

Renewable Electricity for California, 2005

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Chapter 1

Forward

I have for long been unclear about how renewable electricity generation resources match up against the requirements of electricity consumption in California. I often found that by reading a single source, only one topic is covered and I would miss the overall picture. While browsing numerous (what I deemed credible) sources, I tried to extract salient points. I found it interesting that a number of sources, which I decided not to include, had a tendency to over or under estimate numbers, - all depending on the author's bias. In order to better understand the renewable energy situation, I spent time reading through what I could find about renewable energy, more specifically in California, and I have gathered my findings into this paper. I have however gathered together a comprehensive look at hydro power, solar photo voltaic power, wind power, geothermal, and a brief look at coal/natural gas power. Please consult the references for details and I hope you find it interesting, I certainly did!

-Mogens

Chapter 2

Overview of California's Current Situation

California's Electricity Consumption for the year 2007 was 285,000 Gigawatt Hours (GWh). California (12% of the US population) accounts for 2.5% of the total US consumption. The projected Annual Electric Consumption for the year 2018 (based off California's 2007 Annual Electric Consumption of 285 TWh) is 327 TWh (Terawatt Hours), a 11% increase. The annual US Electricity Consumption in 2002 was 3,660,000 GWh, 25% of the world consumption.

The CEC (California Energy Commission) allocated \$118million for their Emerging Renewables Program from 2002 through 2006, a rebate program to encourage renewable energy. In 2007, the California Public Utilities Commission initiated the California Solar Initiative, with the goal of creating 3,000 MW of new solar generation capacity by 2017. The CSI's budget is \$3.3million over 10 years. A strict environmental message simply has not been very effective at getting customers to want to buy green power.

Figure ES-2: Statewide Electricity Consumption



Source: California Energy Commission, 2007

Chapter 3

Hydro Power

As of the year 2002, hydro power accounted for 25% (13.3 GW) of California's generating capacity. It is predicted that by the year 2003 hydro power will account for 22%. Although hydro power is 25% of the generating capacity, it only accounts for 14% (37.3 TWh) of the total annual production.

In California, most dams were built years ago to provide water for irrigation. Hydro power was either an afterthought, or a convenient way to finance the dams. Not all dams utilize the available hydro power. The estimated untamed hydro capacity is 2.5 GW, a potential 19% increase in hydro capacity, which could be harvested from over 300 un-powered or underpowered dams. Furthermore, 37% of our system (5GW) is due for relicensing by 2015. When a dam is re-licensed, Government decides whether to allow the dam to continue operation or to demolish the dam. Potentially, California could lose much of its hydro power capacity in the near future.

Hydro Power Plants will be affected by global warming. Currently, the snow pack serves as a way to store water. If climate change results in precipitation coming down as rain instead of snow, our dams will not be able to hold all of the watershed during the rainy season. Assuming a 3 deg C. temperature rise over the next 100 years due to global warming, snow levels will drop by 1500ft. Foothill dams, which account for 2.3 GW capacity (20% of total hydro) with 7 TWh of production (19% of total), will be affected by global warming the most. Also, we will not be able to meet future California water requirements without additional surface water storage. With the onset of global warming, California needs to re-think its dam and hydro electric system.

3.1 The Argument For Hydro

One of the main advantages to hydro power is that it is a non-polluting renewable resource. Another main advantages to hydro power is that it has a comparatively fast ramp up time (10MW/min for a hydro plant compared to 1-2MW/min for conventional thermal plant), although newer dual cycle natural gas turbine plants are faster. This means that hydro can provide the flexibility needed to meet the ever changing demand on the power grid and provides most of the total operating reserve requirement. For a hydro power plant, spinning the reserve requirement is 5%, while the reserve requirement for a thermal site is 7%, indicating that hydro is more reliable than thermal power.

Some hydro plants can perform double duty – pumping water from lower to upper reservoirs in off-peak hours and generating up to 2.8GW during peak hours. This serves as a battery to store un-used power on the grid. Hydro power is 85% efficient per phase, so there is a net loss of 25-30% energy when pumping water back up (since each pumping cycle loses some). As we have to rely more and more on nature (like wind and solar) for providing power, it becomes more and more important to be able to control how much energy is available on the grid. Hydro provides this means of control with its reliability and ability to store energy, and can be coupled with solar and wind energy to provide customers with consistent renewable energy.

3.2 The Argument Against Hydro

Although hydro does not produce any air pollution, hydro does block miles and miles of spawning and rearing habitat. This slows fish down or stops them during migration and allows reservoirs to harbor predators that eat the fish as they migrate through. Also, peaking power often leads to salmon red strandings. Another concern is that dams inundate the habitat for amphibian species such as frogs and salamanders, and this becomes a major issue when re-licensing foothill reservoirs. Dams have eliminated 95% of the original 6000 miles of Central Valley salmon & steelhead habitat, reducing it to 300 miles.¹

Hydro plants also necessitate long transmission lines, as they are often far away from population centers.

¹US Fish & Wildlife, 1998

3.3 Other Hydro/Water Points

On hot summer days, California imports 6 GW of hydro power from northwest. Hoover dam alone has a generating capacity of 626 MW (5% of the total hydro power capacity).

Water is essential to every aspect of life in California. There is tremendous competition for it. California constitution even prohibits the unreasonable use of water. It is important that we manage our water resources carefully and consider what will be necessary to manage our water in the future.

Chapter 4

Solar Photo Voltaic Power

Currently, California solar PV energy generation amounts to less than 0.01% of the electrical power production. If we installed a system comprising of solar panels on 1 million California rooftops (at 2.5KW per roof), the system would generate 5% of the total generating capacity produce 4 TWh per year (1.6% of annual consumption), and require a \$15B gross investment. Solar is a nearly inexhaustible resource. If we were to cover a 500 square mile area (25mi by 25mi) with solar panels, the resultant system would produce around 289,000 GWh per year and would meet California's electricity demand. This is assuming an average daily solar radiance of $4KWh/m^2/day$ for California (according to the Solar Energy Industry Association) and a 15% efficiency for solar panels.

$$\frac{289,000GWh}{year} / \left(\frac{4KWh}{m^2day} * \frac{365days}{1year} * \frac{1GWh}{1x10^6KWh} * \left(\frac{1609.349m}{1mi} \right)^2 * 15\% \right) = 509.5mi^2$$

However, the system would require 56 years of the world's solar cell supply at the 2007 world wide rate of solar cell production. This is assuming the 2007 world wide rate of solar cell production is 3,500 MW per year and that the solar intensity is 1,000 watts per square meter along with the previous assumptions.

$$500mi^2 * \left(\frac{1609.349m}{1mi} \right)^2 * \frac{1000watts}{m^2} * 15\% * \frac{1MW}{10^6watt} * \frac{year}{3,500MW} = 55.5years$$

Also, covering 12% of Arizonas surface with solar cells produce sufficient electricity to cover US consumption. This is based on an annual US energy consumption of 11,890 TWh, an average of $6KWh/m^2/day$ for Arizona, a 15% efficiency for solar panels, and an area of $295,254Km^2$ for

Arizona.

$$\frac{11,890TWh}{year} / \left(\frac{6KWh}{m^2day} * \frac{365days}{1year} * \frac{1GWh}{1x10^9KWh} * 15\% \right) / \left(295,254Km^2 * \left(\frac{1000m}{1Km} \right)^2 \right) = 12.3\%$$

The current demand for Solar PV panels is very high, and the worldwide annual Solar PV panel production capacity is continually increasing to meet it.

Not all solar systems are equivalent. A 2-axis tracking Solar PV panel will produce 40% more energy than a fixed (roof) mounted panel per day. There is the potential to build more efficient solar cells and more efficient solar systems to maximize the amount of energy captured.

4.1 The Argument For Solar

Residential Solar PV (Photo Voltaic) systems are convenient because they generate the power where it is needed. Also, an added benefit of having the panels on the roof is that they shade the roof, resulting in longer roof life time and cooler attic space.

4.2 The Argument Against Solar

Currently, Solar PV systems are expensive and without the current incentives, residential Solar PV is not cost effective. Also, peak solar PV generated power (1pm local time) does not coincide with peak power demand (4pm), however the use of hydro (or pumped hydro) generation can mitigate this problem. Solar PV, by itself, cannot solely power California.

Demand for residential solar access can create neighbor friction because of the eye sore and the tension over trees shading the panels. Also, not every house is suitable for a solar PV system. Roofs can be overshadowed by neighboring trees and houses, or in the wrong orientation for an efficient system. Putting solar panels on residential houses is not enough, and we need to consider utility scale Solar PV sites with optimum solar access.

Chapter 5

Wind Power

The amount of energy generated annually by wind in 2005 was 4.3 TWH (1.5% of annual consumption) It is possible to profitably develop 26 TWH of wind-generated electricity per annum by the year 2010 (approximately 10% of annual consumption) and 34 TWh per annum by year 2030 by developing wind farms in 36 specific sites. The total potential for wind generated energy is 59 TWh according to AWEA (American Wind Energy Association).

As of 2003, California has been at 2 GW production capacity for 10 years in a row. Only about 300 of that, though, has been built in the last three or four years, including the large project here in Solano County. If natural gas prices remain at \$11-12/BTU delivered to the burner, it will most likely provide a boost to new wind power development. Wind installations currently cost around \$1.6/*W*. The biggest issue is permitting time and money. Wind installation cost is not likely to be reduced. In fact, it's trending up. This is not because GE, Vestas, or anybody is doing a bad job at manufacturing equipment. It is just the interconnection costs, the siting issues, the land cost, everything has a cycle to it. In 2008, there is a three year lead time on critical components such as blades.

One concern with wind is that it is hard to predict how much electricity wind power will produce at a given time (although wind is statistically predictable over longer periods of time if given adequate data). This makes it difficult to sell wind power, as wind can quickly go from 100% capacity to 0% capacity, and this sort of unpredictability is not desirable for the grid. With a firm contract (like a Power Purchase Agreement, or PPA), wind generation plants might get stuck in the situation of not being able to produce what their PPA says they have to, or they could have extra power. With an intermittent contract, wind power plants could end up with electricity but no one to sell it to. To help with this problem, backup generation or storage (like pumped hydro) could

improve the economics of wind generation and help provide a constant source of energy.

5.1 The Solano Project

The Solano Project was to build 90 Vestas 1.8MW turbines in Solano County. To make everything work, there are about 24 miles of access roads that had to be built to interconnect all of the wind turbines and about 21 miles of underground 34.5 KV interconnection cable that had to be installed to take the output from each of the turbines to the project substation. The project substation is located immediately adjacent to a PG&E 230 KV line, where the power is stepped up and then directly connected into that system.

Over the life of the project, the county will generate \$24 million in property taxes and the land owner will generate about \$22 million in land lease. It took roughly 17 months to acquire the appropriate permits.

5.2 Wind Technology

If you can make the cost for a longer blade increase linearly with respect to the length of the blade, then wind farms will have lower costs per watt. The reason is that for a given blade length of r , the area the blades sweep out is equal to πr^2 . The amount of energy produced is proportional to the area the blades sweep out, so if cost is made directly proportional to the length of the blade, then the amount of energy produced is proportional to the square of the cost. The differential between the square and the linear is the savings that comes with economies of scale. The tough part is making the turbines reliable while holding the cost increase to only linear, and this challenge involves material and design intelligence, intelligent control, and so on.

Another challenge with wind technology is that the wind comes in gusts but wind turbines still need to maintain a constant frequency in order to interface with the grid. To solve this problem, wind turbines do not connect the blades directly to the grid but instead interface through an electric transmission, so that when there is a gust the blades (which are essentially a 60,000 pound flywheel) speed up slightly and then the additional speed is slowly converted into electrical energy during times of low wind.

Chapter 6

Geothermal

Geothermal can cost as low as \$2,800 per installed KW and 5cent to 7.5cent per KWh. Although geothermal has a high initial cost, it is a renewable energy source with low fuel and maintenance costs.

California has largest geothermal capacity in US, with the potential of more than 4000 MW using current technology. In 2007, geothermal produced 13,000 GWh, 4.4% of California's total production. There are 25 known geothermal locations in California, 14 of which have temperatures of over 300 degrees Fahrenheit, and these sites have been developed into 43 plants with combined capacity of 1,800 MW. There is over 2,800 MW of geothermal capacity in the US, and over 8,200 MW in world.

Geothermal energy is not just limited to power plants, as some areas use the geothermal water directly to heat buildings, producing 500 thermal MW from direct use. Also, some geothermal plants inject waste water into the reservoir to supplement the natural recharge rate and increase power output.

6.1 benefits

Geothermal plants are clean, completely renewable, reliable, and can coexist in sensitive environments because they only emit steam. Geothermal plants can be built in places like the middle of crops, forested recreation areas, fragile deserts, and tropical areas with minimal environmental impact. To minimize their environmental impact, geothermal plants dump the waste heat into air, not rivers or lakes like other thermal plants.

Also, the structure of geothermal plants is often modular, so the plant can be developed and

built over time.

6.2 Concerns

Although geothermal plants have few emissions, building plants require drilling wells and making roads out in wilderness and sensitive areas. Because geothermal activity often results in spectacular natural phenomenas like geyser and places like Yellowstone, geothermal power plants need to coexist with and not disturb hot springs and other natural geothermal tourist attractions. Some geothermal plants also produce solid waste, but it is often possible to recover valuable minerals from the waste.

There is a concern that taking lots of water out of the ground and then re-injecting water back into the ground might induce seismic activity. At The Geysers in California, they are experiencing increased seismic activity, which might be related to their waste water injection system.

Chapter 7

Coal or Natural Gas Produced Electricity (as a reference)

It's hard to beat coal for cost. The cost of production in 2005 was \$9/*MWh* for coal vs \$40 – 50/*MWh* for natural gas.

New natural gas fired plants will require 1300 miles of transmission lines, which will cost about \$6 billion, and that that's just normal expansion planning. New coal plants should be located near coal fields. They will have to add 7600 miles of new transmission lines, about \$16.7 billion, but because of the low cost of coal, this is not out of the question! It is actually cost effective. Renewables are somewhere in between the cost of gas and coal.

Cost per MBTU		
	Coal	Natural Gas
1997	\$0.92	\$2.71
1998	\$0.89	\$2.34
1999	\$0.82	\$2.55
2000	\$0.81	\$4.27
2001	\$0.82	\$4.49
2002	\$0.83	\$3.59
2003	\$0.81	\$5.43
2004	\$0.88	\$6.44
2005	\$1.01	\$8.26
2006	\$1.04	\$6.93
2007	\$1.03	\$7.12

Chapter 8

Other Information

Transportation is California's biggest source for CO_2 , while current electricity generation only accounts for 16% of California's total CO_2 output.

California also needs a new utility investment model, something like remote solar/wind with net metering.

Chapter 9

References

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<http://www.energy.ca.gov/maps/wind.html>
- California Wind Energy Collaborative Forum
http://cwec.ucdavis.edu/forum2003/proceedings/CWEC_Forum2003_transcript.html
- California Energy Commission
<http://www.energy.ca.gov/>
- Committee Workshop Before the Energy Resources Conservation and Development Commission
http://www.energy.ca.gov/2003_energypolicy/documents/2003-06-05_workshop/2003-06-05_TRANSCRIPT.PDF

Chapter 10

About the Authors

Travis Schuh recently graduated from Mountain View High School in California and plans to attend Franklin W. Olin College of Engineering in the fall. He is currently working for Lauritzen Inc. where he is learning lots about alternative energy solutions.