$1.6 Billion Clean Energy Initiative

Solar Flagships Program

Recommendation for Appropriate Technology for the four flagship projects

As supporters of the Government's direction with regards to the Solar Flagships Program, we would like to ensure that the taxpayer is getting the best value for its investment in solar power technology. While it is understood that the Solar Flagships Program is designed to test different solar power technologies, in order to achieve the best value for this investment, it is recommended that:

- Storage (7-18 hours of full plant capacity) be an obligatory criterion for funding so that dispatchable solar can be provided. Molten salt storage of heat is currently the best commercially-available and cheapest form of storage, and is now operating in Spain and the USA.
- Solar photovoltaic plants not be considered for Solar Flagships funding.
- Hybrid solar plants that incorporate fossil fuel inputs not be considered for Solar Flagships funding.
- Construction commencement for the Solar Flagships Projects be brought forward to July 2011.
- A follow-on program be announced prior to construction of the 2011 plants which will allow for deployment of next generation technologies such as Solar Brayton cycles and advanced storage, including Australian ammonia thermochemical storage and concrete storage.

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1. Concentrating Solar Thermal Power with Storage

Concentrating Solar Thermal Power (CSP) with storage is dispatchable – meaning that electricity is produced on demand and can be produced when the sun is not shining and the wind is not blowing. In contrast, there are no large-scale commercial storage options for PV with a reasonable cost and storage efficiencies exceeding 95%.

CSP operates by concentrating sunlight to a focus with curved mirrors, and using the resultant heat to drive a Rankine (steam) or Brayton (air) power cycle. A central receiver or "power tower" CSP plant is illustrated in Figure 1. A steam cycle may be operated by directly generating steam at the focus, or by heating a fluid such as molten salt. Molten salt has the advantage that it can be stored at temperatures in excess of 600^{o}C in insulated tanks, and then fed to a heat exchanger to produce steam for power production on demand. This storage is 95% efficient, and has been in full-scale commercial operation in the 100MW Andasol power plants in Spain since 2008 [1], following the R&D phase of the Solar Two Molten Salt Power Tower at the Sandia National Laboratories in the 1990s. Many larger plants incorporating molten salt storage are now in construction in the USA and Spain.

Fig 1. Left: a schematic representation of central receiver technology.. Right: the Abengoa PS10 power tower in operation near Seville, Spain.

The four main desirable characteristics for solar power stations in the Solar Flagships program would be:

- A point focusing system – central receiver power towers or dishes.
- Storage (7-18h of full plant capacity) – preferably molten salt.
- High temperatures (550-650^{o}C) – allows efficient supercritical steam turbines.
- Air cooling to minimize plant water usage (increases parasitic load by 1.3-5%).

The four principle CSP concentrator types – parabolic troughs, linear fresnel, power towers and dishes – are illustrated in Figure 2. Line focusing CSP systems, namely parabolic troughs and linear fresnel, are not able to match the temperatures of point focusing systems – central receiver "power towers" or dishes. Current line focusing systems achieve temperatures in the range of 290^{o}C (Ausra) to 450^{o}C (Solar Power Group). In comparison, current central receiver systems from Solar Reserve, Torresol, Brightsource, Abengoa and eSolar achieve temperatures of 550-650^{o}C. These plants can then leverage current supercritical steam turbine technology – with power cycle efficiencies of 40-46% – that is mass-produced by Siemens, GE and Mann Turbo for coal-fired power plants. Non-supercritical Rankine power cycles have efficiencies around 35%. In addition, power towers require a smaller mass of molten salt storage than troughs or linear fresnel for the same power output, because they store the salt at a higher temperature. Power towers and dishes can even reach temperatures of over 1500^{o}C for use in Solar Brayton Cycle operation, but these are largely in the development phase.

In Australian conditions, air-cooling is essential for solar thermal plants. This represents another area in which power towers and dishes perform better than troughs or linear fresnel. High temperature central receiver towers that have high thermal efficiency (40-46%) have lower parasitic air cooling loads, averaging out on an annual basis at 1.3% [2]. In contrast, lower efficiency troughs and linear fresnel systems would have a parasitic electrical load of 5% for air cooling.

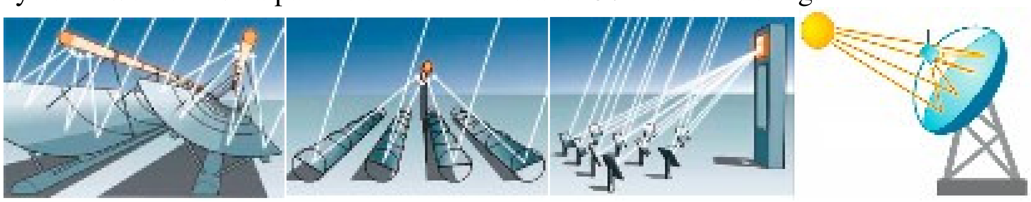

Fig 2. Concentrator types. From left: parabolic troughs, linear fresnel, central receiver "power tower" with heliostat field, and paraboloidal dish.

2. Centralised Solar PV – an inefficient allocation of funds

Solar photovoltaics (PV) is heading towards 'grid parity' around the world, and will soon be installed from private finance because on a ROI of 7 years, PV system cost would compete with the retail metered price of electricity. Figure 3 shows the predicted retail electricity price for a number of grids around Australia. The points at which these retail price curves intersect the PV Average or PV Best curves indicate a massive uptake of privately funded grid PV connections. The best methods to encourage the approach of grid parity for PV systems are subsidies for domestic or small commercial systems, and feed-in tariffs (such as that existing in the ACT), until such time as grid parity is reached.

Funding for a centralised PV power plant, however, would be an inefficient allocation of funds. This is because there are currently no large-scale commercial storage options for PV with a reasonable cost and storage efficiencies in excess of 95%. Therefore, the privately installed PV systems will produce power at the same time that a centralised PV plant would produce power, creating surplus power during peak sun hours. The energy produced by a centralised PV plant would hence be of very low value.

Therefore it is preferable that all plants constructed under the Solar Flagships program incorporate storage, in particular 7-18 hours of molten salt storage in concentrating solar thermal plants.

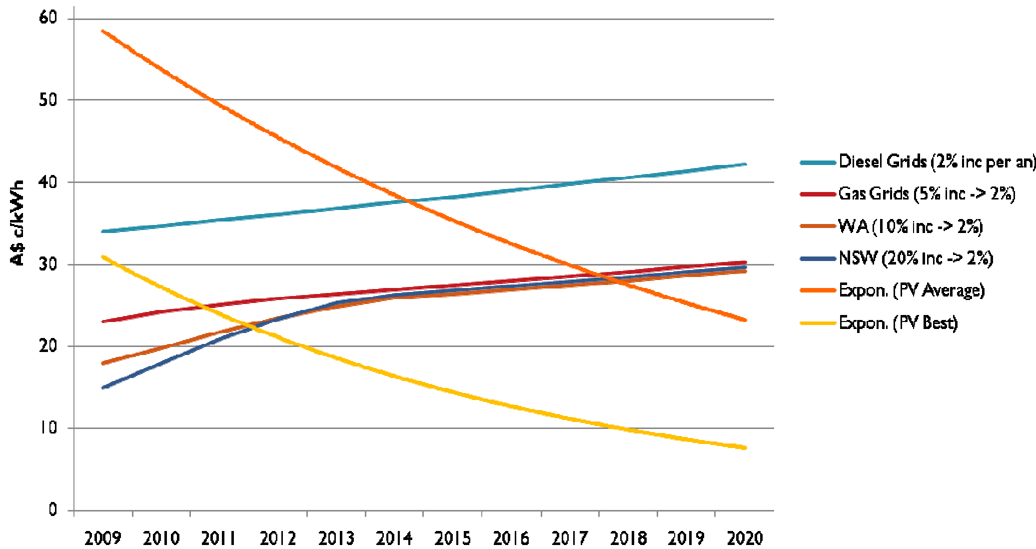

Fig 3. Retail electricity price projections. (Courtesy of Dr Muriel Watt, UNSW/IT Power.)

3. Hybrid Plants underutilize the Solar Resource

In recent years, Spain has seen the most construction of solar thermal plants of any country in the world. This is largely due to the Spanish Royal Decree 436 legislation. Amongst other specifications, this legislation states that CSP plants may not use any more than 15% natural gas backup. This specification has ensured that CSP technologies have been fully developed, rather than building gas-fired facilities with token CSP plants attached. Given the objectives of the Solar Flagships program to develop large-scale solar power plants, it is advisable that hybrid solar and gas generation plants be excluded from the program. Molten salt storage should instead be used to deliver dispatchable solar power.

In addition hybrid generation with natural gas, such as the Worley Parsons and Brightsource proposal, creates solar power stations that are dependent on the price and availability of gas. Australian energy consumers will soon be exposed to higher gas prices, due to the imminent opening of a LNG export terminal in Queensland. Therefore it is paramount to de-couple the Australian domestic energy supply from those commodities that will be subject to international parity pricing.

4. Solar Flagships Timeline

The Solar Flagships Program, as outlined in the Clean Energy Initiative paper, schedules a construction start in 2012. However, given that the successful projects are expected to be chosen by July 2010, construction could easily start from July 2011. At this time a number of full-scale molten salt storage projects will have been built and commissioned around the world, including Torresol Energy's *Gemasolar* plant near Seville, Spain. A construction commencement of 2011 would allow Australia to benefit from the lessons learned in these first-of-a-kind projects and resultant cost reductions, without falling too far behind the pack.

In addition, it is advised that a follow-on program be announced prior to construction of the 2011 plants. This will allow for deployment of next generation technologies such as Solar Brayton cycles and advanced storage, including Australian ammonia thermochemical storage and concrete storage.

5. Implementing CSP for the Solar Flagship Program

5.1 Location of CSP plants

Location of CSP plants is important both to ensure that the plants produce a consistent power output throughout the year, and to ensure proximity to transmission infrastructure and load centres.

In the NEM this would mean an appropriate number north of the central Hunter Valley load centre and an appropriate number south of the main load centre load. On the WA grids we suggest interconnection with a solar farm in the middle dispatching north and south in a location like Carnavon.

A consistent total output profile over the year can be achieved by locating the plants at different latitudes. In the Figure 4, annual average output is quoted for various sites around Australia. However, the minimum desired plant output should be compared to the median of the remaining 7-8 months for optimum plant sizing. Lower seasonal output during winter in lower latitudes (for example, June and July in Mildura) is well offset by higher output in northern latitudes (June and July in Longreach), and vice-versa during the monsoon period. For example, two plants could be built in the north, and two in the south, not withstanding that not all the plants will necessarily be built on the eastern sea board grid.

			SPH for selected Cities in Australia												
lattitude	longitude		jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	Average	Max/min :1
-13	132	Darwin	4.52	3.91	5.19	6.6	7.35	7.6	7.84	7.96	7.46	6.64	6.12	5.17	6.38	2.0
-16	144	Cook Town	5.1	4.48	4.99	5.94	6.19	6.59	6.84	6.94	7.51	7.51	6.89	5.85	6.25	1.7
-22	148	Rockhampton	6.24	5.46	5.92	5.47	5.66	6.04	6.63	6.85	7.65	7.19	6.89	6.73	6.4	1.4
-22	144	Longreach	6.63	6.36	6.63	6.54	6.38	6.61	7.05	7.3	7.54	7.05	7.18	7.13	6.87	1.1
-27	152	Toowoomba	5.85	4.94	5.25	4.86	4.94	5.34	5.57	6.05	6.59	5.99	5.97	6	5.62	1.4
-26	147	Charleville	7.06	6.37	6.86	6.24	6.21	6.2	6.59	7.24	7.7	7.48	7.36	7.34	6.89	1.2
-27	152	Brisbane	5.85	4.94	5.25	4.86	4.94	5.34	5.57	6.05	6.59	5.99	5.97	6	5.62	1.4
-32	151	Newcastle	5.5	4.94	4.86	4.67	4.32	4.53	4.73	5.5	5.8	5.94	5.51	5.85	5.18	1.4
-33	151	Sydney	5.5	4.94	4.86	4.67	4.32	4.53	4.73	5.5	5.8	5.94	5.51	5.85	5.18	1.4
-34	150	Woolongong	5.64	5.02	4.99	4.52	4.2	4.17	4.32	4.92	5.45	5.75	5.52	5.94	5.04	1.9
-30	147	Bourke	7.17	6.62	6.52	5.99	5.54	5.45	5.73	6.31	6.96	6.9	6.89	7.39	6.46	1.4
-32	148	Dubbo	7.71	7.15	6.82	5.95	5.38	5.09	5.2	5.78	6.73	7.13	7.23	7.85	6.5	1.5
-35	147	Wagga Wagga	7.7	7.17	6.92	5.79	4.84	4.03	4.12	4.75	5.39	6.4	6.91	7.29	5.94	1.9
-32	141	Broken Hill	7.96	7.31	7.1	6.26	5.29	5.12	5.32	5.95	6.59	6.98	7.39	7.49	6.56	1.6
-34	142	Mildura	8.09	7.5	7.05	6.06	4.93	4.57	4.7	5.36	6.1	6.85	7.32	7.63	6.34	1.5
-38	144	Melbourne	5.9	5.96	5.12	4.27	3.56	3.14	3.33	3.78	4.02	4.62	5.04	5.45	4.51	1.9
-32	137	Pt Augusta	7.71	7.29	6.85	6.28	5.32	5.02	5.36	5.87	6.47	6.85	7.13	7.23	6.44	1.5
-29	135	Cober Pedy	7.69	7.15	6.71	6.08	5.02	4.89	5.17	5.59	6.26	6.56	6.97	7.04	6.26	1.6
-22	133	Alice Springs	7.44	6.86	7.24	7.4	7.03	7.14	7.69	7.98	7.7	7.36	7.36	7.39	7.39	1.1
-30	120	Kalgoorlie	8.63	7.62	6.83	5.95	5.22	5.38	5.64	6.33	7.46	8.26	8.45	8.87	7.05	1.7
-32	116	Perth	8.24	7.48	6.38	5.37	4.53	4.23	4.26	4.7	5.42	6.69	7.49	8.27	6.08	2.0
-25	114	Carnavon	9.63	8.8	8.27	7.13	6.42	6.33	6.66	7.72	8.78	9.57	9.72	9.98	8.25	1.6
-21	119	Pt Headland	7.19	6.22	6.46	6.69	6.25	6.03	7.05	7.82	8.19	8.23	8.31	7.72	7.19	1.4
				Hottest month				Coldest Month								

Fig 4. Direct normal insolation data for selected cities around Australia – the number of peak sun hours (equivalent hours with solar radiation of $1kW/m^2$) for a two-axis tracking system (power tower or dish), courtesy of NASA.

5.2 Economics of CSP plants

The most widely respected source of Solar Thermal commercialization cost trajectories is the 2003 report by Sargent and Lundy for the US Department of Energy: *Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts* [3]. This report conservatively predicts that the levelised cost of Solar Thermal Power from towers with storage will drop to 5.5c/kWh USD when global installed capacity reaches 2,600MW, and 3.5c/kWh when 8,700MW of Solar Thermal central receiver power towers are installed globally. This 2003 report predicted that these capacities would be installed by 2018. However this prediction has been proven conservative with 14,000MW of projects proposed in Spain and 2,200MW under construction as of 2009. A further 10,000MW of projects are proposed in Middle East and North Africa and 97,000MW of projects are currently before the US Bureau of Lands Management for approval. This is five times greater than the Australia's combined coal-fired generating capacity of 23,000MW.

Sargent & Lundy and Sunlab estimate first plants will produce electricity at levelised energy cost of cost 11.4-14.3cents per kilowatt hour for first-of-a-kind plants. The next plants to be produced after the FOAK plants would produce power at 4.7-6.8c/kWh.

5.3 CSP plant recommendations

Given the analysis presented in this document, we recommend the following options as being best suited to the Solar Flagships program. These options include 7-18hours of storage. The following options are expressed in terms of gross turbine size, which is consistent with Australian coal-fired generation reporting.

Option 1 (Preferred option)

2x Torresol Power Tower Plants 250MW (gross)	75% Capacity factor (18 h molten salt storage)
2x Solar-Reserve Tower Plants 250MW (gross)	75% Capacity factor (18 h molten salt storage)

The final turbine size should depend on standard turbine sizes. Similarly, each plant may consist of several towers, to allow for optimal tower size. Manufacture of components such as mirrors and other plant equipment, as well as plant construction would be carried out in Australia. Torresol Energy is a joint venture between SENER of Spain and Masdar of Abu Dhabi. Their 17MW power tower near Seville, Spain is currently under constuction. See the Resources section for more details on Torresol and Solar Reserve.

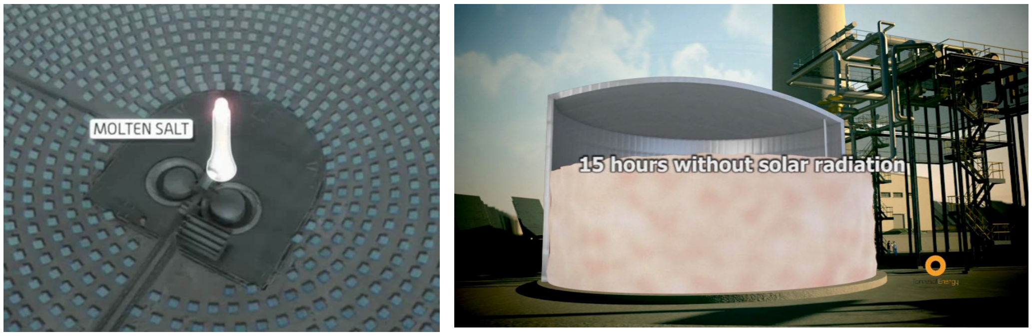

Fig 5. The Solar-Reserve Power Tower System (left) and a cut-away view of a Torresol molten salt storage tank.

Option 2

1x Torresol Power Tower Plant 250MW (gross)	75% Capacity factor (18 hours storage)
1x Solar-Reserve Tower Plant 250MW (gross)	75% Capacity factor (18 hours storage)
1x Brightsource or eSolar 270MW plant (for example 6x46MW eSolar units)	Request storage options.
1x ANU SG4 "Big Dish" array 250MW	Request storage options.

The Torresol and Solar Reserve plants would demonstrate already commercial dispatchable solar with storage in Australia.

Although we do not recommend building plants without storage options, there are certain advantages to building a Brightsource or eSolar plant, and hence storage options for these plants should be investigated. As with the Torresol and Solar Reserve options, mass production would be demonstrated, but in this case with smaller mirrors, and this would contribute to the scaling that is required to bring the cost of these projects down to 3.5-5.5c/kWh. Additionally, as no sagged glass is required (unlike trough plants), the manufacture could be performed in Australia.

Option 3

1x Torresol Power Tower Plant 250MW (gross)	75% Capacity factor (18 hours storage)
1x Solar-Reserve Tower Plant 250MW (gross)	75% Capacity factor (18 hours storage)
1x Brightsource or eSolar 270MW plant (for example 6x46MW eSolar units)	Request storage options.
1x Solar Millenium Trough 250MW (gross)	55% Capacity factor (7.5 hours storage)

Solar Millenium troughs are featured in the 150MW Andasol 1, 2 and 3 plants near Granada in Spain. At the writing of this document (2009), 100MW of the Andasol plant is already operating. However, trough systems have lower efficiencies than towers, the mirrors manufacture involves a more complicated sagging process, and they are a more mature technology than towers. Therefore, the learning experience gained by constructing such a plant would not be so great.

Resources

Attend the SolarPACES 2009 Symposium – Sept 15-18 Berlin, Germany.
(Concentrating Solar Power and Chemical Energy Systems)
http://solarpaces2009.org/cms/front_content.php

Attend the 3rd Concentrated Solar Thermal Power Summit – Nov 11-12 Sevilla, Spain.
Summit includes site visits to operational CSP plants with storage.
http://www.csptoday.com/eu/

http://www.esolar.com/
http://www.youtube.com/watch?v=YAO8hXlpL7Y

http://www.brightsourceenergy.com/
http://www.youtube.com/watch?v=0phPIzY7DPA&feature=fvw

http://www.torresolenergy.com/en/noticia1.html
http://www.youtube.com/watch?v=z3ypQo-gzf0

http://www.solar-reserve.com/
http://www.youtube.com/watch?v=IiBzmvoWsBU&feature=related

Andasol Plants
http://www.solarmillennium.de/Technologie/Referenzprojekte/Andasol/Die_Andasol_Kraftwerke_entstehen_,lang2,109,155.html
http://www.youtube.com/watch?v=bxCUYPzHsug

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