Arizona Solar Power Project Calculations

Posted by Robert Rapier on January 7, 2009 - 10:03am
Topic: Alternative energy
Tags: arizona, concentrating solar thermal power, solar power [list all tags]

The following guest post was written by Tom Standing, a member of ASPO-USA and a "semi-retired, part-time civil engineer for the City of San Francisco." Here Tom takes on the calculations for a 280 MW solar thermal plant in Arizona that I looked at back in February. My conclusion from that essay was that the electrical capacity of the U.S. could in theory be met on 10,000 square miles of land (with the normal caveats about storage, costs, etc.) Tom peels the onion a few more layers and puts the energy production into perspective.

Hello Robert,

You and I met at the Sacramento Peak Oil conference. Your presentations and discussions were most enlightening. I was heartened by your analysis of cellulosic ethanol. I have always been deeply skeptical of the notion that the U.S. might displace a meaningful portion of transportation fuel with biofuels from cellulose. I could give you some of my thoughts on this subject, but you have already covered the territory thoroughly.

I want to comment on your calculations you posted in TOD in February, regarding the proposed 280 MW solar thermal plant in Arizona. First, a bit about my background. I started my career as a chemical engineer, first in refinery operations, and then chemical processing design. But that was only about 4 years. Most of my career has been as a registered civil engineer in a variety of disciplines for the City and County of San Francisco. Over the years, I have become interested in, maybe even fascinated by, the prospect of utility-scale generation of electricity from qualified renewable sources.

Throughout North America and Europe, many people have focused on renewable energy as a means of reducing dependence on Middle East oil and reducing CO_2 emissions. They see renewable energy as an important element to achieve emissions targets of the Kyoto Protocol. In the U.S., renewable energy from wind, solar, and biofuels appears to be a keystone for energy policy in the Obama Administration. In Texas, T. Boone Pickens is campaigning for a new American energy policy centered on major input from wind-generated energy to displace electricity generated from gas-fired power plants. Natural gas would then be redirected as CNG to power autos and trucks. In California, Governor Schwarzenegger sees his “Million Solar Roofs” program as leading other states to do likewise, thereby reducing CO_2 emissions. California utilities are mandated to supply 20% of electricity from qualified renewable sources (wind, solar, bio/waste, geothermal, and small hydro) by 2015. Contributions from these sources have been stuck in the range of 10-11% since 2000. The 20% mandate appears to be a major challenge, maybe unrealistic.

Many questions come to mind in looking at the proposed Arizona plant. What precisely does the

280 MW refer to? Is it the plant's output at capacity? Is it an annual average output? How much electricity will it generate annually? How will output vary during the day, or by season? How will output be affected by clouds?

There is important data available and a few fundamental design features that will answer these questions. Costs for construction, however, are not my strong suit. Other analysts will have much better information on costs. Cost of the plant will not change the results of my analysis.

1. Insolation Data

Reliable data for site-specific solar radiation (insolation) is critical to estimating solar capabilities. Fortunately, a massive database for insolation is posted on the National Renewable Energy Laboratory (NREL) website. In 2000, an engineer who designed solar facilities directed me to the site; I was utterly amazed at what was there. I had to be extremely selective to get the most useful data. I settled on 30-year (1961-1990) average insolation for 239 U.S. cities: monthly and annual average insolation in kWh per square meter per day. Readings for all 239 stations are given for all possible orientations of solar collectors, either fixed or tracking systems. Amazingly, insolation data is also tabulated for averages of each hour during the 30 years for all 239 stations (kW/m^2), enough data to make your head spin! Data is also tabulated for insolation of all collector orientations at 239 locations above Earth's atmosphere! For reference, I eventually copied pages that filled a binder weighing 10 lbs.

2. Site Coverage with Solar Collectors

A rough approximation for coverage of the 1,900-acre site with solar collectors is 50%. Space is needed for maintenance and control centers, electrical converter units, towers for power lines, and maybe a backup power facility fired by gas or oil. Proposed facilities to store electricity for release at night will also consume land.

In 2001, I toured a solar thermal plant at Kramer Junction in California's Mojave Desert.

http://www.solargenix.com/pdf/CSPDOEJUNE2003.pdf

At one square mile, it is about 1/3 the size of the Arizona plant. I would say that close to half of the site is taken up by gravel roads for maintenance vehicles. At least weekly, wash trucks at night clean the collectors of dust that frequently blows around. The roads also provide necessary space between rows of collectors to prevent shading. Collectors tilted upward to gather more sunlight cast shadows at low sun angles. If the designers in Arizona are really stingy with land use, they may be able to cover 50% of the site with collectors, including facilities for power storage.

As with Kramer Junction, the entire site will be dedicated to industrial use, fenced off and completely secure. Areas covered by collectors are denuded of vegetation, graded, and compacted. There is hardly space for a rodent or a bird to live. Collectors are supported by steel columns embedded in reinforced concrete foundations designed to resist maximum wind forces upon the considerable surfaces of the collectors. These are real-world features that solar advocates overlook when they envision hundreds of square miles devoted to solar power.

3. Calculate Collector Area

We calculate the area of solar collectors in square meters to utilize NREL insolation data.

The 1,900 acres converts to 7.7 million sq m. With 50% for collectors, 3.8 million sq m are on the site.

4. Model the Collection Array

The Arizona plant is to be a concentrating system that tracks the sun. Surprisingly, NREL data shows that concentrating systems collect less sunlight per sq m than systems consisting of flat plates, one-axis tracking, tilted at an angle = to latitude of site. Thus to be generous, I will calculate the output based on flat plates, 1-axis tracking, tilt = latitude.

For Phoenix, NREL data gives average annual insolation for our model as 8.6 kWh per sq m per day (i.e. all days averaged for 30 years). For Tucson, insolation under our model is 8.7, with slight differences for each month.

5. Calculate Insolation Striking the Collectors

Here we convert solar energy striking collectors during one day, to the average rate during the day. Thus, for Phoenix (the nearest station with NREL data to the plant):

The average annual rate of solar power striking collectors

= [8.6 kWh/ (m^2-day)] [one day/24 h]

= 358 watts/m^2, say 360 watts/m^2

Scaling up this power for the entire plant, average daily solar power striking all collectors

= (360 W/m^2) (3.8 million m^2)

= 1,370 megawatts

6. Assume 15% Conversion of Insolation to Useful Electricity

The solar thermal plant at Kramer Junction converts about 15% of insolation striking the collectors into electricity. Therefore, a decent assumption for the Arizona plant that would be consistent with our other assumptions is 15% conversion.

Average electrical power generated by the plant over the entire year

= (0.15) (1,370 MW)

= 205 MW

This power output is, of course, highly variable, depending on time of day, season, and cloud cover. To get an idea for seasonal changes, the NREL data tells us that plant output would average 257 MW for an average day in June, to 138 MW for an average day in December.

7. Maximum Electrical Power Output

What might be the maximum electrical power output of the plant? It would correspond to maximum insolation, which is roughly 1,000 watts/m^2. Fifteen percent conversion gives a plant output of 150 W/m^2, times 3.8 million m^2, so maximum electricity generation = 570 MW.

According to NREL data for the desert, maximum insolation duration is about two hours a day under cloudless skies from late spring through early summer. The duration of maximum shortens with increasing time away from June 21. In early spring and late summer, maximum insolation slips below 1,000 W/m^2.

Clouds have a widely variable effect, from a 10 or 15% reduction from thin cirrus clouds, to a 50-70% reduction from dense cumulus clouds (thunderheads). At Kramer Junction, operators adjust flows of the heat transfer fluid whenever a cloud drifts over the array. I seem to remember that operators engage small electric pumps to keep the fluid flowing in portions of the array that experience cooling. The Arizona array, with three times more area, will experience more frequent effects of cloud shadows.

8. Annual Energy Generated

One final simple calculation gives us the average annual electrical energy that the Arizona plant will generate. It is the product of four factors:

Insolation, average day (NREL data) = 8.6 kWh/ (m^2-day)

15% conversion of insolation to electricity

Area of solar collectors = 3.8 million m^2

365 days/year

Thus the 1,900-acre Arizona plant will generate roughly 1.8 billion kWh per year.

Let's give this quantity some perspective. EIA statistics for renewable energy in 2007 show that wind-generated energy in Texas was 8.1 billion kWh. Thus it would take four and one-half plants the size of the Arizona plant to match Texas wind energy for 2007.

A more telling comparison is with the recent growth of electrical consumption in the U.S. EIA statistics show that the U.S. consumed 2,885 billion kWh of electricity in 1992; in 2002 consumption was 3,660 kWh. Average growth, then, was 77 billion kWh per year over the 10 years. Thus the electrical energy that would be generated by the Arizona plant would supply only 2.3% (1.8/77) of one year's growth of U.S. electrical consumption. I do not have electrical consumption broken down by state, but I would guess that Arizona could build a solar plant of equal size every year, and they would barely cover their own growth in electrical consumption.

PV Potential

I have not touched on PV, but there is much to discuss. NREL data is so extensive that there is almost no limit to analyses that could be done. For now, I should only refer you to an article that I published in the Oil and Gas Journal, June 25, 2001 issue. I graphically displayed annual insolation curves for a wide range of locations. At a glance the reader can see how insolation varies with latitude, longitude, and collector orientations. I also ran through sample calculations to see how much energy can be generated. An important finding is that insolation for most of the eastern half of the U.S. stays within a narrow range: 4.6 to 5.2 kWh/ (m^2-day), with fixed collectors facing south, tilted at latitude for maximal exposure.

The above calculations are purely rational, using insolation data and general assumptions in design. Actual practice shows that solar installations typically generate 10 to 15% less energy than what the calculations show.