2995	2	12	39	43	270	874
Contra Costa	2084	6	40	130	129	809	2623
Del Norte	2631	28	177	572	288	1798	5827
El Dorado	4636	49	305	990	98	615	1994
Fresno	15586	54	337	1091	185	1158	3754
Glenn	3437	1	4	13	11	67	216
Humboldt	9282	158	991	3211	468	2926	9483
Imperial	11608	234	1460	4733	1911	11943	38711
Inyo	26496	825	5155	16710	3505	21908	71008
Kern	21113	1490	9311	30180	2352	14701	47649
Kings	3605	0	0	0	4	25	81
Lake	3446	1	8	27	93	579	1875
Lassen	12220	70	440	1427	583	3642	11805
Los Angeles	10584	838	5236	16970	2167	13544	43898
Madera	5577	20	124	400	53	334	1082
Marin	1534	25	154	498	202	1262	4090
Mariposa	3784	1	6	20	7	43	139
Mendocino	9100	8	50	162	292	1825	5916
Merced	5103	10	60	193	148	924	2996
Modoc	10888	117	730	2366	354	2213	7172
Mono	8114	437	2732	8855	781	4879	15814
Monterey	8581	14	88	286	149	931	3018
Napa	2047	1	7	24	29	183	595
Nevada	2522	5	33	106	46	286	926
Orange	2070	8	50	161	171	1067	3457
Placer	3885	14	89	288	76	473	1534
Plumas	6773	33	207	671	287	1797	5823
Riverside	18908	863	5397	17492	4160	26006	84292
Sacramento	2574	0	0	0	60	372	1206
San Benito	3599	0	1	3	19	120	389
San Bernardino	52072	1198	7486	24265	12308	76940	249377
San Diego	10976	520	3249	10532	1485	9283	30089
San Francisco	278	0	0	0	45	282	914
San Joaquin	3690	0	1	2	49	308	999
San Luis Obispo	8599	4	27	88	156	975	3160
San Mateo	1430	3	20	65	129	807	2616
Santa Barbara	7119	466	2911	9434	859	5367	17396
Santa Clara	3383	0	0	0	6	39	125
Santa Cruz	1156	0	0	0	3	18	58
Shasta	9963	111	693	2247	577	3607	11691
Sierra	2492	31	191	618	175	1095	3549
Siskiyou	16452	207	1297	4203	1039	6496	21054
Solano	2356	50	310	1005	1029	6431	20844
Sonoma	4150	8	48	157	128	800	2593
Stanislaus	3924	0	0	0	11	66	213
Sutter	1577	0	1	3	17	105	340
Tehama	7668	5	28	91	197	1232	3995
Trinity	8310	21	130	422	184	1148	3721
Tulare	12539	88	548	1775	232	1448	4695
Tuolumne	5899	52	323	1047	140	875	2835
Ventura	4833	193	1209	3917	794	4960	16077
Yolo	2646	0	3	10	119	744	2412
Yuba	1668	0	0	0	0	0	0
Statewide	410594	8415	52605	170504	38806	242582	786257

HWS=High Wind Speed (Wind Power Density >500 W/m^2)
LWS=Low Wind Speed (300 W/m^2 <Wind Power Density <500 W/m^2)
AEP= Annual Energy Production

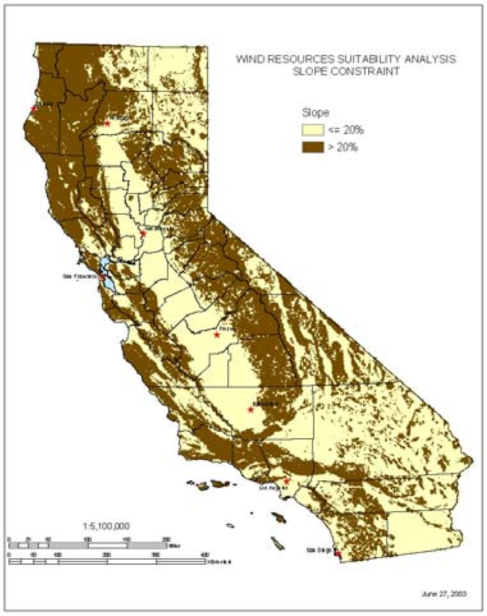
Gross Wind Resource by County at 70m

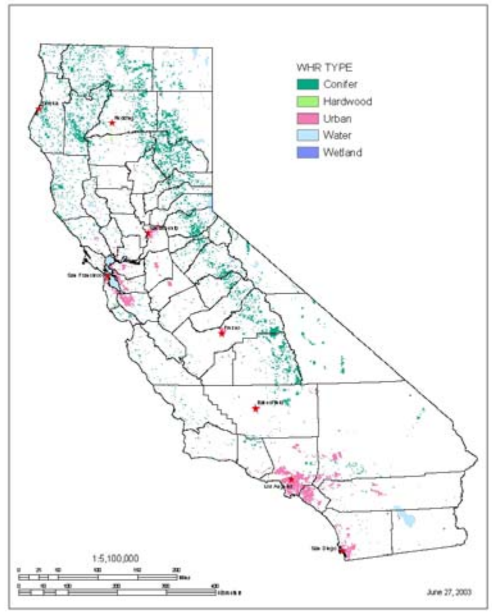


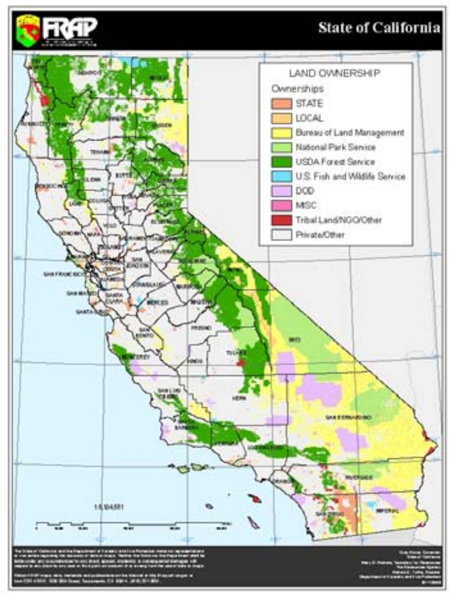
California Wind Resource Map at 70m



California Wind Resource Map at 30m







Data Layers used in Technical Filtering of Wind Resource Maps

Endnotes

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