REALISING THE POTENTIAL OF CONCENTRATING SOLAR POWER IN AUSTRALIA

PREPARED BY IT POWER (AUSTRALIA) PTY LTD
FOR THE AUSTRALIAN SOLAR INSTITUTE

MAY 2012

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Presentation by Keith Lovegrove, 16 July 2012. Report available from http://www.australiansolarinstitute.com.au/reports/.aspx

- This study seeks to:
  - Provide a summary of the global status of CSP.
  - Review previous investigations of the potential for CSP in Australia.
  - Establish a best estimate of current costs.
  - Analyse the value of CSP electricity in the market place, with particular examination of the value of dispatchability and ancillary services.
  - Analyse the various potential market segments for CSP electricity in Australia.
  - Examine the challenges facing a CSP industry in Australia.
  - Identify pathways for CSP industry development.
- Scope covers utility scale CST and CPV but not solar fuels or process heat

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TROUGH

> The most widely deployed CSP technology, with 1,400 MW_e (CST) installed as at 2011.

> Parabolic mirror tracks sun east to west, and focuses energy onto a linear 'evacuated tube' receiver.

> Mature technology with systems operating for over 25 years.

1,500MW, mature

Important to remember, CSP is currently 95% troughs with steam turbines

LINEAR FRESNEL

> Long rows of flat or slightly curved mirrors, moving independently on one axis.

> Energy reflected up to fixed linear receivers mounted on towers well above the mirrors.

> Medium maturity, 38 MW_e (CST) installed as at 2011.

38MW, medium maturity

DISH

> Paraboloidal shape with two-axis tracking focuses sunlight to a point receiver.

> The highest optical efficiency of all CSP types, because full aperture directed toward the sun avoids the 'cosine loss effect'.

> Low maturity, 6 MW_e (CPV & CST) installed as at 2011.

6MW, least mature

TOWER

> An array of heliostats (large mirrors with two-axis tracking) concentrate sunlight onto a fixed receiver at the top of a tower.

> Large single receiver facilitates complex conversion processes such as direct heating of molten salt.

> Medium maturity, 60 MW_e (CST) installed as at 2011.

60MW, medium maturity

FRESNEL LENS

> Flat plastic lenses made as a series of concentric steps.

> Point focus used with high efficiency PV cells.

> Mounted in arrays to track the sun in two axes.

> Medium maturity, 15 MW_e (CPV) installed as at 2011.

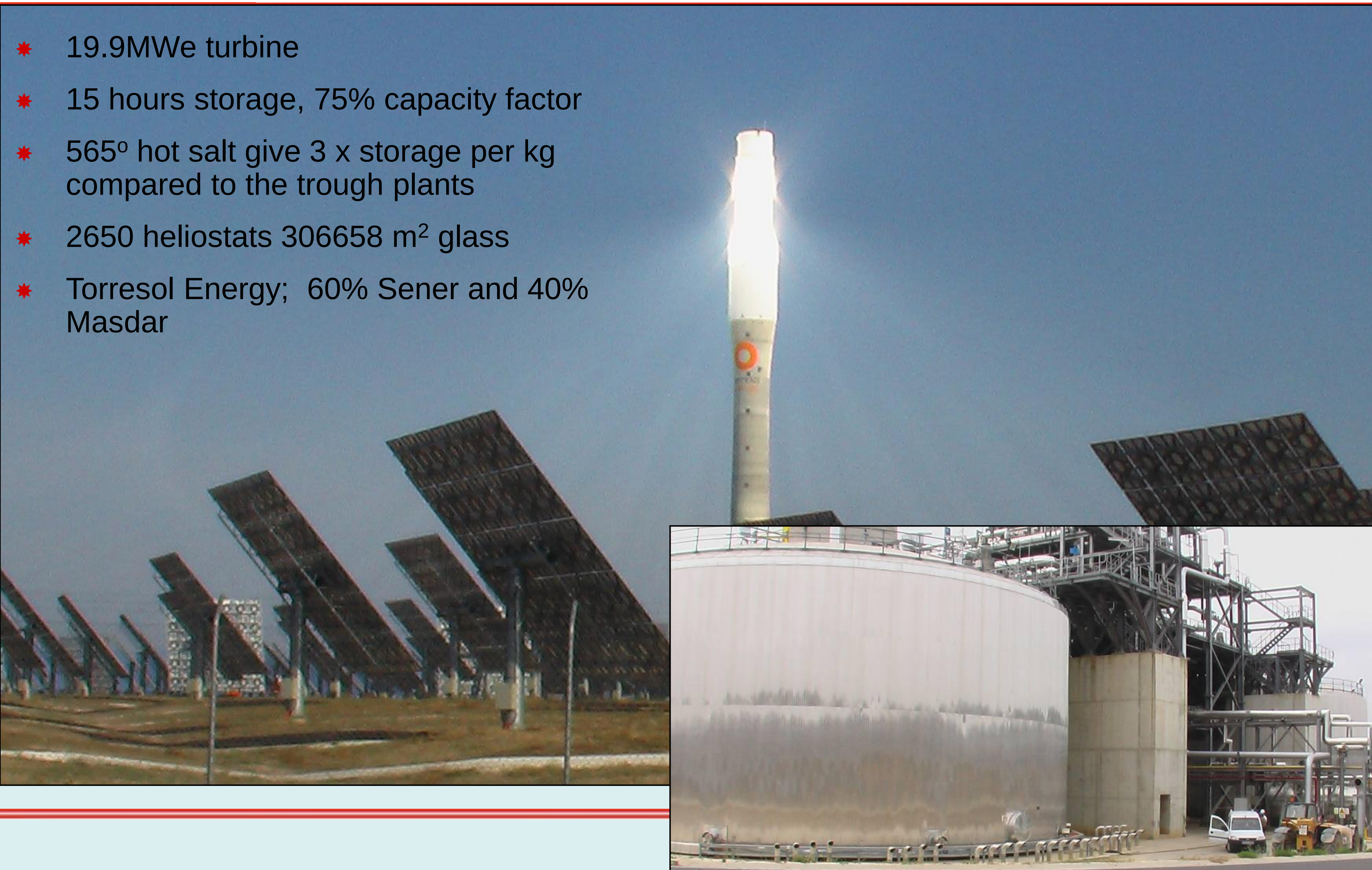
15MW, medium maturity

Andasol 3 – a recent typical system

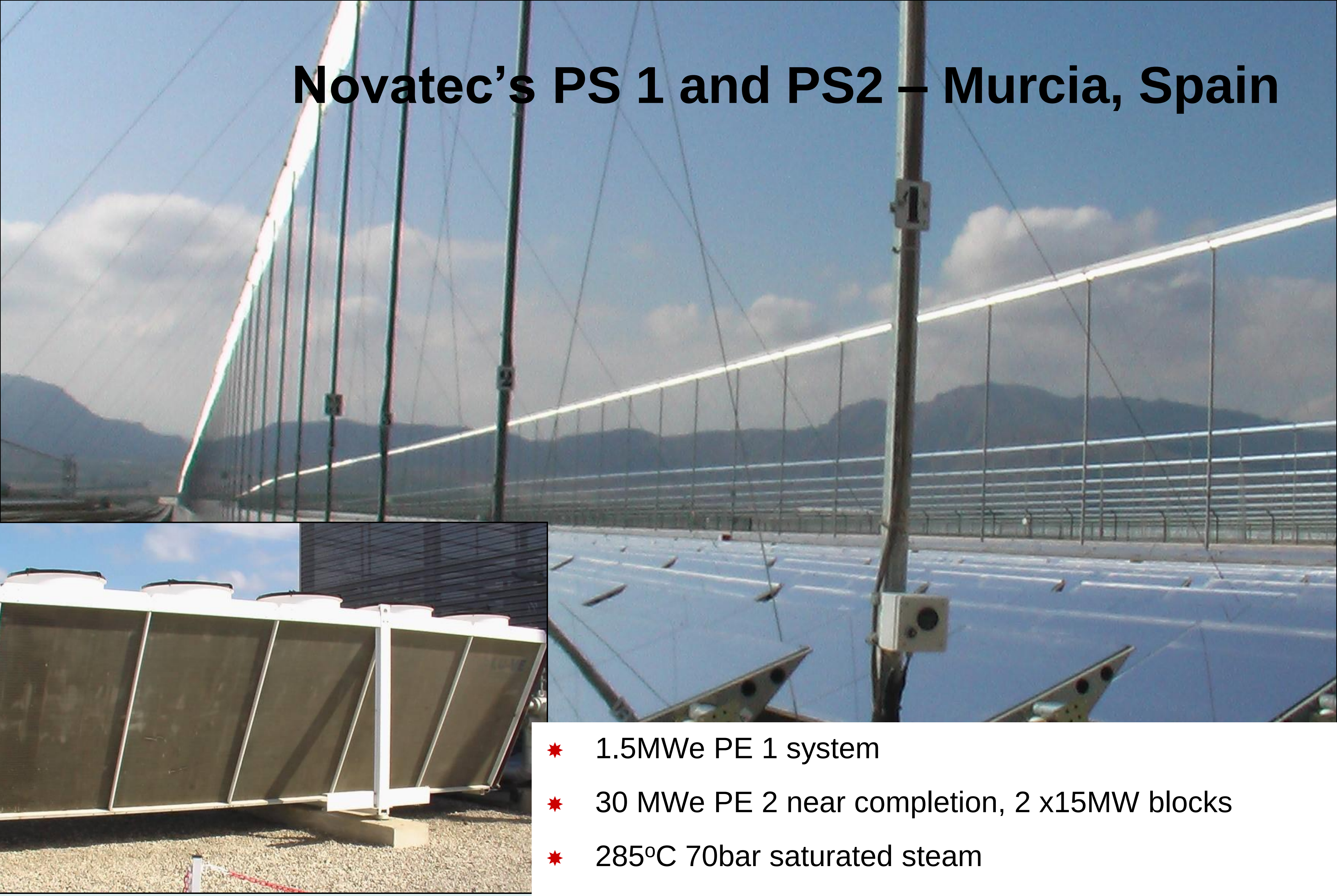
- Typical Spanish 50MW$_e$ trough plant
- 7.5hrs molten salt storage
- New high efficiency MAN turbine
- Construction around 18 months from ground breaking to on grid

Gemasolar, near Seville a capacity factor milestone

- 19.9MWe turbine
- 15 hours storage, 75% capacity factor
- 565º hot salt give 3 x storage per kg compared to the trough plants
- 2650 heliostats 306658 m^2 glass
- Torresol Energy; 60% Sener and 40% Masdar



Novatec's PS 1 and PS2 – Murcia, Spain



- 1.5MWe PE 1 system
- 30 MWe PE 2 near completion, 2 x15MW blocks
- 285^{o}C 70bar saturated steam
- Both feature dry cooling
- Transfield (Australia) the major shareholder

Brightsource moving ahead in US

Ivanpah Overview

- 392 MW electric for PG&E and SCE
- Bechtel as EPC with financing participation
- Siemens Turbine/Riley Boiler
- $1.63B DOE loan guarantee
- ITC cash grant eligible
- NRG Energy lead project investor
- Google secondary project investor
- Financial close – April 2011
- Commenced construction October 2010

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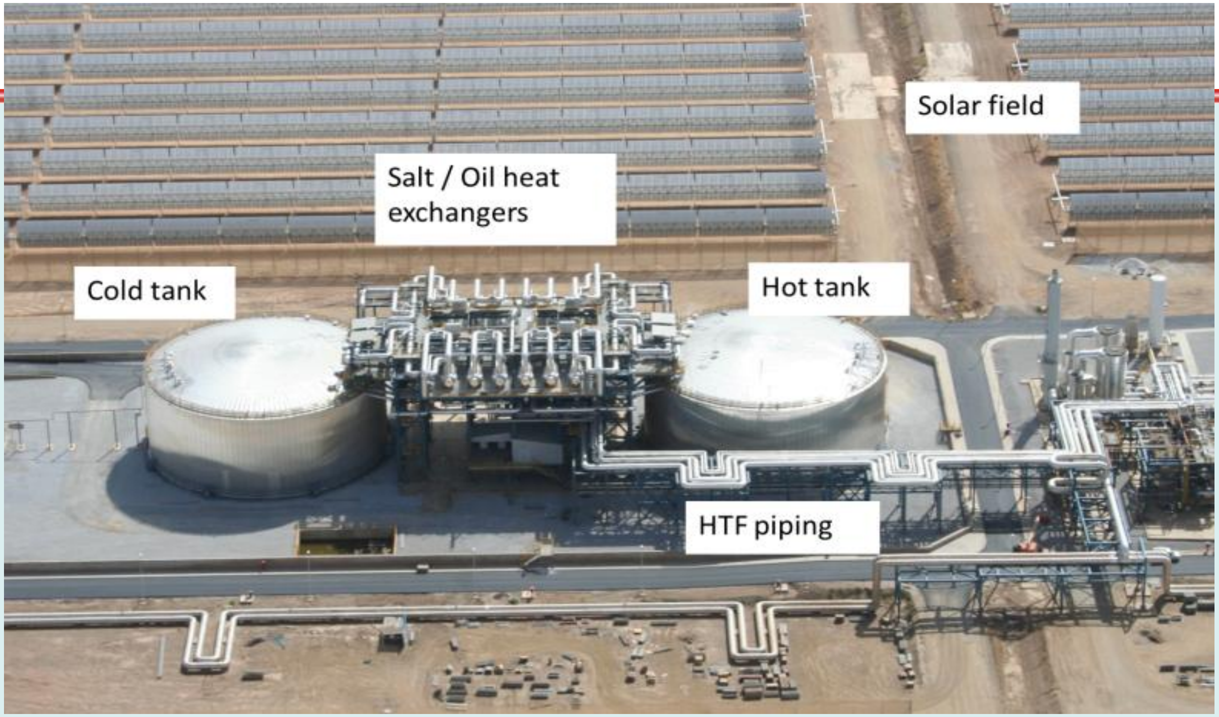
Thermal Energy Storage



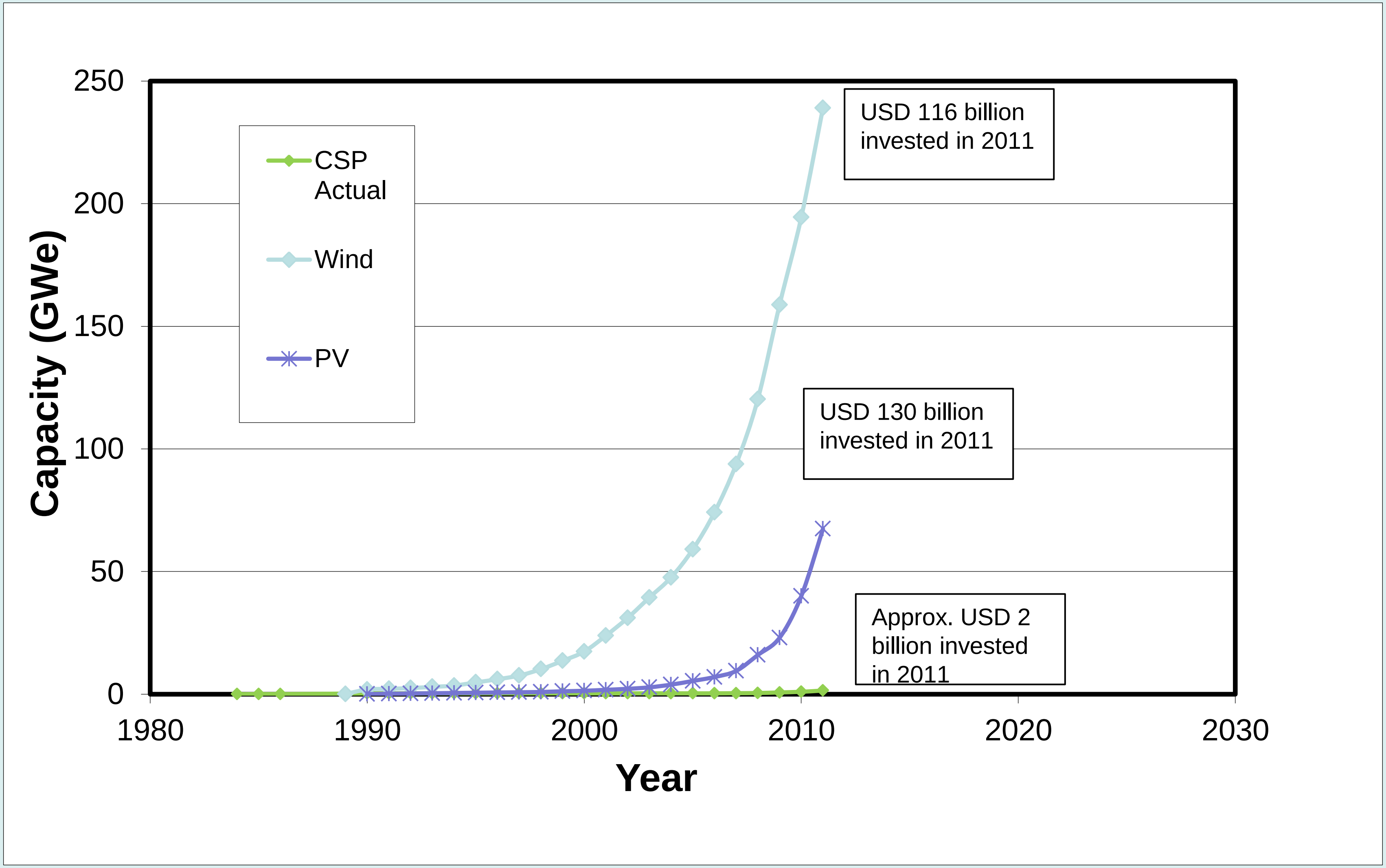
Background pic, Andasol 3 courtesy Ferrostaal

- Thermal storage is "integrated" – improves output, little or no extra cost
- Two tank molten salt is proven / standard (62% plants in Spain)
- A Higher temperature range makes it cheaper
- Steam accumulators are also proven for up to 1 hour storage
- Other options in R&D phase

Key observations

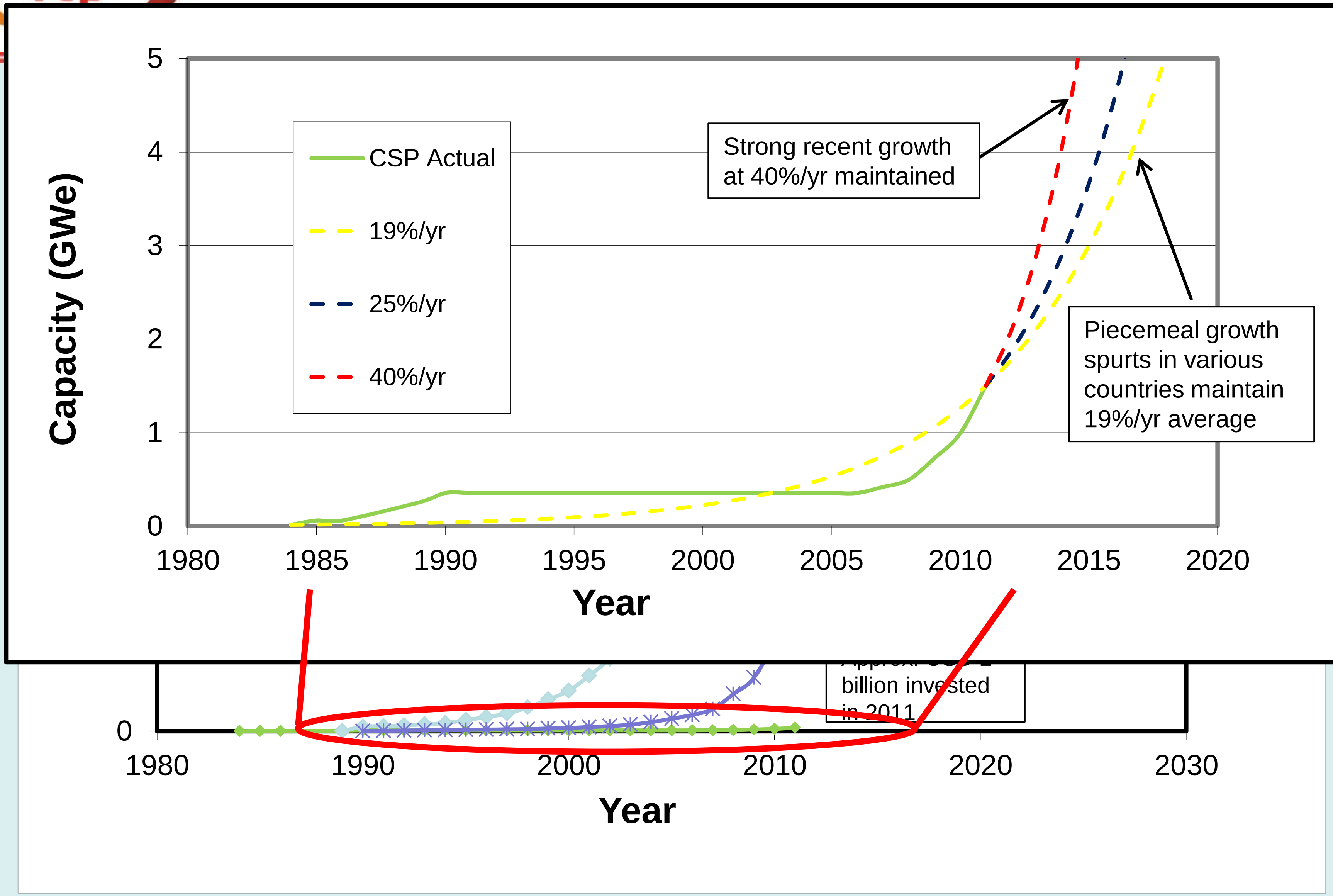
- Major changes in worlds energy supply driven by Greenhouse, oil prices, local pollution, energy security and competition to lead
- Dramatic cuts to PV costs just as CSP is getting going – failure of "Solar Millenium" and "Stirling Energy Systems" surprise developments
- Major trough players seeking lower cost by;
  - a) pursuing initiatives with towers and molten salt,
  - b) making wider aperture troughs
- Australia aiming for 80% reduction of GHG by 2050 – could logically suggest close to zero emissions in electricity sector
- A portfolio approach offers least cost / least risk pathway
- A significant fraction of future generation mix must be dispatchable (fully scheduled)

CSP in context – has it lost the race?

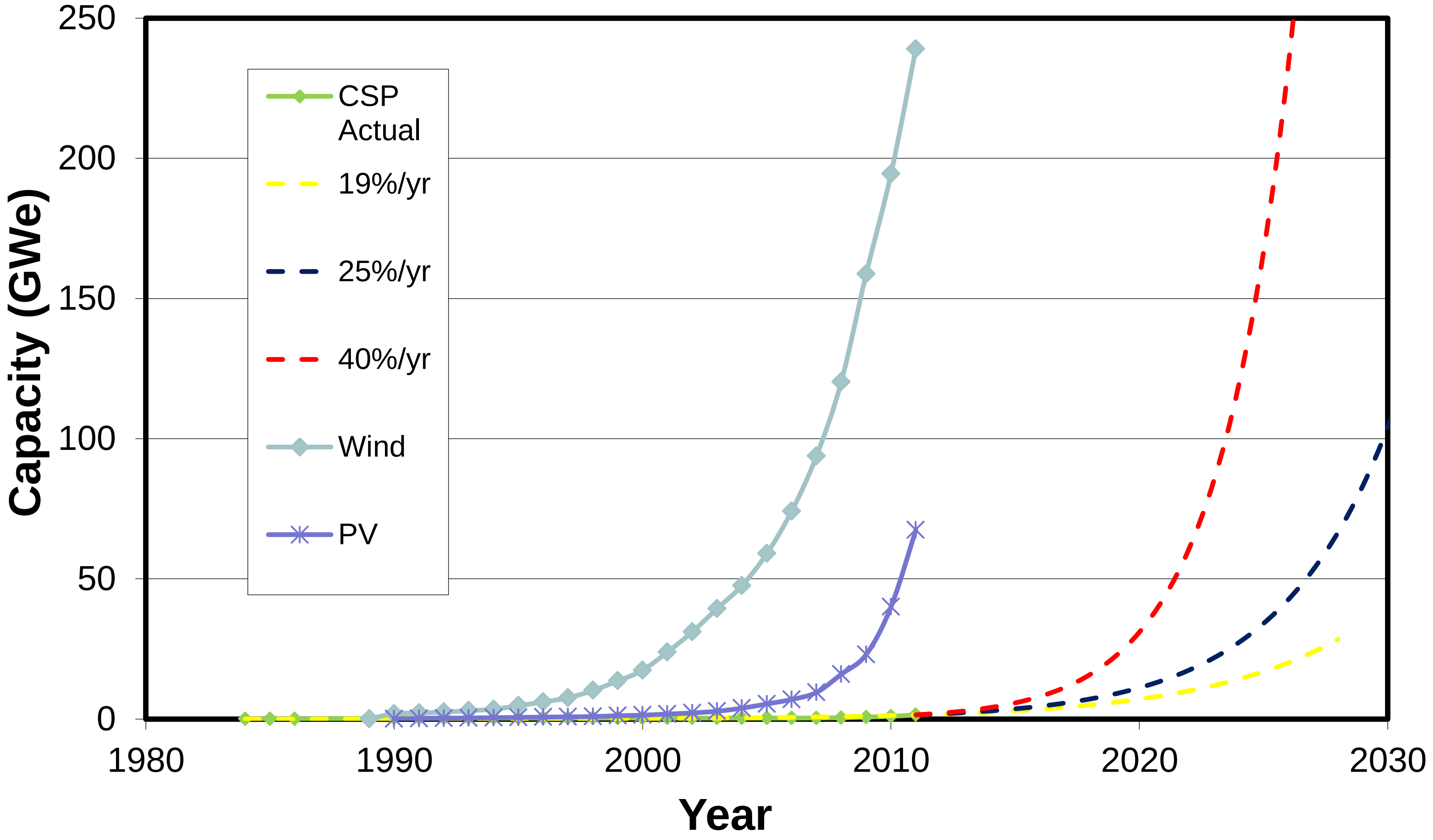


3% of world's electricity from wind and PV in 2011

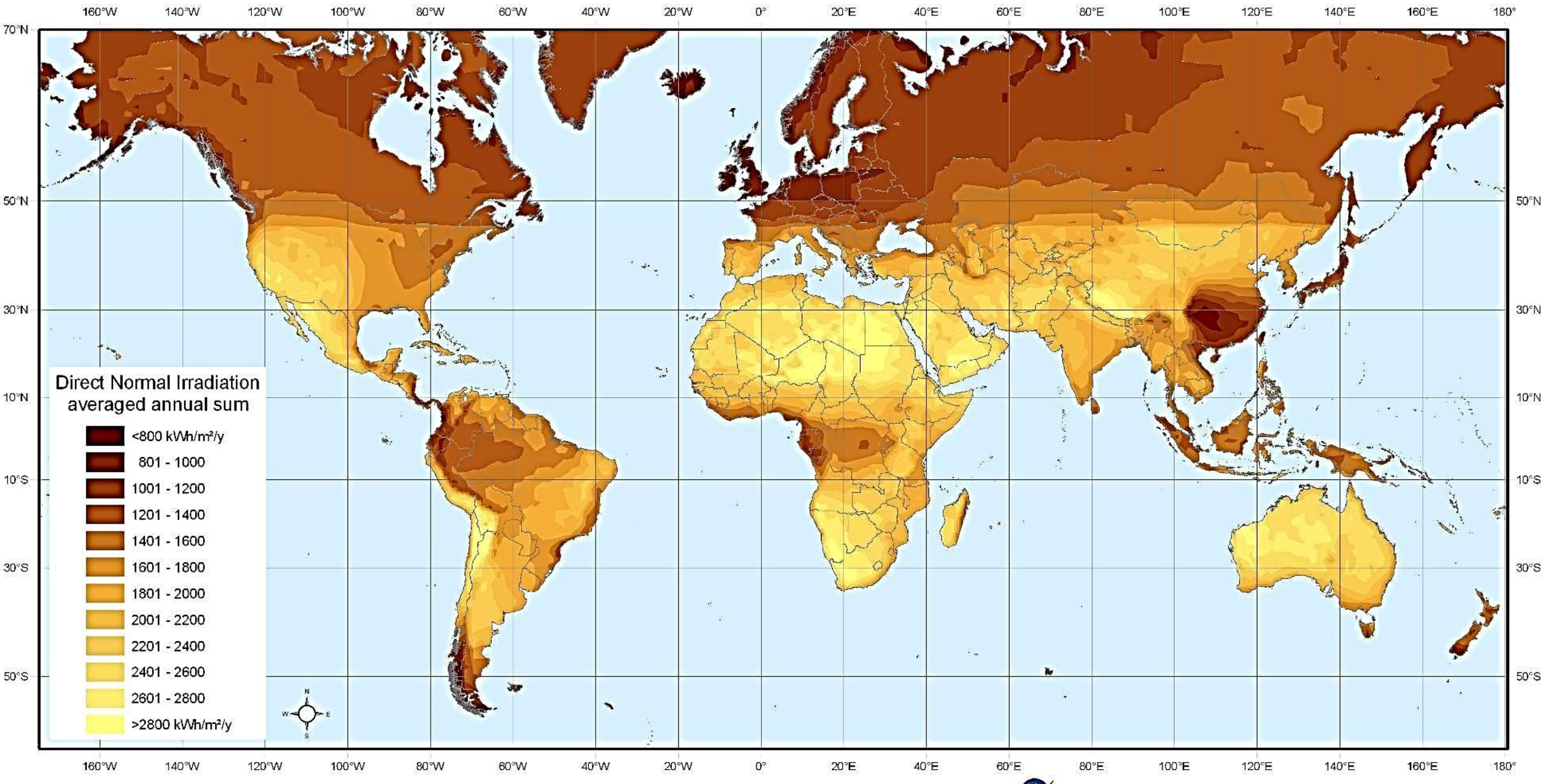
Global CSP growth?



CSP in context – it's the next big thing



CSP uses “Direct Normal Irradiation” (DNI)



Data based on NASA SSE 6.0 dataset for a 22-year period (July 1983 - June 2005)
(http://eosweb.larc.nasa.gov/sse/)

Map created and map layout by DLR 2008
(http://www.dlr.de)

So far most activity in Spain and USA.

North Africa, West India, West China and most of Australia are notable for as yet un exploited good solar resources

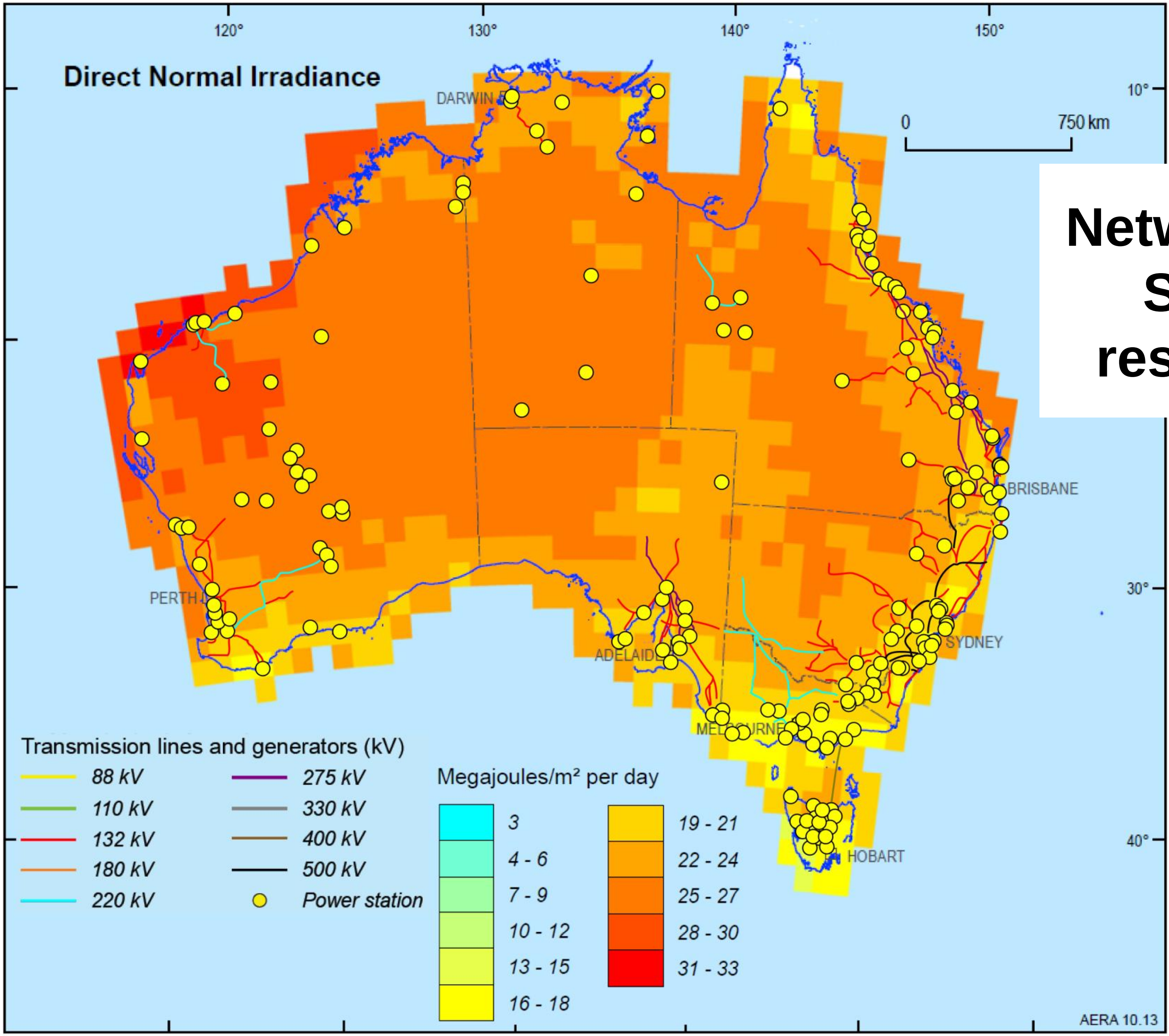
First CSP installations in Australia

- Australian National University dishes
- CSIRO National Solar Energy Centre
- Solar Systems Pty Ltd Dish CPV
- Graphite Energy
- Liddel power station LFR feedwater heating
- Kogan Creek solar Boost and solar flagships projects

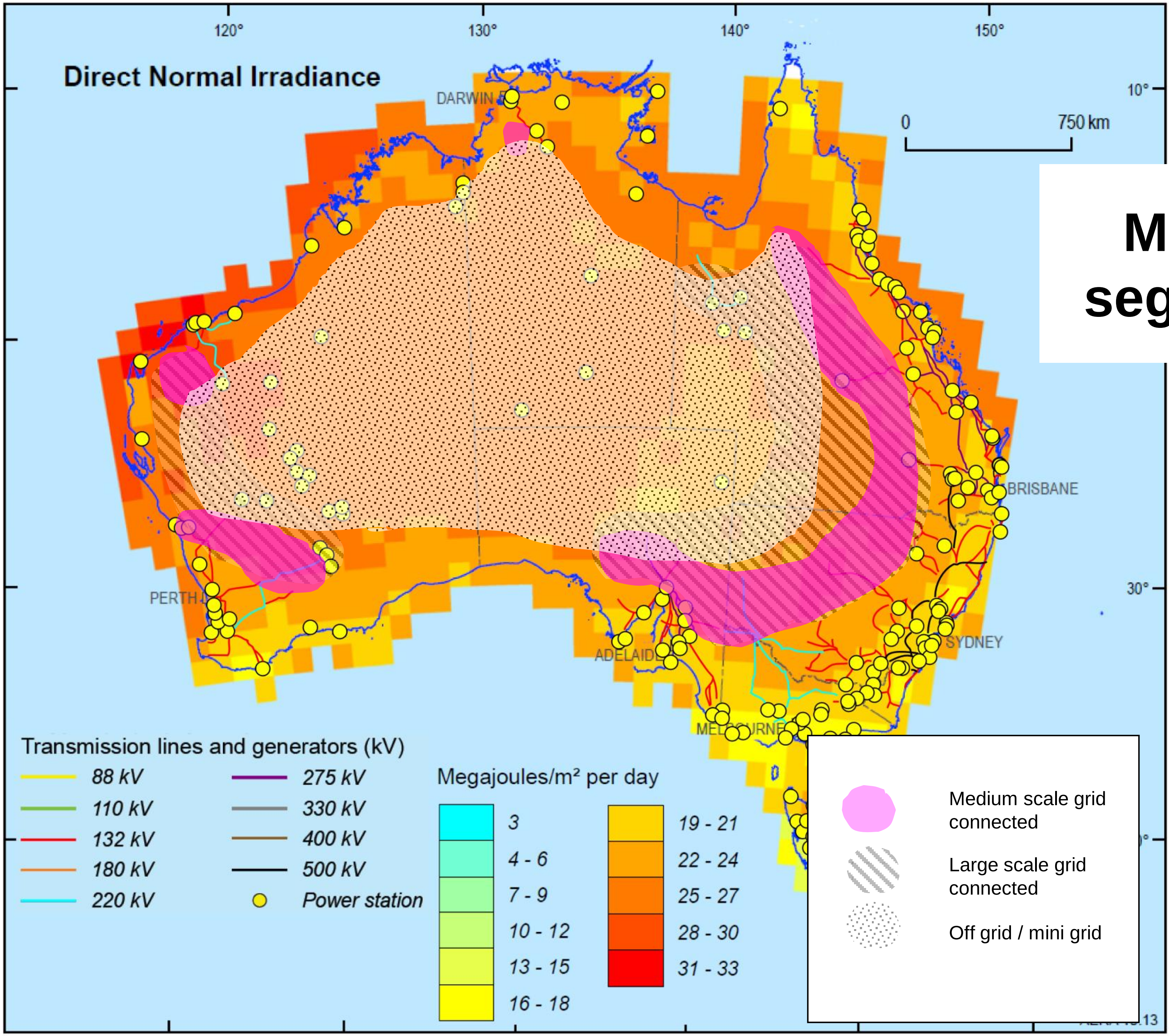





Network vs Solar resource



Market segments



Estimating Technical Potential of Australian market segments

Market segment	Technical potential	Notes
Large-Scale grid-connected		
Hybridisation with existing fossil fuel plants or industry (CST only)	2 GW_e	Assumes 25% of appropriate coal-fired power station's steam needs are delivered by CSP.
Stand-alone 50–150 MW systems (grid-connected)	3 to 4 GW_e	Requires grid connection point capable of receiving significant new energy injections.
Stand-alone< 1 GW clusters (modest grid extensions)	8 GW_e	Likely requires high-capacity plants with thermal storage whose economics cover cost of grid extension
Stand-alone > 1GW clusters (nation-building grid extensions)	Limited by market demand	Available high solar resource land area vastly exceeds all conceivable demand if accessed with dedicated major grid extensions
Medium Scale grid-connected		
Grid-connected (1–20 MW systems)	0.6 GW_e	Particular systems (large solar field, large storage, smaller capacity, high capacity factor) suited to distribution networks with capacity constraints.
Mini-grid-connected (1–10 MW systems)	0.12 GW_e	Would need thermal storage and dispatchability to have an advantage.
Off-grid		
Mining (systems < 10 MW)	0.1 GW_e	> 50 remote mine sites may be suitable for small-scale CSP, but short mine life and risk avoidance by mine owners/operators limit uptake.
Remote Towns (1–10 MW systems)	< 0.005 GW_e	Relatively small-scale demonstration systems.
Remote Towns (CPV systems < 1 MW)	< 0.005 GW_e	Could be suitable to test equipment and integration strategies.
Total	**~ 14 to 15 GW_e**	

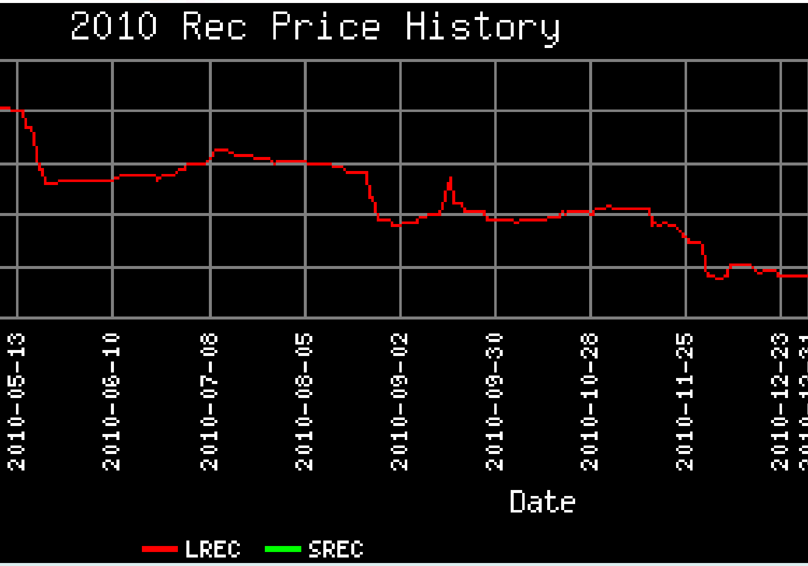
CSP offers

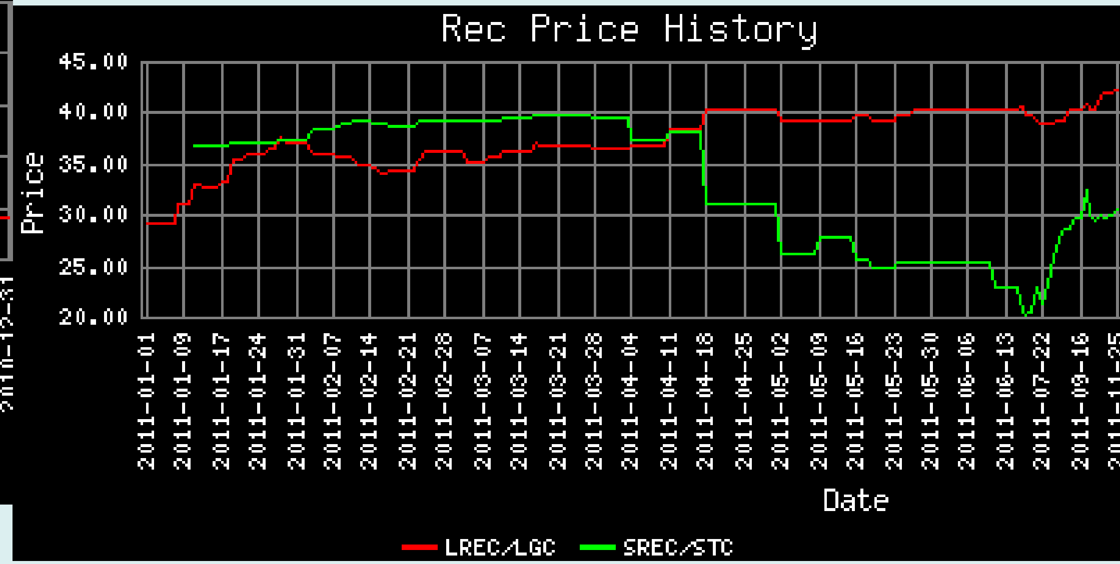
- **Dispatchable energy supply:** the range of baseload to peaking
- **Extensions for existing technologies**: hybrid with coal and gas plants to enable least-cost transition.
- **Emission reduction**: 10GW of capacity would reduce by roughly 30Mt CO_2 per year (15% of current sector emissions.)
- **Clean energy sector growth:** chance for Australia to claim a place in the global clean energy supply chain.
- **Community-supported generation:** need not compete for land or water. Every 100MW system would create around 500 job years during construction and 20 O&M jobs mostly in regional areas.
- **Potential for future solar fuels**: For domestic and export markets.

Wholesale electricity markets value solar with storage the highest

	Wholesale Market average price	Solar Immediate dispatch average sale price	Ratio Solar immediate / market av	Solar Dispatch from storage average sale price	Ratio Storage / market av
Vic	$39.17	$58.89	1.50	$74.56	1.90
SA	$49.51	$89.70	1.81	$136.88	2.77
Qld	$36.93	$50.03	1.35	$77.24	2.09
NSW	$41.32	$54.66	1.32	$80.67	1.95
WA	$50.13	$58.05	1.16	$65.83	1.31
AVERAGE	**$43.41**	**$62.27**	**1.43**	**$87.04**	**2.01**

Income from RECs / LGCs





- $40 ish…..
- Future price?
- The present rules do not recognise time of day of generation

CSP Revenue value in National Energy Market

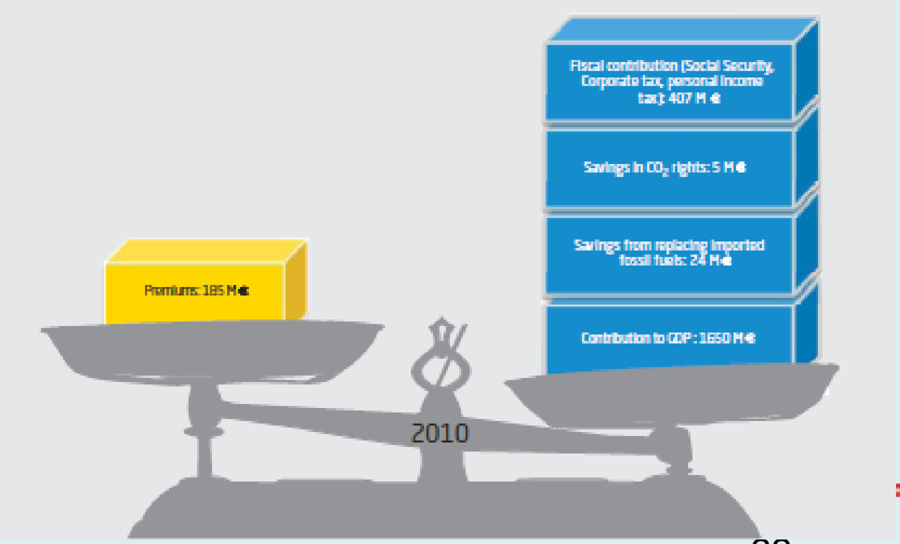
Contributor to value of energy	Value for CSP with no storage	Value for CSP with significant storage	Future Trend / comment
Basic average energy price	$43/MWh	$43/MWh	Future trend upward
Increment for CSP	$19	$44	Varies
REC	$40/MWh	$40/MWh	Future trend uncertain
Ancillary services	0	$0 to $0.8	future depends on generation mix, may grow.
TOTAL recognised in market place	**$102/MWh**	**$128/MWh**	
Avoided line losses	$0 -$2	$1 - $5	Varies depending on generator's impact on MLF and DLF
Avoided grid augmentation	-$2 - +$2	-$5 - +$5	
TOTAL overall Value	**$100 - $106/MWh**	**$125 - $138/MWh**	Depends on location

CSP revenue value off grid

Contributor to value of energy	Value for CSP with no storage	Value for CSP with significant storage	Future Trend / comment
Basic average energy price	$300 to $400 / MWh	$300 to $400 / MWh	Depends on location and load size, future trend upward
Increment for CSP	-$50	$0 to $10	
REC	$40/MWh	$40/MWh	Future trend uncertain
TOTAL recognised in market place	**$290 to $390 / MWh**	**$340 to $450 / MWh**	
Ancillary services	0	Wide range feasible	
Avoided grid augmentation	0	0	Relevant if a grid extension planned
Increment to REC based on Remote Solar Credits	Varies	Varies	
TOTAL overall Value	**$290 to $390 / MWh**	**$340 to $450 / MWh**	Depends on location

Other benefits

- CSP in Spain in 2010 according to Deloitte 2011
  - 185mEuro energy premiums
  - Contributed 1650mEuro to GDP (during a growth phase however)
  - More than 70% of investment stayed in Spain
- “Option value”
  - Keeping CSP progressing keeps an important option on the table
  - An insurance policy for future stable clean energy supply



Cost: published and confidential data lead to

Subsystem	Per unit cost	Note / unit
Concentrator field (excluding receivers and HTF)	402	$/kWth capacity, delivered to power island at design point
Receiver/ transfer system (including receivers, HTF, piping, Tower as appropriate)	246	$/kWth capacity, delivered to power island at design point
Thermal Storage System	80	$kWhth of installed thermal energy storage capacity
Power block	882	$/kW$_e$ output capacity
BOP and Other	529	$/kW$_e$ output capacity
Indirect project costs	25%	Of subtotal of others (=20% of total)

But Thermal Storage System actually T dependant: ((Th-Tc)/150)x 80$/kWhth

Installed cost examples

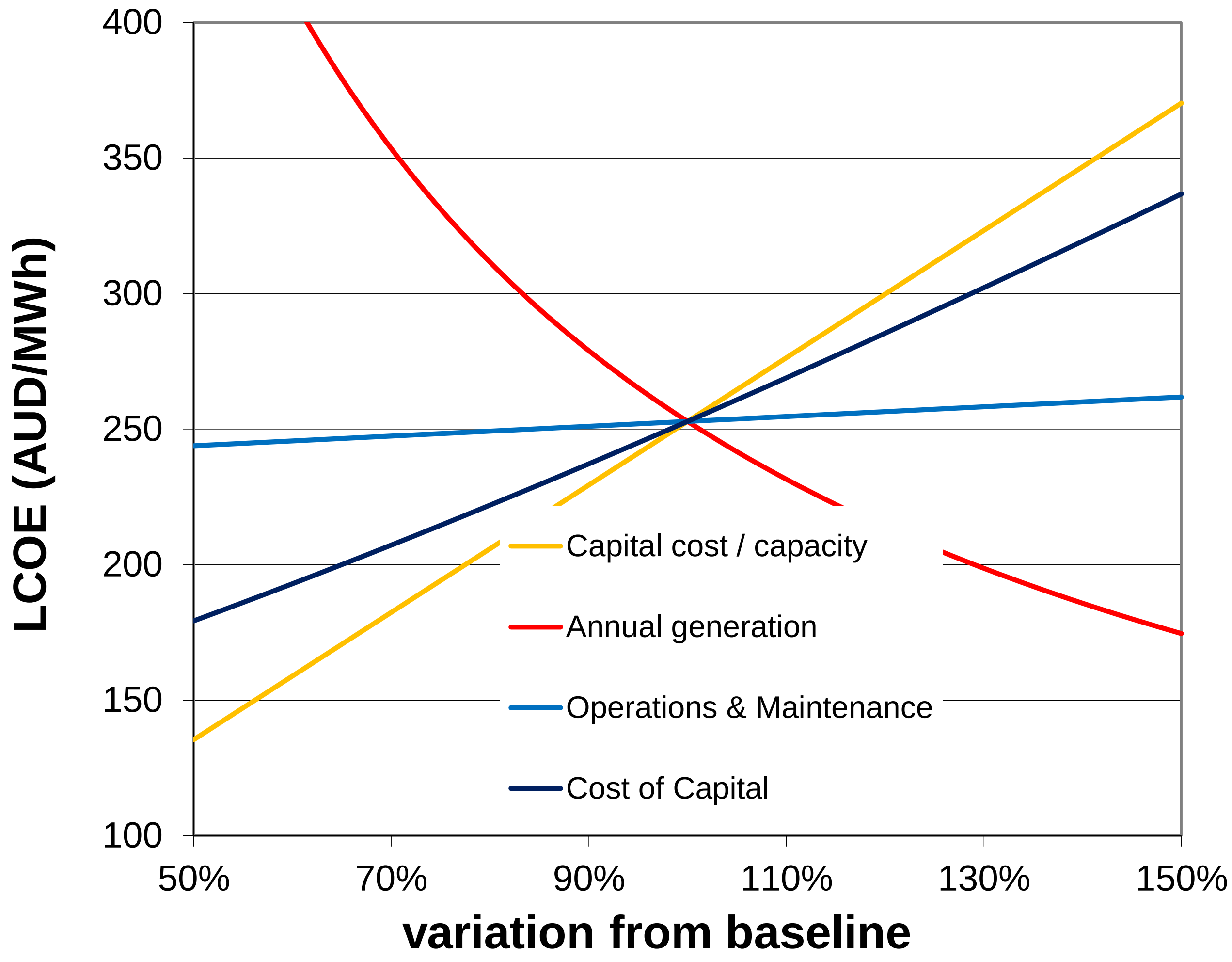
	No storage (lowest capital cost)	2 hours storage (approx min LCOE)	5 hours storage (earns higher value)
Configuration	100 MW_e block, 350 MW_{th} field, 21% cap factor at 2,400 kWh/m^2/year	100 MW_e block, 395 MW_{th} field, 30% cap factor at 2,400 kWh/m^2/year	100 MW_e block, 526 MW_{th} field, 40% cap factor at 2,400 kWh/m^2/year
Specific installed cost (AUD 2012)	\$4653 / kW_e	\$5534 / kW_e	\$7350 / kW_e

Baseline LCOE – trough @ Longreach

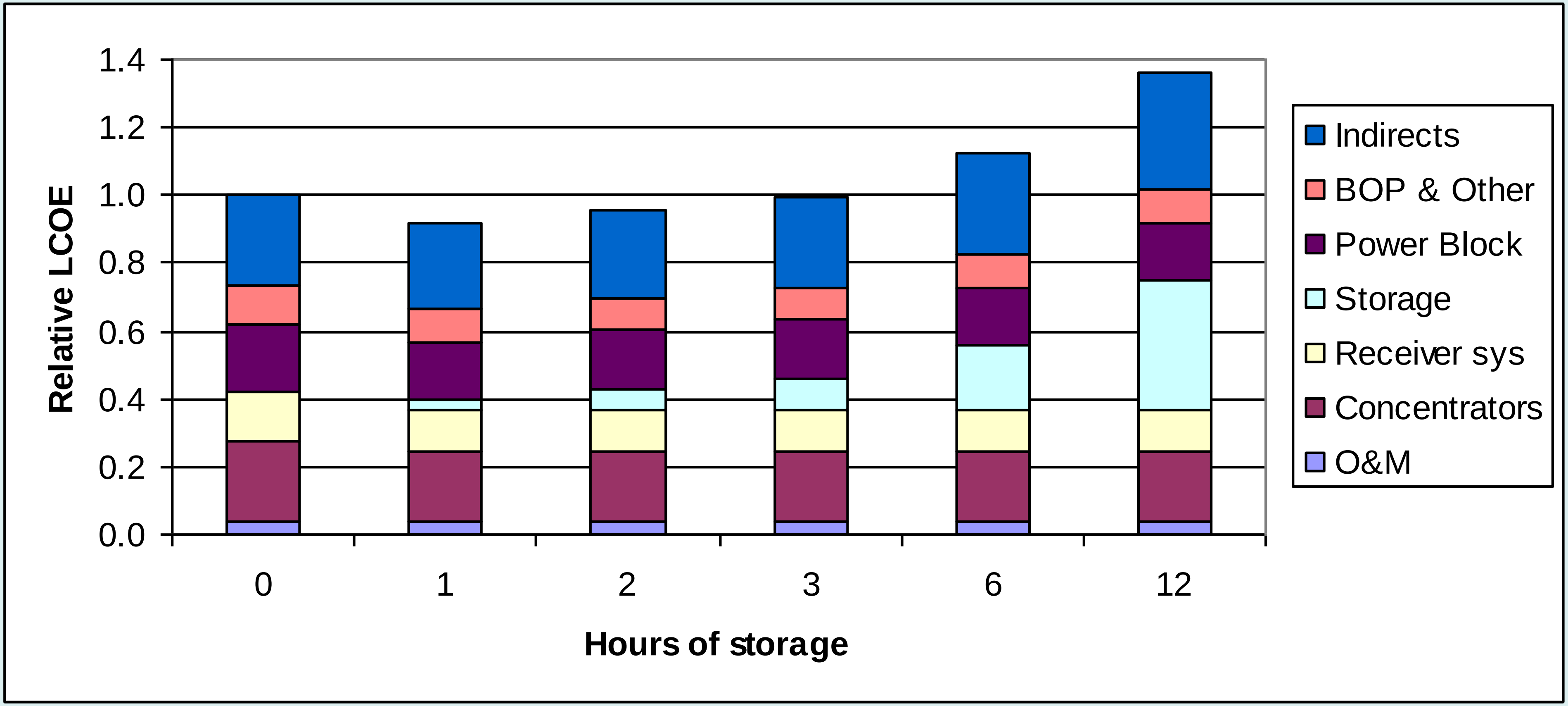
The least risk technology at a “most favourable” site

	Mature Business	
Financial parameters		
Loan fraction of total	0.6	
Loan period	15	Years
Loan interest rate (nominal)	7.78%	/year
Discount rate for equity (nominal)	10.29%	/year
Tax Rate	30%	/year
Depreciation period	20	year
Project Life	25	year
Salvage value	5%	
Inflation	2.50%	/year
System parameters		
Variable O&M	0.018	$/kWhe
Fixed O&M	0	/year
Capital cost after construction	$318,000,000	
Annual generation	128,800	GWh
REAL LCOE 2011 AUD	**252**	**$/MWhe**

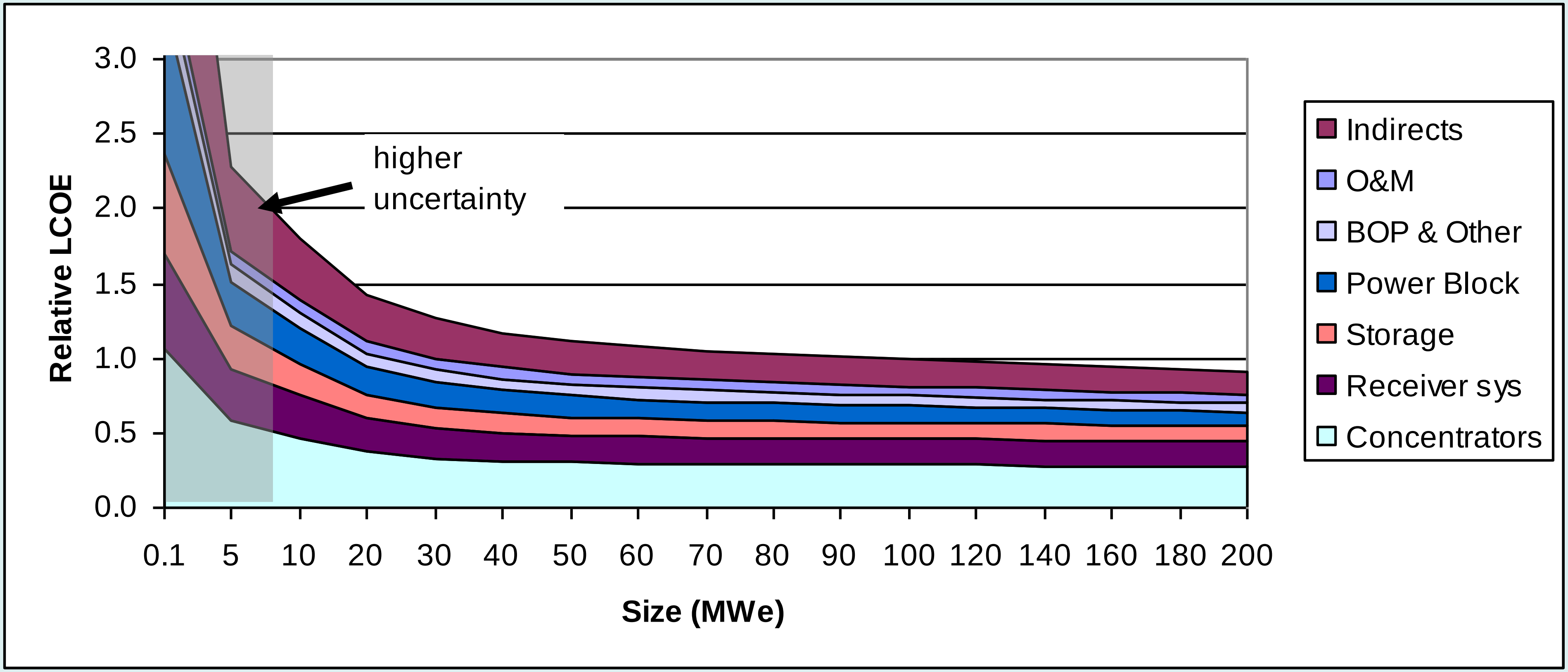
LCOE depends on many things



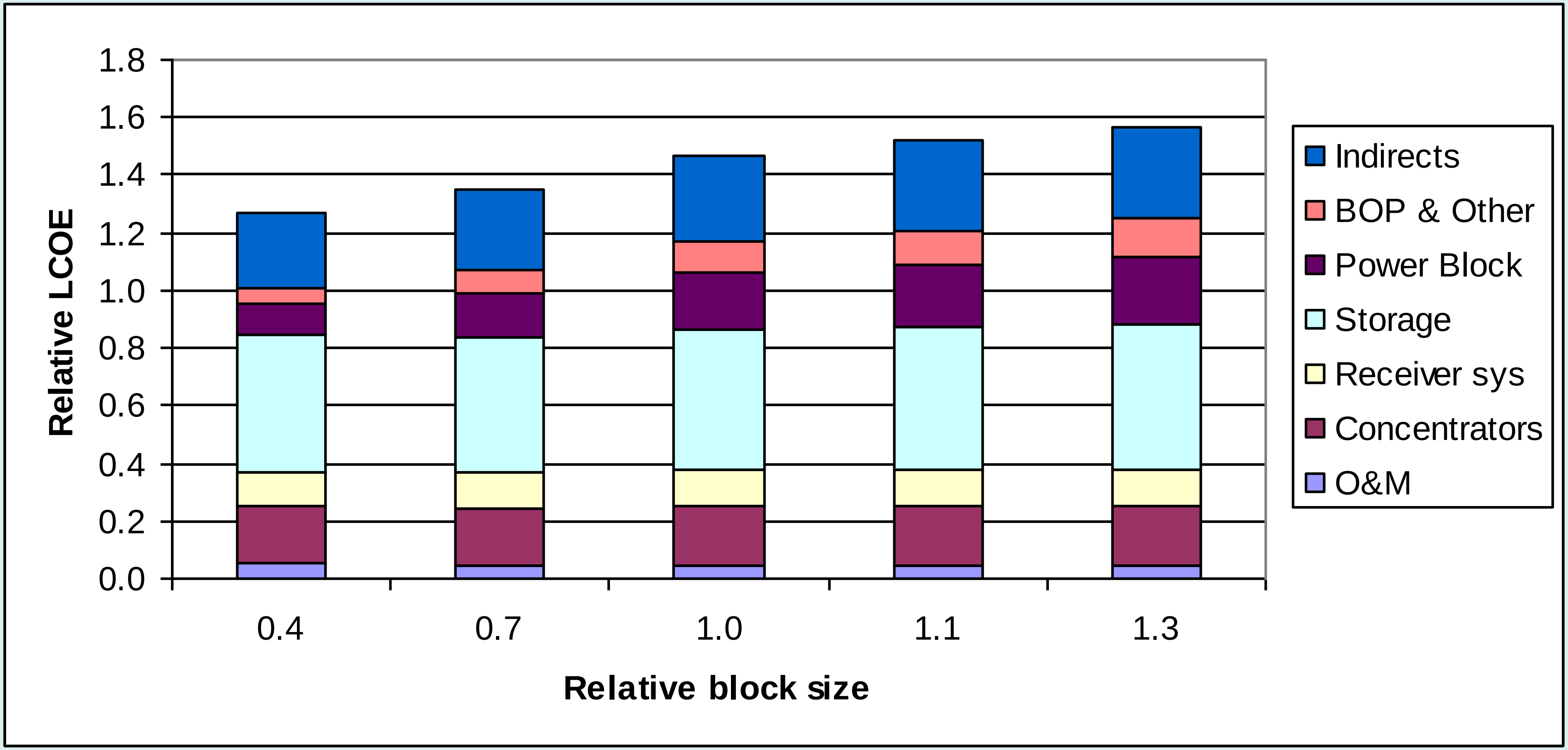
Some storage reduces LCOE



Effect of system size



Baseload or intermediate / peak



Value vs cost in NEM

Parameter	CSP with no storage	CSP with significant storage
System size (MW_e)	50 - 250	50 -250
DNI (kWh/m2/yr)	2100 -2500	2100 -2500
Value in market	$102/MWh	$128/MWh
Currently un rewarded value	$0 - $8/MWh	$2 -$10MWh
LCOE	$220 -$300/MWh	$250 -$360/MWh
Current Cost gap	$115+/MWh	$110+/MWh

Value vs cost off grid

Parameter	CSP with no storage	CSP with significant storage
System size (MW_e)	1 to 10	5 to 10
DNI (kWh/m2/yr)	2400 to 2600	2400 to 2600
Value in market	$290 to $390 / MWh	$340 to $440 / MWh
Currently un rewarded value	0	0
LCOE	$400 to $550	$500 to $650
Current Cost gap	$10+/MWh	$50+/MWh

Lots of sound reasons for costs to drop

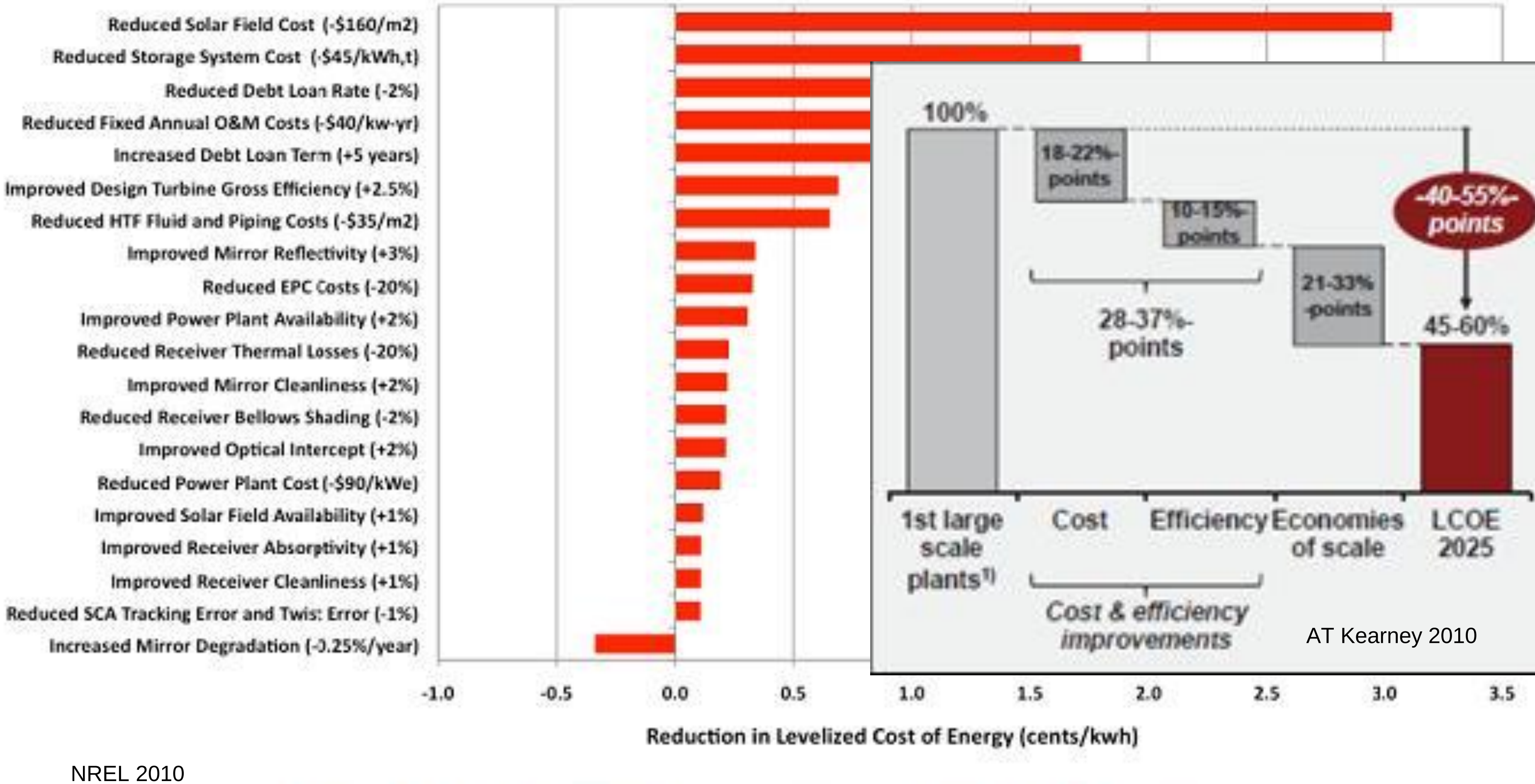
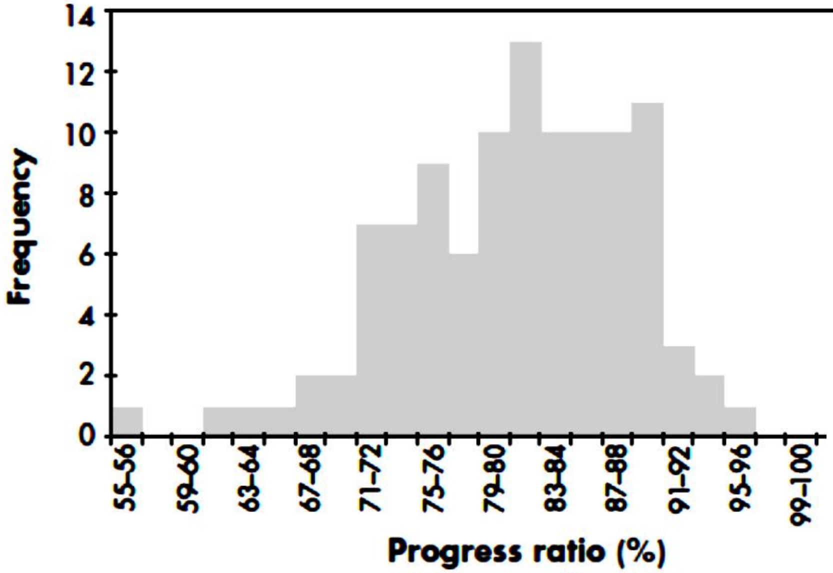


Figure 4. Sensitivity of LCOE to potential cost reductions in different areas.

Every thing has a progress ratio

- PR is factor by which cost changes for each doubling of capacity
- Only applies in early stages of a technology – wont tell us final cost



Source: OECD/IEA, 2000, Experience Curves for Energy Technology Policy, Figure 1.3, p.

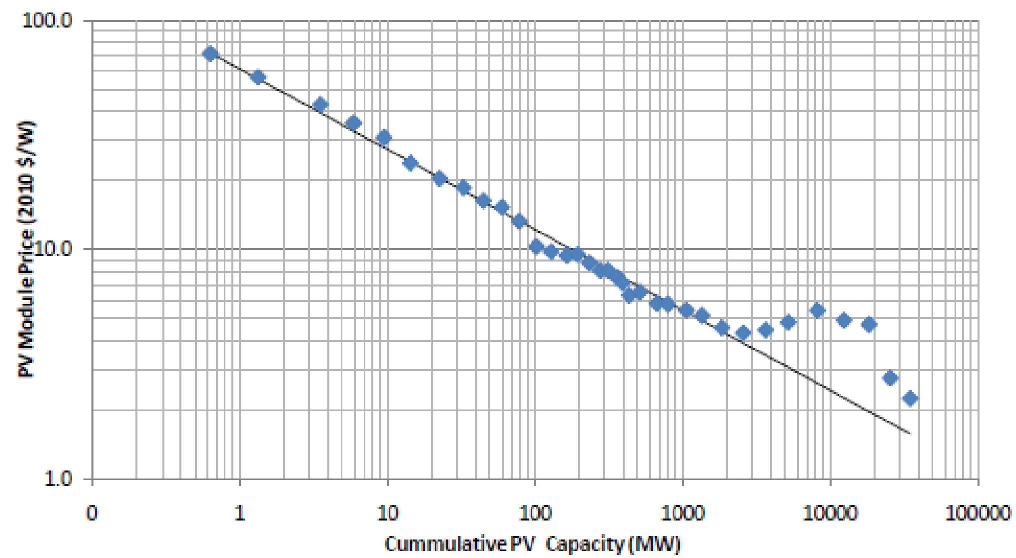
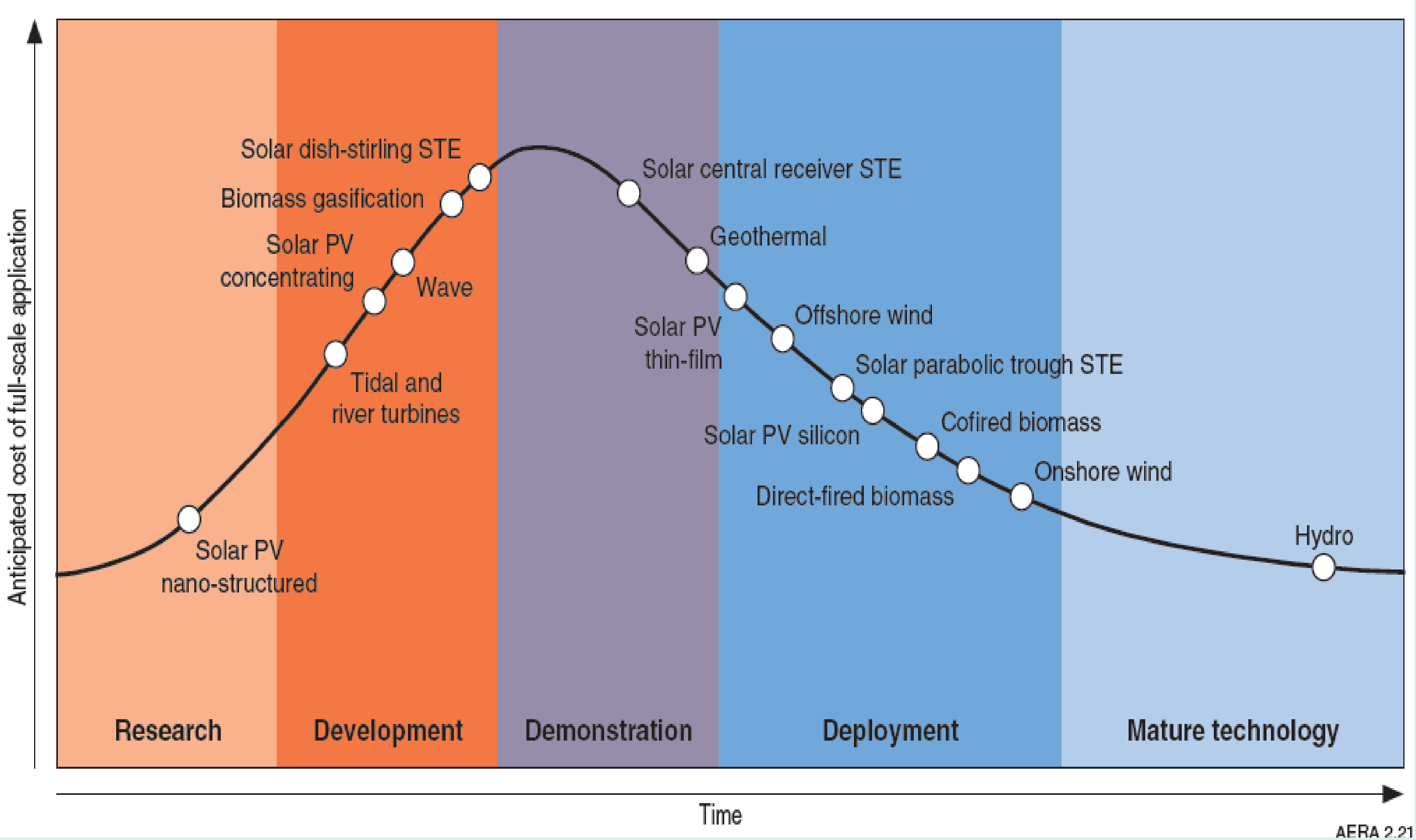


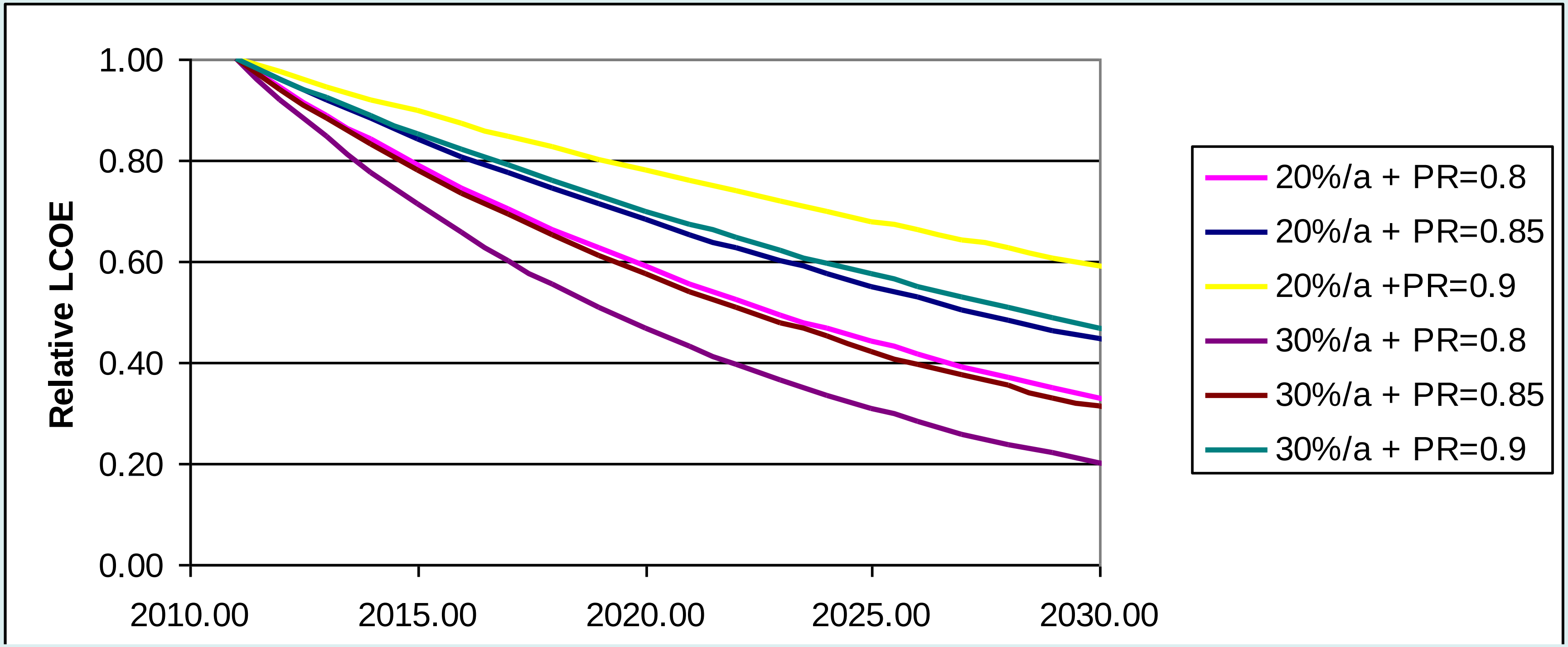
Figure 8: Historic Experience Curve for PV, with 22% Learning rate[10]

Mature CSP is over the cost hump

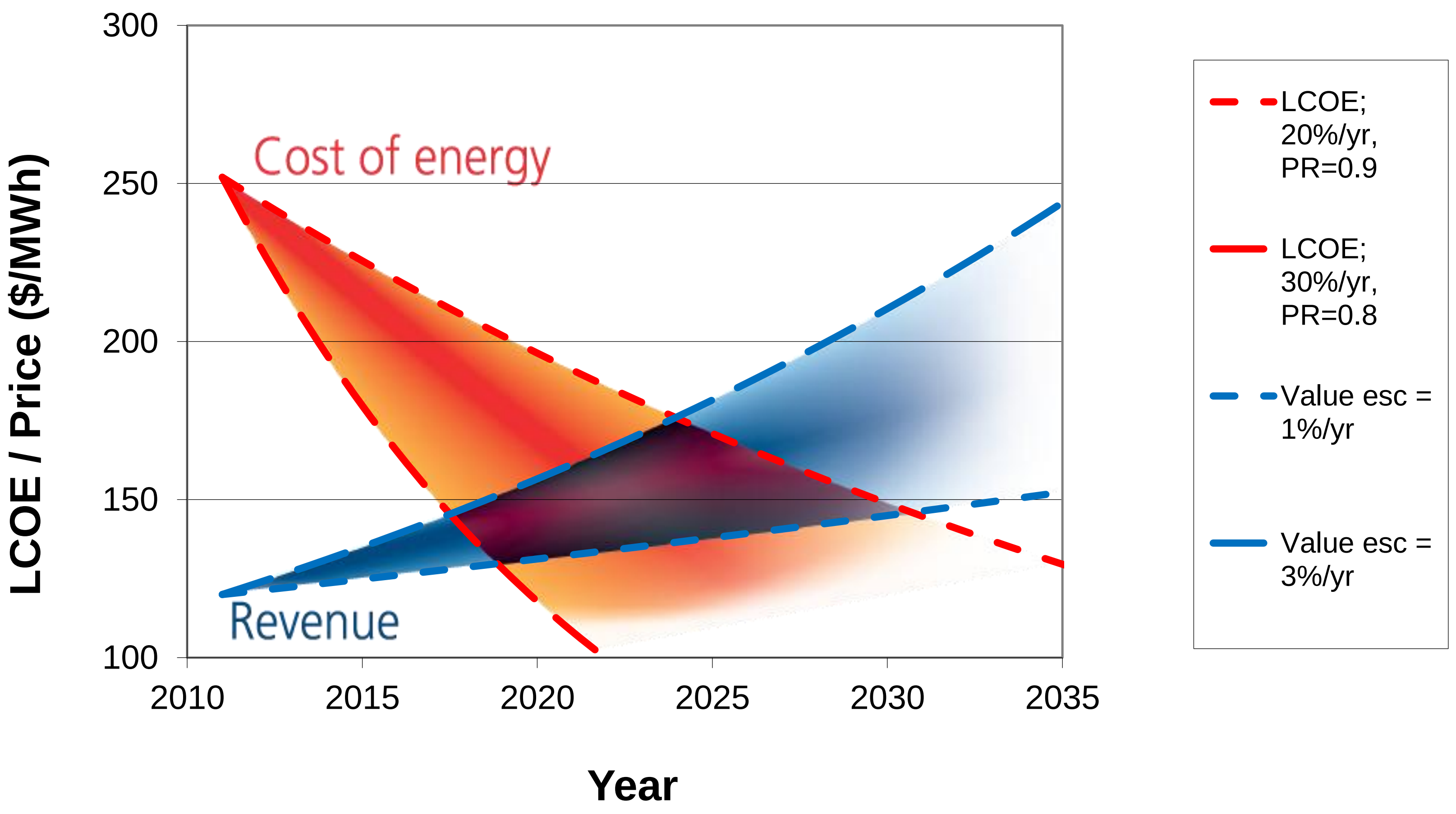


Cost Progress over time

- PR < 0.9 a pretty sound bet for CSP unless deployment stops dead
- 10 years will make a big difference
- If industry does well on Progress Ratio, it will feedback to growth …



Cost and value will converge in 6 – 18 years



Challenges

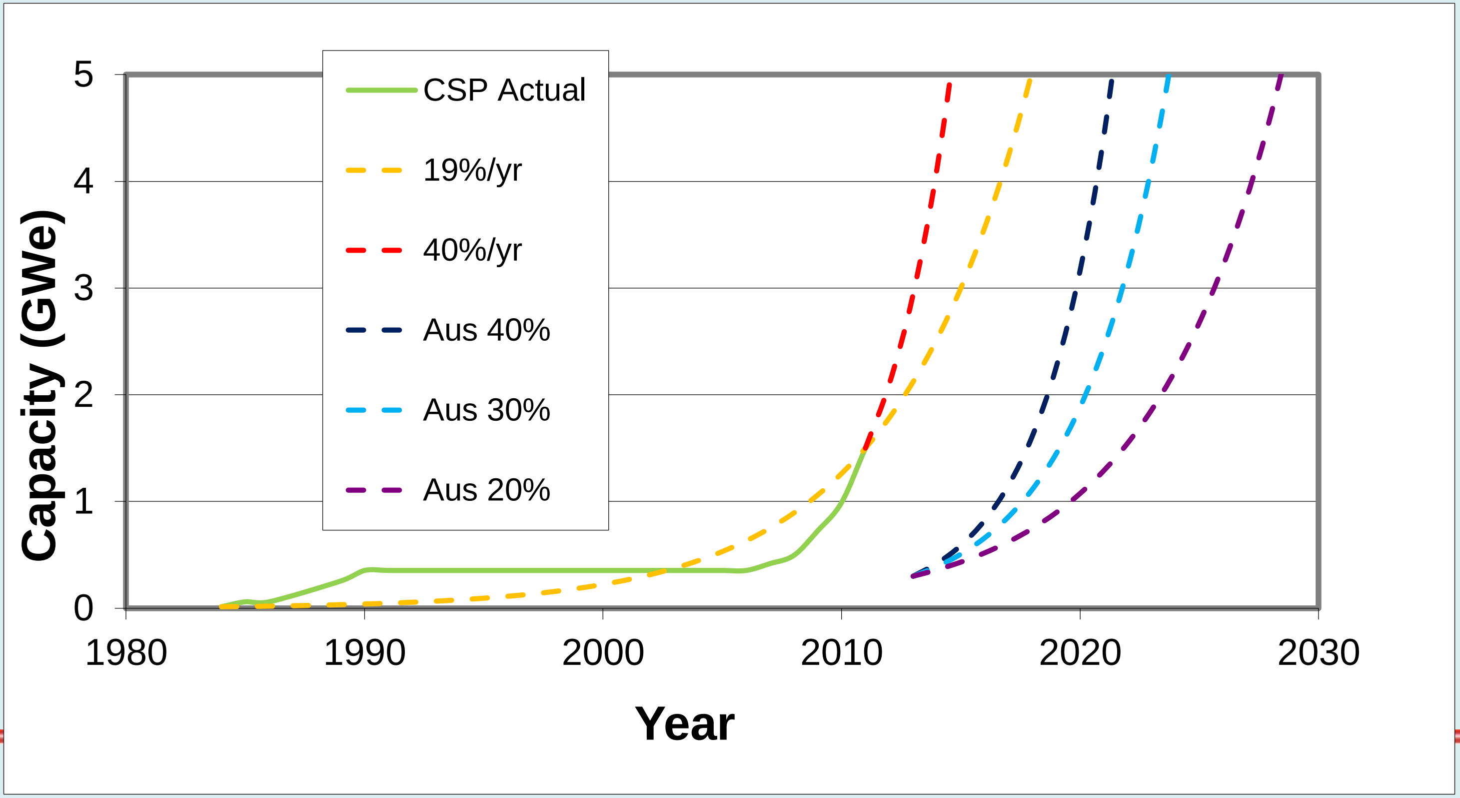
- The current cost gap is the biggest challenge, if this is not bridged there will be no CSP deployment in Australia
- Others
  - Building confidence in Australia among off-takers, financiers and governments.
  - Lack of transmission infrastructure to optimal solar locations.
  - Potential to avoid line losses or network augmentation that CSP could provide are not rewarded well under current market settings.
  - Small systems for mining and off grid applications are closest to matching energy cost to customer value, however there are other key barriers in this market segment.

Actions to build an Australian industry

- ***Bridge the reducing cost-revenue gap***
  - work with governments and regulators to increase the reward for clean energy systems that better correlate generation to real-time demand.
- ***Build confidence in CSP's offer***
  - better communicate CSP's value proposition to key stakeholders including AEMO, AEMC, electricity retailers and financiers.
- ***Establish CSP-solar precincts***
  - work with governments and network service providers to pre-approve and provide connections for CSP systems in selected areas of high solar.
- ***Better target CSP research, development and demonstration***
  - continued public and industry investment in RD&D, with more emphasis on: building skills and capabilities, systems below 50MW, energy storage; efficiency improvement; hybridisation with fossil plants; and advanced cooling.

What will Australia's share be?

- After Kogan Creek and Lidell….?
- 30%/ year would achieve 2GW by 2020
  - Total investment of $5.5bn
  - A significant contribution to ensuring global industry sustainability and continued cost reduction



CSP – a major opportunity for Australia

Cumulative capacity	Timing	Fraction of national demand	Notes
100s GW	2050 +		Significant source of export income via solar derived fuels and or HVDC links to Asia
100 GW	2050	30–50%	CSP provides between 30–50% of Australia's electricity in a mature 100% clean energy scenario
10 GW	2030	5–10%	CSP provides significant contributions in all market segments. Established Australian supply chain
2 GW	2020	1%	First fully commercial projects in the most prospective market segments
0.3 GW	2013	0.2%	First assisted demonstration systems at various scales