Concentrating Solar Thermal Power with Heat Storage

ATA Melbourne Branch, May 19, 2010

Notes:

Aim of talk: Show that CST (Concentrating Solar Thermal) with thermal storage (hot salt) can give "better than baseload" power in a 100% renewable electricity system.
The Group: BZE (Beyond Zero Emissions) http://beyondzeroemissions.org/
The Plan: ZCA2020 (Zero Carbon Australia 2020) – a 10 year plan for Australia
Executive Summary http://media.beyondzeroemissions.org/preview-exec-sum14.pdf

Background Information:

Excellent background talk (thanks to Lance Collins - clear outline of the ideas and the physics):
http://www.youtube.com/watch?v=cjwKIQ2ON-M&feature=player_embedded

The Presentation:

The **aim of the Zero Carbon Australia 2020 Stationary Energy plan** is to convert Australia's stationary energy system to 100% renewable energy in 10 years. This means finding a serious and viable way to make the transition, without looking for a whole lot of intermediate technologies that only do half the job.

The Carbon Budget 2010-2050 graph notionally allocates a per capita CO2 emissions budget for people around the world. This is the budget for a safe limit of CO2 emissions. Because Australia and the U.S.A. have high per capita emissions, we use up our budget very quickly, and so we need to reduce our emissions to zero in about 10 years. Doing half the job in twice the time does not solve the problem. Other countries with less per capita emissions have more time to act, but still need a renewable energy solution within the next 15 or 20 years, and need to totally convert within about 35 years.

Baseload solar thermal power uses the good old proven **steam turbine**, just like fossil fuel and nuclear power stations. But the heat comes from concentrated solar energy. Here we talk about just two kinds of solar concentrator: **Parabolic troughs**, and **power towers**.

This technology is not exactly new – parabolic troughs were **proven technology in 1911**. This plant was generating steam to drive pumps to irrigate cotton fields in Egypt. But it was bombed in World War 1, and then they found oil, so they didn't rebuild it.

More modern parabolic trough systems date from **the early 1980's**. Slide 15 shows a 354 MW parabolic trough plant in the Mojave Desert in California. This is still operating today.

Linear Fresnel Arrays are a variant on parabolic troughs. Again, Linear Fresnel Arrays have been around for a long time (e.g. 1962 in France). A parabolic trough has a long thermal collector tube at the focal point of the reflector. The trough and the collector tube both move as the trough tracks the sun. A linear Fresnel array also has a long collector tube, but it is held up in a fixed position, and only the mirrors move to track the sun. For both these schemes, the tracking movement is just in one direction (East-West). The mirrors do not try to follow the Nort-South seasonal movements of the sun.

Power Towers use an array of mirrors (heliostats) to track the sun, and focus on a single fixed point where the receiver is housed, at the top of a tower. This has two benefits:
1. The solar energy is very concentrated, which allows higher temperatures, and therefore **higher turbine efficiencies**.
2. It is relatively easy and **efficient to pipe the heat to the turbine area** – the piping is short and with a simple, fixed path.

Again, power towers are not so new. This one (slide 20) was **built in USSR in 1978**.

The really exciting technology is the **molten salt power tower systems** – they were proven by the U.S. Department of Energy back in the 1990's. Slide 23 shows how the system works. The working fluid is molten salt (a mixture of potassium nitrate and sodium nitrate, which is molten above 220 degrees C. The 'cold' tank of liquid runs at 290 degrees C. This is pumped up the tower, where the heliostat mirrors focus the sun's radiation onto a receiver, and the molten salt is heated to 565 degrees C – the same temperature as used in a coal plant. This is stored in the 'hot' tank – like a big insulated thermos flask. Whenever you need electrical power, the hot salt is used to generate steam and drive the turbine, and then it is sent back to the 'cold' tank. This heat storage lets you generate electrical power around the clock, 24 hours/day. Heat energy is much easier and cheaper to store than electrical energy, and the heat that is captured during sunlight hours can be despatched as electricity at night, or whenever it is needed. This kind of power generation is more flexible than baseload power from coal fired plants, which a slow to respond to changes in demand, and so need support from more flexible plants. The Solar Thermal plants offer a combination of reliability and flexible response.

This idea was proven by the U.S. Department of Energy **in the 1990's** with their 'Solar Two' project, run by Lockheed Martin and a number of other natioanl energy laboratories and energy companies.

Various baseload solar thermal plants are now in operation and being built in Spain (slide 25). The Andasol plants (at the top) use parabolic trough technology with molten salt storage. They have enough storage to run at full output for 7.5 hours without sunlight. The **Torresol Gemasol** plant uses power tower technology, and when it is operational at the beginning of next year, will have enough storage for 15 hours. That gives **baseload power all through the year**. This technology has a 'capacity factor' of 75%, which is higher than for a NSW black coal plant. 'Capacity factor' is the percentage of the nameplate capacity of the plant that is used on average over the year.

The Andasol **graph of energy dynamics** is shown in slide 27. The top (orange) curve shows the solar radiation, and the brown curve below shows the thermal energy collected by the reflectors. The dotted red curve shows heat flow to the power block, to run the turbine and produce electricity. The red curve along the bottom shows the continuous electricity produced. The two blue-green curves show heat going to storage during the day, and flowing back from storage after the sun goes down. The dotted blue curve shows excess heat being dumped, particularly late in the day when the solar storage is full, but the sun is still shining quite strongly. In this example, power output is delivered for 20 hours out of a 24 hour day. For a full baseload system, the plant would have a slightly different balance of resources – a somewhat larger mirror field and thermal storage, and somewhat smaller turbine capacity.

This technology is not waiting for more R&D. Here (slide 29) are some of the **companies around the world** who are involved now in building and operating industrial scale solar plants.

The ZCA2020 plan is based around the **Solar 220 modules** of Sandia Laboratories, which are run by Lockheed Martin as part of the U.S. Department of Energy. This size is chosen because it is about the maximum for a single tower system, and so gives the best economies of scale, by getting the most power per tower/receiver/turbine system. These engineering drawings (slide 30) are for projects that are currently being commercialised by the U.S. Company Solar Reserve in Spain and U.S.A. This technology gives high temperatures (and hence good storage and high turbine efficiency) and low thermal losses in the piping runs.

The **thermal storage** tanks are big, but simple steel tanks (slides 32 and 33). Thermal energy storage these tanks is much **cheaper and simpler than** chemical energy storage in **batteries**.

What's happening **in Spain**? Spain has 2,440 MW of Solar Thermal capacity operating, or under construction, to be completed over the next 3 years. This is enough power for 1/3 of Victoria's energy needs (or 1/5 of NSW's needs). These are as a result of the old feed-in tariff. A further 16,000 MW is in the pipeline – enough to power NSW and South Australia from Solar Thermal. These later plants have a lower tariff input, reflecting the falling cost of plants.

What is **Australia's solar resource** like? This world maps shows that Australia's solar resource is outstandingly good – much better than Spain's for example). The Grid of the Future has a mix of wind power and solar thermal with storage. **Wind** is cheap and plentiful with its energy, but not always reliable. **Solar thermal with storage** complements the wind, and is flexible and reliable. The ZCA2020 Plan is to back up the solar plants with occasional use of biomass or other thermal source, using the turbines and transmission lines of the solar thermal plants. It also uses the available hydro electric power. This occasional backup gives security of supply without needing extra installed capacity.

This plan directly addresses the 50% of **Australia's emissions** that come from stationary energy (slide 37). It also helps to address the other emissions, by offering a renewable energy infrastructure(for example slide 42 suggests some ideas for transport electrification).

The ZCA2020 plan allows for **60% solar thermal with storage**, **40% wind**, and upgraded National Grid, and Biomass backup in the solar thermal plants. The solar and wind sites are geographically spread, for robustness of the solar and wind resources, and are located reasonably close to population centres. Each of the 12 solar plants will have a capacity of 3,500 MW, made up of 19 modules, each with 220 MW cpacity. The wind plants will use 8,000 turbines, spread across 24 sites. A typical pattern of wind and solar input is shown in slide 49 for 3 typical July days in winter. This gives an idea of the value of geographic diversity – when one site has low output, typically other sites compensate for this. This graph uses on real data, but the wind sites are restricted to Tasmania, Victoria and South Australia. Another typical 3 day period is shown in slide 50, with wind and concentrating solar working together to meet the demand. The dark blue block at the bottom shows wind input, and the red block shows electric output from the solar turbines. These together meet the demand (orange line along the top of the red block). The solar input (tall loops of orange) feeds the thermal storage, and the available energy from storage is shown as the purple ripple, high above the demand curve.

The graph of slide 51 shows **one year of real data**. The raw data is uses ½ hour samples, and these are plotted as daily totals. The blue at the bottom is for wind input. The red is for turbine output from the solar thermal plants. The daily demand is the dark line along the top of the red band. The orange peaks above the demand show the excess thermal energy (not needed to meet the demand). The pockets of green and black show when the biomass backup and hydro power are needed (for periods of low wind nd low solar input at the same time).

The **materials** required to construct the plants are a very small proportion of Australia's normal output – less than 7% of our concrete production, and less than 2% of our total iron ore production. The **labour** required is an interesting mix of short term (10 years) construction staff, ongoing staff for plant operation and maintenance, and ongoing staff in new manufacturing industries (slide 53). The common misconception is that the shutdown of fossil fuel plants will create unemployment, but the reality is that the renewable energy plants will create much more employment. The impact of this on Australia's employment is shown in slide 55. This shows the recent demand for similar types of employment. This was expanding quite strongly from 2003 to 2008, then the growth ceased with the global financial uncertainty. The small green band at the top after 2010 shows the **impact of the ZCA2020 plan**. This is comfortably within our capacity to expand employment.

It is a common concern that a renewable energy system will cost too much, and that although wind generation is fairly cheap, solar power is often said to be far too expensive. The ZCA2020 plan uses **cost projections** from Sargent and Lundy – one of the world's largest and oldest power engineering consultancies (slide 56). As with most technologies, there are enormous reductions in costs to be made with Concentrating Solar Thermal power as the industry grows, and more capacity is installed. In particular, we look at the projections for Power Towers with molten salt storage. When 2,600 MW of capacity is installed worldwide (less than 2 Hazelwoods), the price of power tower technology is **projected to fall to the equivalent of wind power**. With a further 6,100 MW (3 and a bit Hazelwoods), the price is **equivalent to that for new coal plants** - about 5 cents Australian per kWh. The whole cost of the renewable energy system is about 3% of GDP over the 10 years of the project (slide 59) – and this is a mixture of public and private money. In the short term, as costs fall, some form of price support is required, and this makes it viable for private companies to invest capital.

An analysis of Net Present Costs (slide 60) shows that the renewable energy system not only reduces CO2 emissions, but also has a **direct economic payback compared with Business-As-Usual**. The renewable energy system is installed between now and 2020, and the graph continues through to 2040. The zero line (just above the year dates) shows Business-As-Usual as the zero reference line. The bottom (red) curve shows expenditure on the renewable energy system in the first 10 years – roughly $A 35 Bn/yr for the last few years before 2020. Then after 2020, the renewable energy system returns a continuing benefit of $A 10-15 Bn/yr compared with Business-As-Usual. This benefit is because we avoid the expansion costs and fuel costs of Business-As-Usual. The middle (green) curve is more spectacular. This allows for the savings in oil costs, and gives a saving of $A 65 Bn/yr after 2020. The saving in oil is because the overall ZCA2020 plan moves most transport to electric vehicles (and the electrical energy comes from the renewable energy sources). This project has good value for the environment, for the economy, and for employment. It gets us involved in forward-looking technologies.

Solar thermal power with molten salt storage is a **powerful and viable source of 'baseload' power**, but is also much more flexible. We don't need fossil fuel plants, and we don't need nuclear plants.