Concentrating Solar Thermal Power System Economics

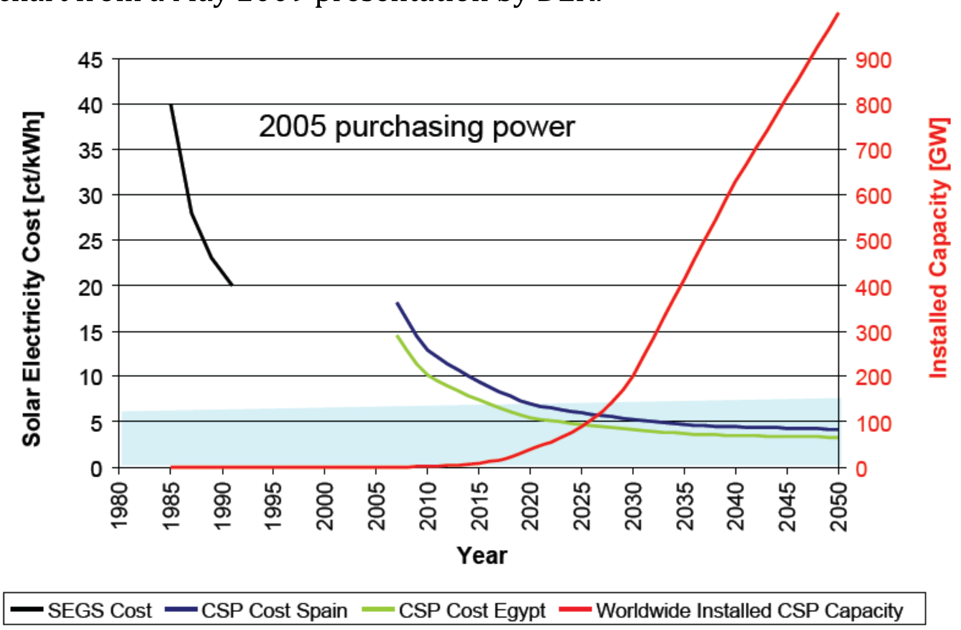
Introduction

Concentrating solar thermal power (or "CSTP") is increasingly discussed as a key low-carbon electricity supply technology. Until very recently there was little understanding except among specialists that the umbrella term "solar power" actually encompassed at least two very different categories of power generation – PV and CSTP – but CSTP has begun to emerge from the shadows as a distinct category of renewable power supply. Yet while it is now more often cited as distinct from solar PV, there is still little understanding of why the distinction is worth making, and the few good sources available publicly about its economics have not been widely disseminated beyond specialist circles. This note is intended to address the issue of economics. A good summary (by Joe Romm of the Center for American Progress) for the generalist on the significance of CSTP, as distinct from other forms of renewable power, can be found at: http://www.salon.com/news/feature/2008/04/14/solar_electric_thermal/index.html.

Research institute sources

Probably the most widely cited source of academic research on the economics of CSTP is a series of reports from the Deutsches Zentrum für Luft- und Raumfahrt e.V. (the German Aerospace Agency, or "DLR"). Perhaps the most thorough of those reports was co-written with CIEMAT and submitted to the European Commission; it can be accessed online at:
http://www.needs-project.org/docs/results/RS1a/RS1a%20D12.2%20Final%20report%20concentrating%20solar%20thermal%20power%20plants.pdf

The economic analysis presented in that report was summarized in the following chart from a May 2009 presentation by DLR:



Source: EU-IP NEEDS (New Energy Externalities Developments for Sustainability

This chart summarizes the economics for a solar-only plant, with 7.5 hours of thermal storage today rising to 16 hours of storage from 2021. The comparable economics for a hybrid solar-and-natural-gas plant in 2007 were 10.26-13.86 € cents/kWh for sites in, respectively, Egypt and Spain.

Another recent research source is a 2006 report prepared by engineering consultancy Black & Veatch for the U.S. Department of Energy's National Renewable Energy Laboratory (available online at:

http://www.nrel.gov/docs/fy06osti/39291.pdf).

That report analyses a nominal 100 MW CSTP plant in Southern California with 6 hours of storage and summarizes the results in the following table:

Table 6-2
Levelized Cost Comparison*

	Capacity, MW	Storage, hours	Capacity Factor, %	Nominal Levelized Cost, $ per MWh (30% ITC)	Nominal Levelized Cost, $ per MWh (10% ITC)	Real Levelized Cost, $ per MWh (30% ITC)	Real Levelized Cost, $ per MWh (10% ITC)
Simple Cycle	85	N/A	10.0	168	168	134	134
Simple Cycle ($8/MMBtu Gas)**	85	N/A	10.0	187	187	149	149
Combined Cycle	500	N/A	40.0	104	104	83	83
Combined Cycle ($8/MMBtu Gas)**	100	N/A	40	119	119	95	95
Parabolic Trough (2007)	100	0	28.4	154	173	125	140
Parabolic Trough (2007)	100	6	40.4	157	176	127	143
Parabolic Trough (2009)	100	6	40.4	148	166	120	135
Parabolic Trough (2011)	150	6	40.4	120	134	97	109
Parabolic Trough (2015)	200	6	40.4	103	115	83	93

*Financial assumptions are essentially per MPR calculation methodology. Assumptions are provided in Table 6-1.
**$8/MMBtu is MPR gas price for 2015.

The "ITC" referenced in the table is the federal investment tax credit for qualifying solar energy facilities. A simple linear extrapolation would imply that the 2007 cost (in 2005 $s) without any tax subsidy would be approximately $151/MWh, declining to $98/MWh in 2015.

Another source that could be characterized as a research source is a series of reports from SolarPACES, "an international cooperative organization bringing together teams of national experts from around the world to focus on the development and marketing of concentrating solar power systems" that is sponsored by the IEA. There are papers available at SolarPACES web site, but they are of an indeterminate vintage. A more recent indication of the IEA's analysis of the economics of CSTP can be found in their *Energy Technology Perspectives 2008*, which states (at page 383): "Plants under construction are expected to generate electricity at a cost of between USD 125/MWh and USD 225/MWh, mostly depending on the location." It goes on to state (at page 384): "Detailed analyses have confirmed that future costs may lie in the range of USD 43 to USD 62 per MWh for trough plants, and USD 35 to USD 55 per MWh for tower plants (Sargent & Lundy LLC Consulting Group, 2003). Significant cost reductions could be achieved with technology improvements limited to current demonstrated or tested technologies and the deployment of 2.8 GW trough plants and 2.6 GW tower plants…". It is worth noting that there are considerably more than this combined total of 5.4 GW of plants already under contract. (for a list of CSTP plants in operation, under construction or under contract, please go to http://en.wikipedia.org/wiki/List_of_solar_thermal_power_stations).

Finally, a February 2009 article in *Scientific American* quotes "NREL senior engineer Greg Glatzmaier" as saying: "Electricity from a solar thermal power plant costs roughly 13 cents a kilowatt-hour…both with and without molten salt storage systems", and it goes on to quote "Thomas Mancini, manager of Sandia National Laboratory's concentrating solar power program" as saying: "If we start valuing carbon and force a coal plant to go carbon-free via sequestration, then we're at or over 10 cents per kilowatt-hour from coal…[CSTP] can get to that same 10 cents level with [molten salt] storage. Then the market will make the call."

Government reports

Another source of economic data is government reports on the costs of various sources of energy. These tend to be compilations by government agencies of the available data on the various technologies.

The European Commission, as part of its 2nd Strategic Energy Review, released in November 2008 its *Energy Sources, Production Costs and Performance of Technologies for Power Generation, Heating and Transport.* That report's base case findings are summarized in the following table:

Table 2-1: Energy Technologies for Power Generation – Moderate Fuel Price Scenario [(a)]

Energy source	Power generation technology		Production Cost of Electricity (COE) State-of-the-art 2007 $€_{2005}$/MWh	Projection for 2020 $€_{2005}$/MWh	Projection for 2030 $€_{2005}$/MWh	Net efficiency 2007	Lifecycle GHG emissions Direct (stack) emissions kg CO_2/MWh	Indirect emissions kg CO_2(eq)/MWh	Lifecycle emissions kg CO_2(eq)/MWh	Fuel price sensitivity
Natural gas	Open Cycle Gas Turbine (GT)	-	65 ÷ 75 [(b)]	90 ÷ 95 [(b)]	90 ÷ 100 [(b)]	38%	530	110	640	Very high
	Combined Cycle Gas Turbine (CCGT)	-	50 ÷ 60	65 ÷ 75	70 ÷ 80	58%	350	70	420	Very high
		CCS	n/a	85 ÷ 95	80 ÷ 90	49% [(c)]	60	85	145	Very high
Oil	Internal Combustion Diesel Engine	-	100 ÷ 125 [(b)]	140 ÷ 165 [(b)]	140 ÷ 160 [(b)]	45%	595	95	690	Very high
	Combined Cycle Oil-fired Turbine (CC)	-	95 ÷ 105 [(b)]	125 ÷ 135 [(b)]	125 ÷ 135 [(b)]	53%	505	80	585	Very high
Coal	Pulverised Coal Combustion (PCC)	-	40 ÷ 50	65 ÷ 80	65 ÷ 80	47%	725	95	820	Medium
		CCS	n/a	80 ÷ 105	75 ÷ 100	35% [(c)]	145	125	270	Medium
	Circulating Fluidised Bed Combustion (CFBC)	-	45 ÷ 55	75 ÷ 85	75 ÷ 85	40%	850	110	960	Medium
	Integrated Gasification Combined Cycle (IGCC)	-	45 ÷ 55	70 ÷ 80	70 ÷ 80	45%	755	100	855	Medium
		CCS	n/a	75 ÷ 90	65 ÷ 85	35% [(c)]	145	125	270	Medium
Nuclear	Nuclear fission	-	50 ÷ 85	45 ÷ 80	45 ÷ 80	35%	0	15	15	Low
Biomass	Solid biomass	-	80 ÷ 195	85 ÷ 200	85 ÷ 205	24% ÷ 29%	6	15 ÷ 36	21 ÷ 42	Medium
	Biogas	-	55 ÷ 215	50 ÷ 200	50 ÷ 190	31% ÷ 34%	5	1 ÷ 240	6 ÷ 245	Medium
Wind	On-shore farm	-	75 ÷ 110	55 ÷ 90	50 ÷ 85	-	0	11	11	nil
	Off-shore farm	-	85 ÷ 140	65 ÷ 115	50 ÷ 95	-	0	14	14	
Hydro	Large	-	35 ÷ 145	30 ÷ 140	30 ÷ 130	-	0	6	6	nil
	Small	-	60 ÷ 185	55 ÷ 160	50 ÷ 145	-	0	6	6	
Solar	Photovoltaic	-	520 ÷ 880	270 ÷ 460	170 ÷ 300	-	0	45	45	nil
	Concentrating Solar Power (CSP)	-	170 ÷ 250 [(d)]	110 ÷ 160 [(d)]	100 ÷ 140 [(d)]	-	120 [(d)]	15	135 [(d)]	Low

[(a)] *Assuming fuel prices as in 'European Energy and Transport: Trends to 2030 - Update 2007' (barrel of oil 54.5$$_{2005}$ in 2007, 61$$_{2005}$ in 2020 and 63$$_{2005}$ in 2030)*
[(b)] *Calculated assuming base load operation*
[(c)] *Reported efficiencies for carbon capture plants refer to first-of-a-kind demonstration installations that start operating in 2015*
[(d)] *Assuming the use of natural gas for backup heat production*

The CSTP plant represented here is a 50 MW solar-and-gas hybrid trough plant. Given the report's premise, it is assumed to be located in continental Europe.

The U.S. Congressional Research Service, also in November 2008, published a report entitled *Power Plants: Characteristics and Costs.* That report's analysis of plant economics, based on a sampling of actual projects in the US, was summarized in the following table:

Table 4. Estimated Base Case Results
(2008 $)

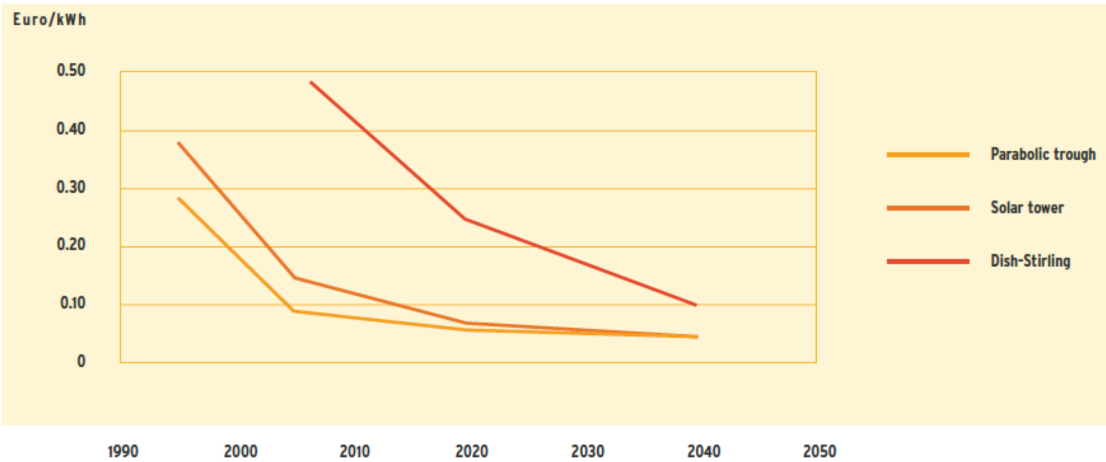
Technology (1)	Developer Type (2)	Non-Fuel O&M Cost (3)	Fuel Cost (4)	SO_2 and NOx Allowance Cost (5)	CO_2 Allow. Cost (6)	Prod. Tax Credit (7)	Total Operating Costs (8)	Capital Return (9)	Total Annualized $/Mwh (10)
Coal: Pulverized	IOU	$5.57	$11.13	$0.61	$0.00	$0.00	$17.31	$45.79	**$63.10**
Coal: IGCC	IOU	$5.46	$10.41	$0.10	$0.00	$0.00	$15.97	$67.02	**$82.99**
NG: Combined Cycle	IPP	$2.57	$30.57	$0.14	$0.00	$0.00	$33.27	$28.50	**$61.77**
Nuclear	IOU	$6.13	$5.29	$0.00	$0.00	($3.18)	$8.23	$74.99	**$83.22**
Wind	IPP	$6.67	$0.00	$0.00	$0.00	$0.00	$6.67	$74.07	**$80.74**
Geothermal	IPP	$13.69	$0.00	$0.00	$0.00	$0.00	$13.69	$45.54	**$59.23**
Solar: Thermal	IPP	$13.71	$0.00	$0.00	$0.00	$0.00	$13.71	$86.61	**$100.32**
Solar: Photovoltaic	IPP	$4.17	$0.00	$0.00	$0.00	$0.00	$4.17	$251.24	**$255.41**

Source: CRS estimates.

Note: Projections are subject to a high degree of uncertainty. These results should be interpreted as indicative given the projection assumptions rather than as definitive estimates of future outcomes. Mwh = megawatt-hour; IGCC = integrated gasification combined cycle; NG = natural gas; CCS = carbon capture and sequestration; SO_2 = sulfur dioxide; NOx = nitrogen oxides; O&M = operations and maintenance; IPP = independent power producer; IOU = investor owned utility.

The cost for solar thermal was inclusive of the 30% investment tax credit; removing the impact of that benefit would raise the cost of solar thermal to approximately $125/MWh. One interesting aspect of that report is that it charted the sample data based on historical and projected in-service dates, with the *only* technologies exhibiting a downward trend being solar PV and solar thermal.

The German government, in April 2006, released a report entitled *Renewable Energies: Innovations for the Future.* That report presents current and projected costs for a solar-only plant without storage as follows:



The text of the report states that current costs for such a plant range from 9-22 € cents per kWh "depending on location and interest rate." It further states: "these costs can be approximately halved within the coming decade." The report states that hybrid solar-and-gas configuration can cut current costs by 50%, and that incorporation of thermal storage will further reduce levelized costs.

The Western Governors Association produced a January 2006 report, *Clean and Diversified Energy Initiative: Solar Task Force Report*, detailing the potential of various solar options among a range of renewable energy technologies for the Western U.S. That report modelled the economics of a nominal 100 MW trough plant with 6 hours of storage, against the rate of deployment in MW of capacity, with the following results:

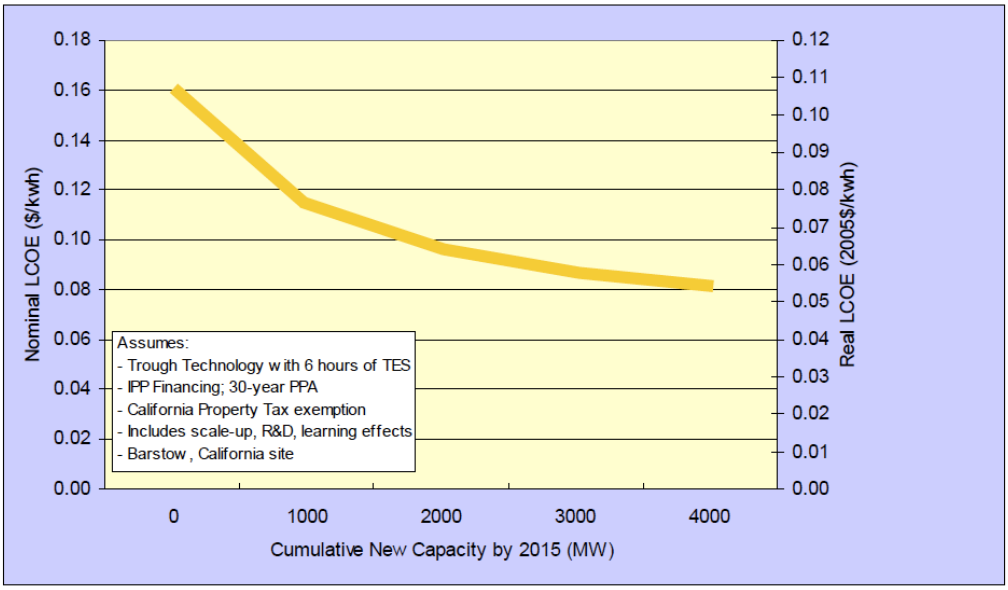


Figure I-5. Projected Cost Reduction Scenario for CSP (based on trough technology)

This analysis assumed a 10% investment tax credit, which lowered the costs by about $0.008/kWh.

Industry data

Finally, a few industry sources are available (including reliable reports of the prices included in recent contracts).

Arizona Public Service, Tuscon Electric Power and Salt River Project published the *Arizona Renewable Energy Assessment* in September 2007, based on a study by Black & Veatch. The study's review of CSTP economics is summarized below:

Table 5-10. Solar Thermal Electric Project Characteristics (Constant 2007$).											
								Capacity Factors (%)			
COD Year	MW	HTF*	Hrs Storage	$/kW	O&M $/kW-year	Land Area Acres	Water Usage Acre-ft/year**	Stoval	Yuma	Phoenix	Tucson
2011	100	VP-1	0	4,200	55	570	610	29.8	29.3	27.3	28.7
2012	200	VP-1	3	4,000	50	1,300	1,450	35.1	34.5	32.2	33.8
2013	200	VP-1	3	4,000	50	1,300	1,450	35.1	34.5	32.2	33.8
2014	200	VP-1	6	4,500	48	1,500	1,740	42.3	41.6	38.8	40.7
2015	200	VP-1	6	4,500	48	1,500	1,740	42.3	41.6	38.8	40.7
2016	200	VP-1	6	4,500	48	1,500	1,740	42.3	41.6	38.8	40.7
2017	200	MS	6	4,500	45	1,450	1,740	42.3	41.6	38.8	40.7
2018	200	MS	6	4,200	45	1,450	1,780	43.3	42.6	39.7	41.7
2019	200	MS	6	4,200	45	1,450	1,780	43.3	42.6	39.7	41.7
2020	200	MS	6	4,200	45	1,450	1,780	43.3	42.6	39.7	41.7
2021	200	MS	6	3,700	45	1,450	1,820	44.3	43.6	40.6	42.7
2022	200	MS	6	3,700	45	1,450	1,820	44.3	43.6	40.6	42.7
2023	200	MS	6	3,700	45	1,450	1,820	44.3	43.6	40.6	42.7
2024	200	MS	6	3,700	45	1,450	1,820	44.3	43.6	40.6	42.7
2025	200	MS	6	3,700	45	1,450	1,820	44.3	43.6	40.6	42.7

* VP-1 is a silicone oil. MS is molten salt.

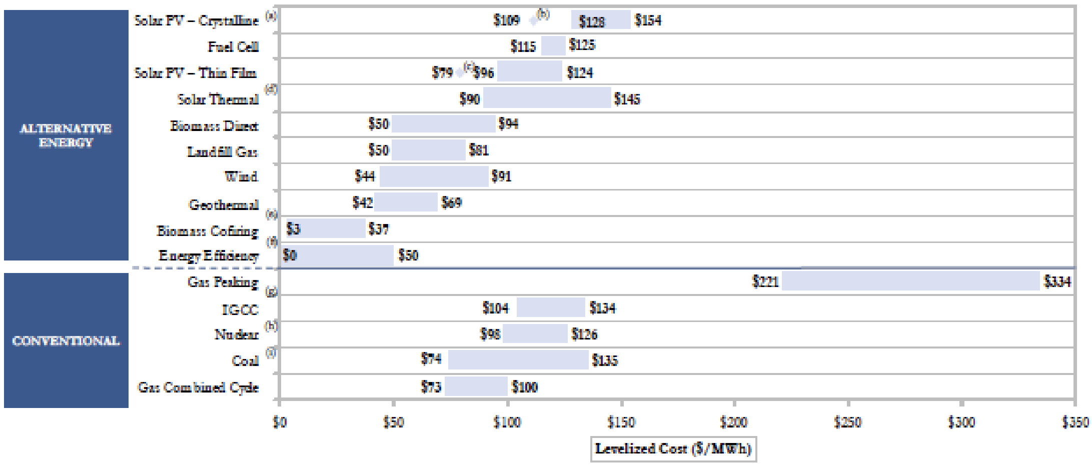
**Water usage based on Stoval site. All plants assumed to use wet cooling.

The cost per kWh derived from these numbers in the text was approximately $0.16/kWh in 2007. Assuming that cost reflects 30% ITC, the unsubsidized cost is approximately $18.4/kWh in 2007.

The Centre for Global Development, a Washington D.C.-based think tank, produced a report in December 2008 entitled *Desert Power: The Economics of Solar Thermal Electricity for Europe, North Africa, and the Middle East*, in which they derived a range of costs for CSTP based on an analysis drawn from regulatory proceedings currently under way in California on four CSTP projects seeking approval. CGD's translates the economics presented by these four projects to a nominal plant with and without storage in the range of environments in the Middle East and North Africa, producing levelized cost of electricity ranging from U.S.$0.128-0136/kWh for a plant with 16 hours of thermal storage, and U.S.$0.158-0.167/kWh for a plant without storage.

Cost information is available to some extent on another project working its way through the regulatory approval process in the U.S. Abengoa Solar has signed a contract with Arizona Public Service Company for the output from a 280 MW parabolic trough CSTP project called Solana, which will have 6 hours of thermal storage and is scheduled for completion in 2011. While the details of the contract are confidential, both the application to the Arizona Corporation Commission (in February 2008) and the Commission's decision (September 2008) provide sufficient information to derive a close approximation of the project's economics. The plant's output is said to cost $20-25/MWh more than a comparable fossil resource over the 30-year life of the contract. That resource is identified as a reference gas-fired combined cycle plant based on then-current forward prices for natural gas in the region. These assumptions, which are based on the California Market Price Referrant used for the California RPS, place the alternative resource against which Solana was evaluated at approximately $110-120/MWh. That would imply a levelized cost of electricity from Solana of approximately $140/MWh, which is consistent with various contemporaneous media comments and with statements in an intervention in the proceedings by the Western Resources Associates, a regional environmental advocacy group. The contract is stated to be contingent on extension of the federal investment tax credit for qualifying solar projects, which would provide a benefit of between $8-24/MWh, making the unsubsidized price for Solana's production $148-164/MWh beginning in 2011.

One additional recent source for industry data comes from investment banking firm Lazard. At the 2008 meeting of the U.S. National Association of Regulatory and Utility Commissioners, Lazard presented a comparison of the levelized cost of energy from a range of conventional and renewable technologies:



The slides note that the low end of the range for solar thermal reflects power tower technology, while the high end of the range reflects parabolic trough technology. This analysis assumed a 30% investment tax credit for solar thermal, which will have reduced the effective cost by as much as $30/MWh.

<u>Conclusion</u>

While there are other sources available, this note has tried to look only at the most recent citations, since the state of knowledge on CSTP is progressing rapidly. The available data exhibits a strong convergence toward a well-defined range of current and projected costs. Several of the sources make the point that these costs must be evaluated not in the same way as intermittent sources like wind and PV, but rather they must be evaluated on the basis that CSTP is a fully controllable resource with a high level of firm capacity credit, and is therefore capable of substituting directly for gas CCGT, coal and nuclear without the need to add large amounts of storage to the system and without the need for any significant restructuring of the existing electricity network.