Solar Power Realities - Addendum

Comparison of capital cost of nuclear and solar power

By
Peter Lang

Introduction:

This paper compares the capital cost of three electricity generation technologies based on a simple analysis. The comparison is on the basis that the technologies can supply the National Electricity Market (NEM) demand without fossil fuel back up. The NEM demand in winter 2007 was:

20 GW base load power;
33 GW peak power (at 6:30 pm); and
25 GW average power.
600 GWh energy per day (450 GWh between 3 pm and 9 am)

The three technologies compared are:

1. Nuclear power;

2. Solar photo-voltaic with energy storage; and

3. Solar thermal with energy storage[1].

This paper is an extension of the paper "Solar Power Realities"[2]. That paper provides information that is essential for understanding this paper.

The estimates are 'ball-park' and intended to provide a ranking of the technologies rather than exact costs. The estimates should be considered as +/- 50%.

Nuclear Power

25 GW @ $4 billion /GW[3] = $100 billion
8 GW pumped hydro storage @ $2.5 billion /GW = $20 billion
Total capital cost = $120 billion

Australia already has about 2 GW of pumped-hydro storage so we would need an additional 6 GW to meet this requirement. If sufficient pumped hydro storage sites

[1] Solar thermal technologies that can meet this demand do not exist yet. Solar thermal is still in the early stages of development and demonstration. On the technology life cycle Solar Thermal is before "Bleeding edge" – refer: http://en.wikipedia.org/wiki/Technology_lifecycle
[2] http://bravenewclimate.wordpress.com/files/2009/09/lang_solar_realities_v2.pdf
[3] The settled-down-cost of nuclear may be 25% to 50% of this figure if we reach consensus that we need to cut emissions from electricity to near zero as quickly as practicable.

are not available we can use an additional 8GW of nuclear or chemical storage (e.g. Sodium Sulphur batteries). The additional 8 GW of nuclear would increase the cost by $12 billion to $132 billion (the cost of extra 8 GW nuclear less the cost of 8 GW of pumped hydro storage; i.e. $32 billion - $20 billion).

Solar Photo-Voltaic (PV)

From 'Solar Power Realities' [4]:

Capital cost of PV system with 30 days of pumped-hydro storage[5] = $2,800 billion.

Capital cost of PV system with 5 days of Sodium Sulphur battery storage = $4,600 billion.

Solar Thermal

The system must be able to supply the power to meet demand at all times, even during long periods of overcast conditions. We must design for the worst conditions.

We'll consider two worst case scenarios:

1. All power stations are under cloud at the same time for 3 days.
2. At all times between 9 am and 3 pm at least one power station, somewhere, has direct sunlight, but all other power stations are under cloud.

Assumptions:
The average capacity factor for all the power stations when under cloud for 3 days is 1.56 % (to be consistent with the PV analysis in "Solar Power Realities"; refer to Figure 7 and the table on page 10).

The capacity factor in midwinter, when not under cloud, is 15% (refer Figure 7 in "Solar Power Realities").

Scenario 1 – all power stations under cloud

Energy storage required: 3 days x 450,000 MWh/d = 1,350,000 MWh

Hours of the day when energy is stored (9 am to 3 pm) = 6 hours

Average power to meet direct day-time demand = 25 GW

Average power required to store 450,000 MWh in 6 hours = 75 GW

Total power required for 6 hours (9 am to 3 pm) = 100 GW

[4] http://bravenewclimate.wordpress.com/files/2009/09/lang_solar_realities_v2.pdf
[5] In reality, we do not have sites available for even 1 day of pumped hydro storage.

Installed capacity required to provide 100 GW power at 1.56% capacity factor (say 6.24% capacity factor from 9 am to 3 pm) = 1,600 GW.

Total peak generating capacity required = 1,600 GW

If the average capacity factor was double, the installed capacity required would be half. So the result is highly sensitive to the average capacity factor.

Scenario 2 – at least one power station has direct sun at all times between 9 am and 3 pm

One power station provides virtually all the power. The other power stations are under cloud and have a capacity factor of just 1.56%.

Energy storage required for 1 day = 450,000 MWh

Hours of the day when energy is stored (9 am to 3 pm) = 6 hours

Average power to meet direct day-time demand = 25 GW

Average power required to store 450,000 MWh in 6 hours = 75 GW

Total power required = 100 GW.

The capacity factor in midwinter, when not under cloud, is 15% (refer Figure 7 in "Solar Power Realities").

Installed capacity required to provide 100 GW power at 15% capacity factor (60% capacity factor from 9 am to 3 pm) = 167 GW.

But the clouds move, so all the power stations need this generating capacity.

To maximise the probability that at least one power station is in the sun we need many power stations spread over a large geographic area. If we have say 20 power stations spread across south east South Australia, Victoria, NSW and southern Queensland, we would need 3,300 GW – assuming only the power station in the sun is generating.

If we want redundancy for the power station in the sun, we'd need to double the 3,300 GW to 6,600 GW.

Of course the power stations under cloud will also contribute. Let's say they are generating at 1.56% capacity factor. Without going through the calculations we can see the capacity required will be between the 1,600 GW calculated for Scenario 1 and the 3,300 GW calculated here. However, it is a relatively small reduction (CF 3% / 60% = 5% reduction), so I have ignored it in this simple analysis .

So, Scenario 2 requires 450,000 MWh storage and 3,300 GW generating capacity. It also requires a very much greater transmission capacity, but we'll ignore that for now.

Costs of Solar Thermal with storage

NEEDS[6], 2008, "Final report on technical data, costs, and life cycle inventories of solar thermal power plants" Table 2.3, gives costs for the two most prospective solar thermal technologies. They selected the solar trough as the reference technology and did all the calculations for it. The cost for a solar trough system factored up to 18 hours storage and converted to Australian dollars is:

		Solar trough
Hours of Energy Storage		7.5
Specific investment costs	€/kWel	5,300
Specific investment costs	A$/kWel	8,830
Factored up to 18h storage	A$/kWel	16,000
Average Power Demand	GW	25
Total cost	A$ billion	572

This would be the cost if the sun was always shining brightly on all the solar power stations. This is about five times the cost of nuclear. However, that is not all. This system may have an economic life expectancy of perhaps 30 years. So it will need to be replaced at least once during the life of a nuclear plant. So the costs should be doubled to have a fair comparison with a nuclear plant.

In order to estimate the costs for Scenario 1 and Scenario 2 we need costs for power and for energy storage as separate items. The input data and the calculations are shown in the Appendix.

The costs for the two scenarios (see Appendix for the calculations) are:

Scenario 1 - All power stations are under cloud at the same time for 3 days

	Unit	Unit rate A$ billion	Quantity	Cost A$ billion
Collector Field	GWel	2.58	1,603	4,127
Energy storage capacity	GWh	0.19	1,350	259
Power block	GWel	2.25	25	56
Total				**4,442**

Scenario 2 - At all times between 9 am and 3 pm at least one power station, somewhere, has direct sunlight, but all other power stations are under cloud

	Unit	Unit rate A$ billion	Quantity	Cost A$ billion
Collector Field	GWel	2.58	167	429
Energy storage capacity	GWh	0.19	450	86
Power block	GW	2.25	25	56
Total				572
Total for 20 power stations				**11,433**

[6] http://www.needs-project.org/docs/results/RS1a/RS1a%20D12.2%20Final%20report%20concentrating%20solar%20thermal%20power%20plants.pdf

Summary of cost estimates for the options considered

Option	Cost ($ billion)
Nuclear power	120
Solar PV with pumped hydro storage	2,800
Solar PV with NAS battery storage	4,600
Solar Thermal with storage	4,400

The conclusion stated in the "Solar Power Realities" paper is confirmed.

The Capital cost of solar power would be 20 times more than nuclear power to provide the NEM demand.

Solar PV is the least cost of the solar options. The much greater investment in solar PV than in solar thermal world wide corroborates this conclusion.

Some notes on cloud cover

A quick scan of the Bureau of Meteorology satellite images revealed the following:

This link http://www.bom.gov.au/sat/archive_new/gms/
provides satelite views. A loop through the midday images for each day of June, July and August 2009, shows that much of south east South Australia, Victoria, NSW and southern Queensland were cloud covered on June 1, 2, 21 and 25 to 28. July 3 to 6, 10, 11, 14. 16, 22 to 31 also had widespread cloud cover (26th was the worst), as did August 4, 9, 10, 21, 22.. This was not a a rigorous study.

Also see the BOM Solar Radiation Browse Service for March and April 2002 (the data on this site only goes up to 14 April 2002).
http://www.bom.gov.au/nmoc/archives/Solar/index.shtml
Notice the low solar radiation levels for 25 to 30 March and 8 to 12 April 2002 over the area we are looking at. The loop viewed is at:

http://www.bom.gov.au/cgi-bin/nmoc/nmoc.sat.monthlylp.pl?satellite=sat/archive_new/solar_radiation&files=IDE3GS01.20020320.gif,IDE3GS01.20020321.gif,IDE3GS01.20020322.gif,IDE3GS01.20020323.gif,IDE3GS01.20020324.gif,IDE3GS01.20020325.gif,IDE3GS01.20020326.gif,IDE3GS01.20020327.gif,IDE3GS01.20020328.gif,IDE3GS01.20020329.gif,IDE3GS01.20020330.gif,IDE3GS01.20020331.gif,IDE3GS01.20020401.gif,IDE3GS01.20020402.gif,IDE3GS01.20020403.gif,IDE3GS01.20020407.gif,IDE3GS01.20020408.gif,IDE3GS01.20020409.gif,IDE3GS01.20020410.gif,IDE3GS01.20020411.gif,IDE3GS01.20020412.gif,

Some comments on Future Costs?

How much cheaper can solar power be?

NEEDS figure 3.7, p31 suggests that the cost of solar thermal may be halved by 2040.

How much cheaper can nuclear be?

The first large reactor[7] ever made was built in 15 months, ran for 24 years, and its power was expanded by a factor of 9 during its life.

If we could do that 65 years ago, for a first of a kind technology, what could we do now by building on experience to date if we wanted to put our mind to it.

Is it unreasonable to believe that, 65 years later, we could build nuclear power plants, twenty times the power of the first reactor, in 12 months, for 25% of the cost of current generation nuclear power stations?

[7] Hanford B http://www.asme.org/Communities/History/Landmarks/Hanford_B_Reactor_1944.cfm , http://files.asme.org/ASMEORG/Communities/History/Landmarks/5564.pdf

Appendix – Cost Calculations for Solar Thermal

The unit cost rates used in the analyses below were obtained from:

NEEDS, 2008, "Final report on technical data, costs, and life cycle inventories of solar thermal power plants", p31 and Figure 3.7
http://www.needs-project.org/docs/results/RS1a/RS1a%20D12.2%20Final%20report%20concentrating%20solar%20thermal%20power%20plants.pdf

Unit rates for Solar Trough:

		€	A$
collector field (solar-multiple 2) *	€/kWel	3,090	
collector field (solar-multiple 1)	€/kWel	1,545	2,575
power block	€/kWel	1,350	2,250
storage capacity	€/kWh	115	192
Total cost per kW	€/kWel	5,302	8,837

* Estimated from Fig 3.7, p31, then adjusted to give the total of €5,302

Cost for 1kW power, 1, 3 and 5 days storage, 6h sunshine per day, no cloud:

Days of storage	days	**1**	**3**	**5**
Collector Field power multiplier	kWel	4	4	4
Power Block power	kWel	1	1	1
Energy Storage capacity	kWh	18	54	90
Collector Field unit cost	$/kW	2,575	2,575	2,575
Power Block unit cost	$/kW	2,250	2,250	2,250
Energy Storage capacity unit cost	$/kWh	192	192	192
Collector Field cost	$	10,300	10,300	10,300
Power Block cost	$	2,250	2,250	2,250
Energy Storage capacity cost	$	3,450	10,350	17,250
Total cost for 1kW and 18 kWh	$	16,000	22,900	29,800

Cost for 25GW baseload power, through 1, 3, 5 days of overcast in winter:

Average Power demand	GWel	25	25	25
Energy storage capacity	GWh	450	1,350	2,250
Capacity Factor		0.75%	1.56%	4.33%
Capacity Factor for 6 h		3.00%	6.24%	17.32%
Collector Field peak power	GWel	3,333	1,603	577
Collector Field cost	$ billion	8,583	4,127	1,487
Power Block cost	$ billion	56	56	56
Energy Storage capacity cost	$ billion	86	259	431
Total Cost for 25 GW	$ billion	8,726	4,442[8]	1,974

[8] Note that, although this table includes calculations for the cost of a system with 3 and 5 days of continuous operation at full power, the technology does not exist, and current evidence is that it is impracticable. The figure is used in this comparison, but is highly optimistic..

Cost for 25GW baseload power, with 20 distributed power stations, at least one in full sun at all times, in winter:

Average Power demand	GWel	25
Energy storage capacity	GWh	450
Capacity Factor		15%
Capacity Factor for 6 h		60%
Collector Field peak power	GWel	167
Collector Field cost	$ billion	429
Power Block cost	$ billion	56
Energy Storage capacity cost	$ billion	86
Total Cost for 25 GW	$ billion	572
20 distributed power stations	$ billion	11,433

About the author

Peter Lang is a retired geologist and engineer with 40 years experience on a wide range of energy projects throughout the world, including managing energy R&D and providing policy advice for government and opposition. His experience includes: coal, oil, gas, hydro, geothermal, nuclear power plants, nuclear waste disposal, and a wide range of energy end use management projects.